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della Società Italiana di Analisi
del Movimento in Clinica

Proceedings
SIAMOC 2025

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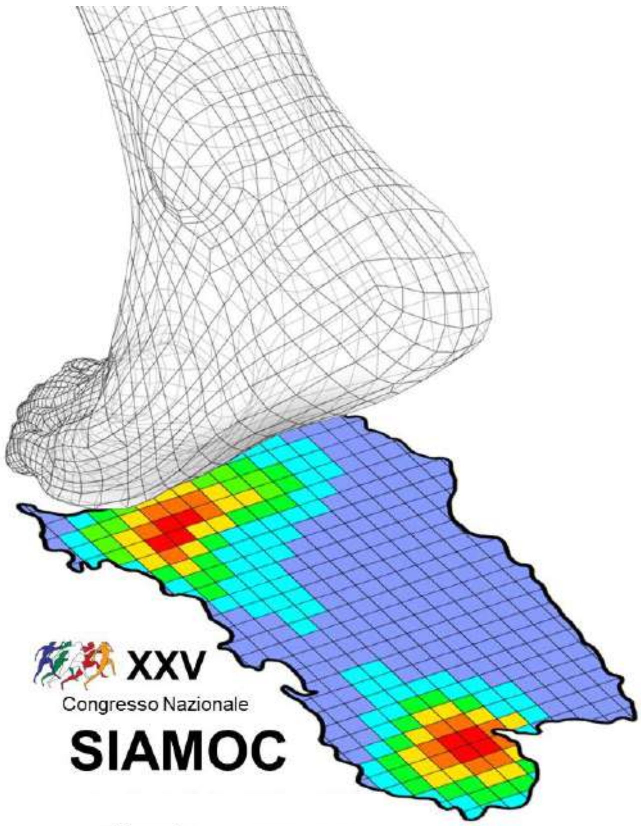

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XXV CONGRESSO NAZIONALE SIAMOC

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BRIDGING RESEARCH TO CLINICAL, INDUSTRIAL AND SPORT APPLICATIONS

Il congresso annuale della Società Italiana di Analisi del Movimento in Clinica (SIAMOC) giunge alla sua XXV edizione, e lo fa tornando in Sardegna dopo l'ormai lontana (ma ancora viva nella memoria) edizione di Alghero del 2009.

La Sardegna è una terra ricca di storia, cultura e tradizione, legata in modo quasi primordiale al concetto di movimento, come testimoniano le sue espressioni artistiche e il suo patrimonio culturale. Basti pensare ai pugilatori tra i Giganti di Mont'e Prama o alla leggenda che la vuole nata dall'impronta (*ichnusa*, dal greco "ichnos") lasciata dal Creatore, schiacciando col piede i sassi avanzati dalla creazione. Un legame affascinante, vero? Proprio l'impronta di un piede che cammina, tema centrale e oggetto di studio emblematico nelle ricerche SIAMOC sull'analisi del passo.

Ospitare il congresso SIAMOC per la Sardegna è una straordinaria opportunità di crescita scientifica e professionale per tutti coloro che operano nell'ambito dell'analisi del movimento umano, ma anche un punto di partenza per chi si avvicina a questo mondo per la prima volta e che nella SIAMOC troverà una comunità accogliente, fatta di ricercatori che da anni guidano la ricerca internazionale del settore e da professionisti di eccellenza aperti all'innovazione e al confronto.

Per questo siamo grati e ansiosi di ricevere questa comunità di colleghi e amici che attendono il congresso come il momento dell'anno in cui ritrovarsi in un clima stimolante, disteso e inclusivo con la voglia di crescere scientificamente e professionalmente. Vi aspettiamo numerosi per condividere questa esperienza!

La Presidenza del XXV Congresso SIAMOC

LETTURE MAGISTRALI

Verso una salute personalizzata e proattiva: passato, presente e futuro della tecnologia indossabile e il suo impatto sulla sanità

Shyamal Patel, Senior Vice President e Head of Science presso OURA, Greater Boston, MA, USA

Negli ultimi decenni, le tecnologie indossabili e connesse alla salute hanno vissuto uno sviluppo rapido e una diffusione su larga scala. Oggi, come consumatori, abbiamo accesso senza precedenti a tecnologie sanitarie complete e ad alta risoluzione che ci permettono di gestire in modo proattivo il nostro benessere. Nei prossimi anni, la democratizzazione dei dati sanitari rimodellerà profondamente la nostra comprensione della salute e delle pratiche sanitarie. In questo intervento, offrirò una prospettiva storica sull'evoluzione della tecnologia indossabile, sulla sua adozione e sul suo impatto nella salute dei consumatori, nella ricerca clinica e nella pratica clinica. Condividerò spunti basati sulla mia esperienza ventennale di ricerca e sviluppo di prodotti e soluzioni di tecnologia indossabile, maturata sia in ambito accademico che industriale. Nonostante i progressi compiuti, ritengo che abbiamo solo iniziato a esplorare il potenziale di questa tecnologia. L'ampia adozione delle tecnologie sanitarie per il consumatore, unita alla convergenza di forze sociali e tecnologiche, è destinata a trasformare il modo in cui gestiamo la salute a livello individuale e di popolazione. Concluderò l'intervento condividendo le mie previsioni su come queste forze rimodelleranno la nostra comprensione della salute e delle pratiche sanitarie.

Biomarcatori multimodali verso una riabilitazione personalizzata della persona con ictus cerebrale

Sofia Straudi, Professore Associato di Medicina Fisica e Riabilitativa all'Università di Ferrara, IT

Una riduzione della funzionalità dell'arto superiore è comune dopo un ictus cerebrale, con ripercussioni sulla qualità di vita e sulla partecipazione. La riabilitazione, orientata alla promozione della neuroplasticità, ha un ruolo fondamentale nel recupero di tali domini. In questo contesto, avere a disposizione biomarcatori multimodali, che riflettano sia la qualità del movimento che l'attività cerebrale, può essere di grande supporto nell'indirizzare i clinici verso un processo riabilitativo efficace. In particolare, la riabilitazione tecnologica, ovvero l'utilizzo di dispositivi robotici, di realtà virtuale e in generale di strumenti digitali, può beneficiare dell'utilizzo di tali biomarcatori per proporre interventi sempre più personalizzati. Nella mia relazione, presenterò i concetti chiave per l'utilizzo di biomarcatori multimodali nella pratica riabilitativa della persona con ictus cerebrale.

La sclerosi multipla nelle persone anziane: sfide diagnostiche e terapeutiche

Matilde Inglese, Professore di Neurologia presso l’Università di Genova e Direttore del Centro Sclerosi Multipla presso l’IRCCS Policlinico San Martino, IT

La sclerosi multipla (SM) colpisce principalmente giovani adulti. Tuttavia, negli ultimi decenni è stato osservato un aumento di incidenza della SM ad esordio tardivo (LOMS) e un aumento di aspettativa di vita di persone con SM. L’immunosenescenza induce cambiamenti biologici ed immunologici che contribuiscono all’aumento di disabilità clinica di queste persone. Inoltre, l’iter diagnostico di persone con LOMS è più difficile che nei giovani adulti ed associato a un maggior rischio di diagnosi erronee a causa della presenza di comorbidità. Anche il trattamento farmacologico pone delle sfide in quanto non esistono dati di efficacia e sicurezza dei “disease modifying treatments” nelle persone anziane. Nella mia relazione discuterò come il processo di invecchiamento influenzi la patogenesi, il decorso della malattia e le opzioni terapeutiche.

Endpoint digitali per accelerare lo sviluppo di farmaci nelle malattie neurologiche

Claudia Mazzà, Head of Research presso INDIVI, Basilea, CH

Le malattie neurologiche pongono sfide significative allo sviluppo di farmaci, principalmente a causa della complessità e variabilità dei loro sintomi, che compromettono sensibilmente la sensibilità degli endpoint tradizionali nei trial clinici. La malattia di Parkinson ne è un esempio emblematico: nel 2024, solo tre dei 57 composti in fase 1 e 2 sono riusciti a passare alla fase 3 dei trial. Le ragioni di questi insuccessi restano in gran parte oscure, ma le limitazioni degli endpoint convenzionali, come il MDS-UPDRS, giocano un ruolo critico. In questo intervento, la Prof.ssa Claudia Mazzà esplorerà come sia possibile superare questo "soffitto di vetro" nello sviluppo di farmaci per le malattie neurologiche. Verranno evidenziate le carenze degli strumenti di valutazione attuali e sarà presentato un argomento convincente a favore dell'integrazione di endpoint digitali — acquisiti tramite smartphone e dispositivi indossabili — per monitorare in modo più accurato le funzioni motorie e cognitive in contesti reali. Sebbene oggi sia più facile che mai raccogliere dati digitali, trasformarli in endpoint validati, interpretabili e clinicamente significativi rappresenta ancora una sfida importante. Claudia approfondirà le problematiche tecniche e regolatorie legate alla validazione, sottolineando l'importanza di mantenere la rilevanza contestuale delle misure digitali lungo tutto il processo di sviluppo del farmaco.

Dai passi dei neonati al cammino indipendente: comprendere lo sviluppo locomotorio tipico e atipico nei primi anni di vita

Nadia Dominici, Professore Associato presso la Facoltà di Scienze del Comportamento e del Movimento della Vrije Universiteit di Amsterdam, NL

I bambini hanno una predisposizione innata al cammino fin dalla nascita: se sostenuti sotto le ascelle, sono in grado di generare spontaneamente movimenti simili al cammino. Tuttavia, occorre circa un anno perché riescano a camminare in modo autonomo. Come si passa da questi schemi rudimentali alle forme di locomozione complesse e mature osservabili nell'adulto? E in che modo questo processo si differenzia nei bambini con disturbi dello sviluppo, come la paralisi cerebrale? Durante questa presentazione illustrerò i principi fondamentali della coordinazione locomotoria nell'adulto e mostrerò come il sistema nervoso centrale semplifichi il controllo motorio attraverso un numero limitato di unità funzionali, conosciute come primitive locomotorie o sinergie muscolari. Descriverò come queste sinergie evolvono durante lo sviluppo del cammino nei bambini con sviluppo tipico e come risultano alterate nei bambini con paralisi cerebrale infantile. Infine, presenterò evidenze recenti su come la corteccia cerebrale interagisca selettivamente con queste primitive durante la deambulazione nei bambini piccoli e negli adulti, offrendo nuove prospettive per la comprensione dei meccanismi neurali alla base dello sviluppo locomotorio e delle sue deviazioni patologiche.

ELENCO DEI CONTRIBUTI PRESENTATI AL CONGRESSO

Biomechanical categorization of camptocormia in Parkinson's disease for botulinum toxin treatment

M. Bacchini [a], G. Chiari [a], M. Rossi [a], C. Bacchini [a], V. Brambilla [a]

[a] *Don Carlo Gnocchi Foundation - Onlus - S. Maria ai Servi Center, Parma, Italy*

Introduction

Camptocormia is often associated with Parkinson's disease (PD) and is indicated by excessive elastic spine anteflexion, with exacerbation of symptoms by a prolonged standing position or by walking [1]. Botulinum toxin treatment is a therapeutic option because a pathogenesis of camptocormia is axial dystonia [2]. These patients show risk of falling [3], in reduction of gait velocity, stride length, hip extension in stance and knee peak flexion in swing. This study investigates the clinical, radiological and gait analysis/EMG data to biomechanical categorization of camptocormia for the purpose of targeted treatment with botulinum toxin.

Methods

23 patients with camptocormia (12 males and 11 females; the average age was 71 years) participated in this study. All patients underwent clinical investigation with TDDS (Trunk Dystonia Disability Scale), X-rays with spine angle flexion and gait analysis on two occasions: at inclusion and 1 month after botulinum toxin injection. A total of 9 trials each patients were carried out using the EL.I.TE. 3-D SMART opto-electronic system (BTS, Milan, Italy) following DAVIS protocol. EMG (Pocket EMG, BTS, Milan, Italy) signals from rectus inferior (RAI), external oblique (OE), internal oblique (OI), iliopsoas (IP), rectus femoris (RF) showed a pattern of abnormal tonic hyperactivity, with potential of more than 100 µVolts/sec. for more than 500 msec. Two dynamometric platforms permitted the measurement of the joint moments and the mechanical energy produced. Two camptocormia subtypes are distinguished based on the fulcrum (thoracic or lumbar) of forward flexion and on EMG simultaneous muscle hyperactivity: upper camptocormia (UCC) and lower camptocormia (LCC). Using electromyographic and ultrasound guidance, we injected botulinum toxin (Dysport, 500 U in 1,0 mL physiologic solution) into the RAI, OE, OI bilaterally in UCC, into the OE, IP, RF bilaterally in LCC, in three sites for each muscle, using 25 U per site. Patients underwent a rehabilitation programme for 4 weeks.

Results

After treatment, TDDS showed a 6-point improvement; significant decrease of X-ray degree of UCC (Cobb angle C7-T12: 42.6° ± 8.4 vs 55.7° ± 8.2° vs.) and LCC (L1-S1: 35.7° ± 8.1° vs. 44.9° ± 8.3°) is recorded. One-way ANOVA revealed that gait velocity and stride length were different among pre and post-botulinum toxin (p=0.018 and p=0.012). There is a reduction in the inclination of the pelvis on the sagittal plane during the stance; the knee shows reduction of flexion throughout the stance and increase in the maximum knee flexion in the swing. The kinetics records an increase in the hip extension moment in stance and especially in pre-swing, a reduction of the hip adduction moment, a reduction of the knee flexion moment at the initial stance (Fig. 1), an increase in the ankle flexion moment at the terminal stance. The co-contraction of abdominal and thigh muscles is reduced.

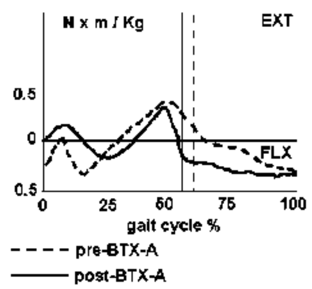

Figure 1. Increased knee flexion moment post-botulinum toxin.

Discussion

Our data demonstrate that different biomechanical mechanism underlie two camptocormia fenotypes and provide different muscle target for chemodenervation. The botulinum therapy attenuates the angle of thoracic/lumbar-level camptocormia. The joint moments demonstrate a recovery of the push capacity of the lower limb. The transition of the gait pattern from anserine pre-toxin to sagittal post-toxin is completed, with the possibility of reducing the risk of falling [3].

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Prolonged walking in persons with multiple sclerosis: fatigue effects and compensatory strategies to control foot clearance during the mid-swing gait phase

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Introduction

Fatigue is a common symptom in people with multiple sclerosis (PwMS), impacting quality of life and compromising foot clearance during swing, which can lead to falls or near falls [1]. The effects of prolonged walking inducing fatigue have been studied in healthy elderly using motion capture methodology, showing a minimal progressive reduction of foot clearance, potentially increasing fall's risk [2]. The present study aims at measuring foot clearance during prolonged and fatiguing walking in PwMS to determine the modification in clearance and the strategies that PwMS use to control clearance in order to walk safely.

Methods

Thirty-eight PwMS (22 females, 52±10 years old, EDSS 3.0±1.5points) and 9 matched healthy subjects (HS) were recruited. They performed a continuous figure-8 walking at their self-selected gait cadence + 15% until complete exhaustion or 30 minutes. A motion capture system measured foot clearance (MTC: Midswing Toe Clearance) and lower limb attitude (FD:Foot Drop primarily determined by ankle plantarflexion, and LL:Limb Length primarily determined by knee extension), during a task of prolonged walking. Physical exertion was self-assessed with Borg scale (Rate of Perceive Exertion; RPE). Trend over time for clearance (kMTC), foot drop (kFD), and lower limb length (kLL) were computed as linear regressions. Results are reported limb-wise for HS (HL) and PwMS (LwMS).

Results

PwMS were forced by perceived fatigue to finish their trials after 14.4±8.3 min, while all HS completed their 30-minute walking bout. At trial start, MTC was 13.7±4.5 mm in HL and 16.8±8.9 mm in LwMS. The relative trend kMTC was almost null for HL (-0.1±0.1 mm/min), while showed different trends among LwMS (-0.3±1.0 mm/min). The HL range allowed for classifying similar LwMS as normally compensated (=kMTC), over-compensated (+kMTC) or under-compensated (-kMTC). A scatterplot of kFD vs. kLL is presented in Figure 1 (scatterplot of trends of foot-drop (kFD), leg length (kLL) and midswing foot clearance (kMTC)).

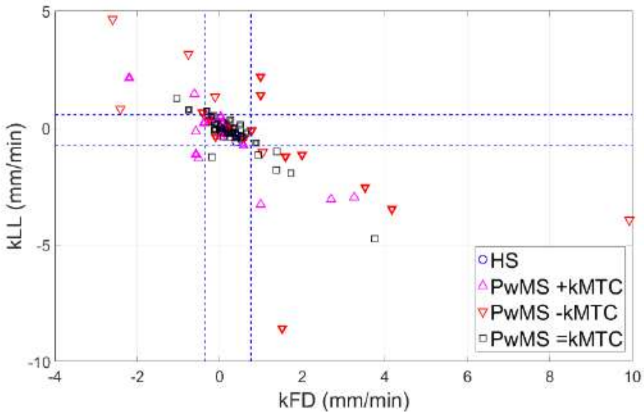

Figure 1. kLL vs. kFD scatterplot.

Discussion

PwMS either had at trial start, MTC deficits (8% had MTC<normal range) or normal MTC (71%), but also had higher than normal MTC (21%). Analogously, we observed different MTC trends (kMTC), when compared to HS: normally compensated LwMS (41%), over-compensated LwMS (26%) and under-compensated LwMS (33%). The motor strategies, described by kLL and kFD, associated with the classification of compensation is retrievable from the quadrants in the scatterplot. The results demonstrate that a single dysfunctional factor, fatigue, can be associated with various combinations of deficits and compensations, suggesting the need for tailored interventions.

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Passive exoskeleton torque optimization for overhead work: insights from muscle activity and perceived exertion analysis

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Introduction

Over the past two decades, passive arm support exoskeletons (ASEs) have been widely used in industry to support workers during the most fatiguing activities. Indeed, by providing shoulder torque through mechanical actuators, ASEs reduce the activity of the shoulder flexor muscles, thus originating an overall decrease of workers' effort and fatigue. While this approach could result favorable in the construction sector, due to the presence of tasks that continuously require the use of upper limbs, especially at and above shoulder level, the use of exoskeletons is still not widespread. One of the reasons for such lack of adoption is associated to the use of the device during dynamic activities that therefore require frequent elevation but also lowering of the arms. Indeed, to return to a neutral posture, workers should counteract the support provided by the exoskeleton, thus altering the extensor muscle activation patterns. Although such phenomenon has been previously investigated [1], to the best of our knowledge, only one study analyzed muscle activity patterns in agonist and antagonist muscles during the arm ascent and descent phases of a simulated working task [2]. The limited existing evidences suggests that, due to the atypical activation of the extensor muscles, the use of a maximum level of support, which is ideal for performing static activities, may not be optimal during dynamic ones. Therefore, it has not been fully clarified yet whether ASE use is preferable during dynamic activities and what is the most suitable level of support (if any). To partly fill this gap, we investigated how different ASE torque influence UE muscle activity, perceived exertion, and fatigue during arm ascent and descent phases of a Dynamic Overhead (DO) task.

Methods

Twenty participants (half of whom were professional construction workers) completed a DO drilling task (for 20 working cycles) under different conditions, namely without assistance (no ASE) and by wearing a commercial ASE (Ekso EVO, Ekso Bionics, Inc., San Rafael, USA) set at increasing levels of torque (i.e., 50, 75, and 100% of the torque required to support the arm in 90° of flexion). Muscle activity was measured bilaterally using surface electromyography over six muscles i.e., Anterior Deltoid (AD), Middle Deltoid (MD), Posterior Deltoid (PD), Upper Trapezius (UT), Infraspinatus (IF) and Thoracic Erector Spinae (TES). Median and peak values were than calculated through amplitude probability distribution functions (APDF 50th and 90th percentile) separately during arm ascent and descent phases, previously identified from arm kinematics data. In addition, participants indicated torque preference and rated, in each torque condition, perceived exertion (RPE) and fatigue at the shoulder.

Results

Overall, 83% of participants expressed a preference for using the exoskeleton to perform DO tasks; between them, 40%, and 53% selected respectively 75 and 100% torque as preferred support level. During the ascent phase, increasing torque levels caused significant reductions in shoulder agonist muscle activity compared to the no ASE condition (e.g., AD and UT respectively up to -43% and -33%). In contrast, during the descent phase, wearing the ASE with the maximum level of torque (100%) increased muscular activity compared to the medium level condition (e.g., PD and TER respectively up to +44% and +20%). In addition, qualitative analysis revealed a significant reduction of RPE and fatigue ($p = 0.001$) with increasing ASE torque.

Discussion

This study revealed that ASE use is preferable to the unassisted condition even during the performance of DO activities characterized by continuous lifting and lowering of the UE, which are typical of the construction industry. Nevertheless, both muscle activity and subjective perceptions suggest that a moderate level of torque (for the Ekso EVO about 75% of the torque required to float the arm at shoulder level) might be the most suitable solution to guarantee a significant reduction of shoulder flexors activity during arm ascent while reducing extensors activity during arm descent.

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Older workers spend less time than young workers in extreme trunk posture during order-picking tasks: lack of capacity or cautious strategy?

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Introduction

Order-picking is a physically demanding job which involves frequent and extensive trunk flexion that, if excessive in amplitude and in frequency, can increase the risk of developing trunk-musculoskeletal disorders (MSD). Such risk is further increased by the ageing of the workforce (those over 45 represent 31.7% of the workforce BLS, 2024), a phenomenon with relevant socioeconomic implications since older workers (i.e., those aged 50 years and over, [1]) experiencing reductions in muscular strength and mobility, are more exposed to MSD. Although previous studies reported a significant effect of age on postural strategies associated with the performance of manual material handling tasks, it remains unclear whether such differences are associated with a physical constraint (i.e., reduction of the trunk mobility) or if they are rather consciously adopted by older workers. In the present study, we investigated the effect of age and trunk mobility collecting data during actual work shifts using IMU.

Methods

Forty-one workers (see Table 1) assigned to the same series of tasks were recruited at the “Conad del Tirreno” warehouse (Cagliari, Italy). Based on age and trunk range of motion (ROM) workers were divided into “Young” and “Old” (cut-off 50 years) and into “Flexible” and “non-Flexible” (using the entire group ROM mean value as cut-off). Trunk movements were continuously recorded during two hours of a regular work-shift using a wearable IMU placed approximately at L1 vertebrae location. The collected data were then classified according to the ISO 11228-2 standard. Potential differences between the two groups were investigated using a 2-way MANOVA with age (i.e., Young, Old) and flexibility (i.e., Flexible, non-Flexible as independent variables).

Results

Statistical analysis found a significant main effect for all considered factors (i.e., age p=0.002, flexibility p=0.001) as well as for age x flexibility interaction (p=0.031). The post-hoc analysis revealed that within Young workers the Flexible ones spent significantly higher percentage of time in flexion >60°compared to non-Flexible, while within the Old group no differences were found (see Table1).

Table 1. Participants’ characteristics and results of trunk flexion monitoring. Values are expressed as mean (SD). Symbols: *a* indicates significant difference with respect to Old Flexible; *b* with respect to Young non-flexible; * with respect to Old group.

	Old (n=19)		**Young (n=22)**	
	Flexible (n=9)	**Non-Flexible (n=10)**	**Flexible (n=9)**	**Non-Flexible(n=10)**
Age (years)	56.0(3.6)	56.7(4.4)	**34.4(4.3)***	**39.0(6.9)***
Height (cm)	173.4(3.9)	169.4(9.7)	173.5(5.3)	169.5(8.0)
Body Mass (kg)	77.0(6.7)	77.4(10.9)	73.7(12.0)	68.3(12.5)
Flexion ROM	99.3(8.6)	75.1(9.4)	107.9(5.0)	76.8(12.4)
%of time in Flex 20-60°	11.6(4.4)	11.4(5.1)	13.9(3.7)	11.1(4.3)
%of time in Flex>60°	3.1(1.3)	2.0(1.1)	**8.1(3.3)[a,b]**	2.8(2.4)

Discussion

Our results showed that a reduction in trunk mobility influences the percentage of time spent in the most severe postures regardless of age. However, even old workers characterized by good trunk mobility show a reduced percentage of time in flexion over 60°, thus suggesting the adoption of a cautious approach probably influenced by superior knowledge and experience, which help them to optimize their posture during the task execution [2]. Nevertheless, since physically demanding postures pose greater health risks to older workers compared to younger ones, it appears essential to monitor workers’ postures to effectively plan job duties optimally aligned with individual physical capabilities.

Acknowledgements: This work was supported in part by the MAECI, grant number US23GR07

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Development and validation of an algorithm for foot contact detection in high-dynamic movements using inertial measurement units

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Introduction

Wearable Inertial Measurement Units (IMUs) offer a promising alternative to traditional motion capture systems for biomechanic assessments in real-world, sport-specific settings [1]. Accurate foot contact detection (FCD) is essential when force plates are not available; however, existing IMU-based algorithms are primarily developed and validated for gait analysis [2]. This leaves a gap in their applicability for high-dynamic movements, such as changes of direction and sprints with deceleration, which are commonly associated with high risk of musculoskeletal injuries in sport contexts [3]. The aim of this study was to develop and validate an IMU-based FCD algorithm, suitable for application in sport-specific high-dynamic movements.

Methods

Thirty-four healthy athletes performed two high-dynamic tasks: a 90° change of direction and a sprint with deceleration. Data were collected using a force plate (1000Hz, Vicon Motion Systems Ltd.) and 8 IMUs (60Hz, MTw Awinda, Xsens) placed on the lower limbs and trunk. Of 302 total trials (164 COD, 138 sprints), 47 were excluded due to errors during acquisition. Two FCD algorithms were developed: one based on Pelvis Vertical Velocity (PVV) and one on Resultant Foot Acceleration (RFA), both aimed at identifying initial contact (IC) and toe-off (TO) events. Force plate data served as the reference system. Performance accuracy was assessed by computing the median offset and interquartile range (IQR) between algorithm- and force plate–based foot contact window. An accuracy threshold of ±50ms margin around IC and TO was established to compare and evaluate algorithms [4].

Results

The PVV algorithm exhibited a higher median offset than RFA for IC detection, though with comparable IQR and a higher offset for TO. IC detection exceeded the ±50ms threshold in 116 trials using PVV and 101 trials using RFA. For TO, 226 trials exceeded the threshold with PVV and 102 with RFA. A significant negative correlation was observed between RFA IC error and foot acceleration magnitude ($r = -0.33$, $p < 0.001$). In low foot acceleration trials ($n = 45$, < 60 m/s²), PVV outperformed RFA with a lower median IC offset (53.7ms vs 77.8ms, respectively).

A hybrid algorithm combining the strengths of both approaches was developed, using RFA algorithm as primary and PVV as fallback. When foot acceleration at IC was < 60 m/s², PVV was used for IC detection. This method improved accuracy (IC offset: - 5.56ms, TO: 20.37ms). Trials exceeding the accuracy threshold decreased, with 92 for IC detection and 102 for TO. Regression analysis showed task influenced TO detection ($p < 0.001$), while gender had a mild effect on IC ($p = 0.043$).

Discussion

An IMU-based algorithm for FCD combining PVV and RFA signal analysis was developed and validated for high-dynamic movements typically adopted in field and return to sport testing. This algorithm offers a robust solution for biomechanical testing in sports movements by accurately identifying foot contact windows and allowing ecologically valid assessments by means of IMUs.

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Algorithms to detect foot contact in high-dynamic movements using inertial measurement units: a systematic review

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Introduction

Inertial Measurement Units (IMUs) are promising alternatives to laboratory-based motion capture systems, returning more trustful results with real-world, sport-specific data [1]. To inspect relevant biomechanics, proper foot contact detection (FCD) is mandatory, and since on-the-field force plates are unsuitable, IMU-based algorithms are required [2]. However, FCD algorithms have mostly been studied in gait analysis, leaving a gap in knowledge regarding their reliability in high-dynamic movements, which are more common in sports and likely to cause musculoskeletal injuries, such as anterior cruciate ligament rupture [3]. This systematic review aims to explore different FCD algorithms through IMUs in high-dynamic movements. The goal was to identify each algorithm's strengths and limitations and provide insights into methodological improvements and future implementations.

Methods

A systematic review was conducted across multi-databases in December 2024, following PRISMA guidelines. Inclusion criteria were articles using IMUs, algorithms with a method for FCD, articles analysing high-dynamic movements, articles focusing on FCD. Two independent reviewers inspected the retrieved papers, solving conflicts with a third reviewer. Review articles were excluded from the analysis. The Downs and Black quality index was used to evaluate the methodological quality of the included studies. Studies were inspected according to the movement type, the cohort, FCD metrics adopted, IMU placement and the ground truth used for validation. A specific focus on the algorithm steps (where available) was reported.

Results

Overall, 106 articles were identified, out of which 15 were included in the final analysis. A total of 30 FCD algorithms were adopted across the 15 articles. 12/15 articles were restricted to running, one to sprinting and two to change of direction tasks. All studies analysed healthy individuals only. The foot was chosen for IMU placement in 10/15 articles. 18/30 algorithms used linear acceleration as the feature inspected. Among these, 12/18 used foot linear acceleration, 4/18 pelvis linear acceleration, 1/18 upper back linear acceleration, and 1/18 shank linear acceleration. As a ground-truth data source, 7/30 algorithms utilised a force sensing system, while the remaining adopted less reliable sources (e.g., high-speed and consumer-grade camera systems, infrared cameras, and photoelectric bars). According to each study threshold, the algorithms' accuracy and consistency were overall high. An effect of movement task speed over algorithmic accuracy was reported in 11/15 articles.

Discussion

This systematic review highlighted lack of IMU-based FCD algorithms on high-dynamic movements. Only 15 articles were identified, mostly related to running in healthy athletes. Foot linear acceleration was the most widely adopted feature. Minimal adoption of algorithms to detect FCD during cutting manoeuvres and AI-based algorithms has been shown and validated so far. Validated FCD algorithms on high-dynamics movement are mandatory to promote the on-field use of IMUs in sports-specific biomechanics testing of healthy and injured athletes.

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Testing ACL-reconstructed football players on the field: an algorithm to assess cutting biomechanics injury risk through wearable sensors

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Introduction

Recent studies have linked Anterior Cruciate Ligament (ACL) injuries in football (soccer) to specific high-risk scenarios, especially during pressing actions against an opponent [1]. On-field assessment of cutting movements is key to identifying risky biomechanics but remains difficult to implement clinically. The study aimed to provide a practical tool, the "Anterior Cruciate Ligament Injury Risk profile Detection" (ACL-IRD), to assess the ACL injury risk during RTS continuum through biomechanical testing. It was hypothesized that the ACL-IRD would identify residual risk factors for ACL injury even after clearance for RTS in ACL reconstructed (ACLR) players.

Methods

Sixty-one football players (40 healthy, 21 ACLR, mean age 16.2 ± 2.2 years), were tested on-field more than 14 months post-surgery for ACLR players. The players performed both pre-planned and unplanned football-specific changes of direction tasks (FS deceiving action). Joint kinematics was collected through 8 inertial sensors (MTw Awinda, Movella) on the lower body and trunk through a validated workflow. The ACL-IRD algorithm was designed to simultaneously evaluate multiple biomechanical risk factors based on quantitative thresholds, based on healthy control players' biomechanics, belonging to three categories: knee valgus collapse, sagittal knee loading, and trunk-pelvis imbalance. A graphical interface with an automatic report for clinicians was developed (Figure 1).

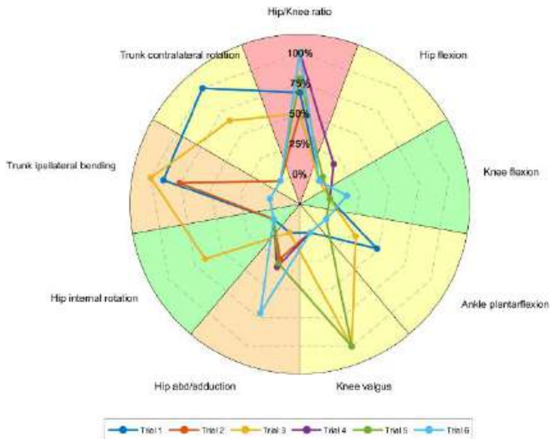

Figure 1. Illustration of the ACL injury risk profile, both the aggregate for each risk factor (color-coded in the pie chart) and the individual trial deviations from normality (lines of the radar chart).

Results

The ACL-IRD algorithm detected at-risk biomechanics in 36-37/104 trials in Agility t-test and 25-41/97 trials in FS deceiving action, respectively at initial contact and peak knee flexion. Over 60% of the at-risk trials were performed with the injured limb. Risk factors such as knee/hip flexion ratio, knee valgus, and hip abduction frequently emerged regardless of the movement task, demonstrating residual deficits and specific areas for neuromuscular improvement dictated by the algorithm.

Discussion

The ACL-IRD algorithm is the first clinical-friendly, data-driven tool to assess the ACL injury risk on the field in testing ACLR football players during RTS continuum. The algorithm was able to detect biomechanical risk profiles related to the occurrence of non-contact ACL injury in young ACLR players.

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Cutting technique of ACLR football players: on the field matched control study

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Introduction

Movement biomechanics is essential for effective rehabilitation and return to sport (RTS) after anterior cruciate ligament (ACL) injuries, particularly in young football (soccer) players. Recent research has identified distinct movement patterns associated with non-contact ACL injuries [1] and cutting manoeuvres have been identified as the highest-risk movements for inducing knee overload and ACL rupture [1,2]. To improve the detection of injury risk patterns and to identify residual asymmetries during and after RTS, there is a growing interest in assessing young players' biomechanics in real-world, sport-specific conditions. The present study aims at inspecting potential differences in cutting technique between ACL-reconstructed (ACLR) young football players and matched healthy controls, through an on-field kinematic assessment by means of wearable inertial sensors.

Methods

A total of 61 young football players (21 ACLR, age 16.8 ± 1.6 years, 15 males; 40 matched healthy controls) were tested on a regular football pitch. Each player performed two tasks (Figure 1): planned 90° changes of direction (Agility T-test), and unplanned football-specific deceiving action against an opponent (FS deceiving action). Lower limbs and trunk kinematics were measured through 8 wearable inertial sensors (100Hz, MTw Awinda, Xsens), previously validated by Di Paolo et al. for high-dynamic movement analysis [2]. Parameters included joint angles in the three anatomical planes at initial contact (IC), peak knee flexion (pKF), peak values and Range of Motion (ROM). Injured limbs of ACLR players were compared to dominant limbs of healthy controls using a two-tailed Student t-tests for the extracted features and SPM1D and Cohen's d effect size was reported alongside p-values.

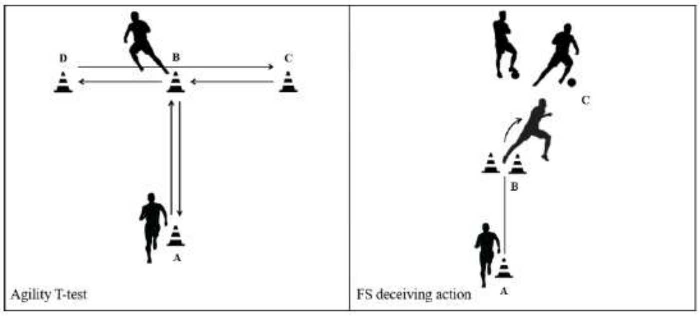

Figure 1. Schematic representation of the two tests performed by all athletes.

Results

During both tests, ACLR players showed a significantly greater pelvic drop than healthy controls, both at IC and pKF ($p<0.001$, $d=0.95-1.01$). During the FS deceiving action, several differences emerged between healthy and ACLR participants, especially in ROM: ACLR players demonstrated a stiffer lower limb strategy, with reduced ROM in the sagittal plane at the hip, knee and ankle ($p<0.001$, $d=1.03-1.73$), compensated through a greater flexion of pelvis and trunk ($p<0.002$, $d=0.65-0.68$). Hip flexion was greater in ACLR subjects at both IC and pKF ($p<0.001$, $d=1.15-1.43$).

Discussion

Biomechanical differences between healthy and ACLR players persisted after RTS clearance during football-specific on field testing. ACLR players exhibited a stiffer kinematic strategy than healthy players and compensatory movements to reduce loading on the injured limb. This study was the first to assess on-field football-specific movement technique in ACLR young players during RTS continuum, this methodology has the potential to underline residual deficits and promote data-driven rehabilitation.

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Intermuscular Coherence during Upright Reaching Tasks

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Introduction

Upright reaching tasks require controlled body weight shifts, increased postural demands, and precise neuromuscular coordination. Intermuscular coherence (IMC) provides a method to study correlated activity between electromyographic (EMG) signals from different muscles, revealing common neural inputs in specific frequency bands that exhibit task-dependent characteristics [1]. This study explores how common neural inputs underlying muscle coordination to plantar- and dorsiflexor muscles are modulated by stability demands using variations of the Functional Reach (FR) test.

Methods

Seventeen healthy volunteers (7F, 27.5 ± 3 y.o.) performed 10 trials of bilateral FR (biFR), unilateral FR (uniFR), and Lateral Reach (LR). Surface EMG signals were recorded bilaterally from the Tibialis Anterior (TA), Gastrocnemius Medialis (GastM), and Soleus (Sol) muscles at 2 kHz, then high-pass filtered (10 Hz), full-wave rectified, and concatenated across trials. IMC was computed using Welch's method (2048-point Hanning window, 75% overlap) [2]. IMC was assessed bilaterally - between homologous muscles of the dominant (D) and non-dominant (ND) limb - and unilaterally (within-limb muscle pairs). The integral of significant IMC (above the 5 % significance threshold [3]) was computed for delta (0-5 Hz), alpha (8-12 Hz), beta (13-35 Hz), and low gamma (35-60 Hz) bands. Statistical analysis was conducted using linear mixed models with subjects as random factors. Post-hoc comparisons were Bonferroni-corrected.

Results

A significant effect of frequency, task, and muscle pair on IMC was observed, with a significant interaction between limb sides and all fixed effects (Fig.1). Across all tasks, bilateral IMC was higher in delta than alpha, beta, and low gamma bands ($p < 0.001$), and higher than alpha and low gamma bands for unilateral IMC ($p < 0.001$). Alpha coherence was consistently the lowest among all bands. With respect to task direction, bilateral delta band IMC was lower in LR compared to biFR and uniFR ($p < 0.001$). Bilateral delta band IMC was higher for the GastM and Sol pairs than TA during forward reaching ($p < 0.001$). Unilaterally, agonist GastM–Sol muscle pairs showed greater IMC than antagonist TA–GastM pairs in the delta and beta bands ($p < 0.001$). During LR, IMC in the delta ($p < 0.001$), beta ($p < 0.01$), and low gamma ($p < 0.05$) bands was higher compared to biFR and uniFR in the ND antagonist TA–GastM muscle pair.

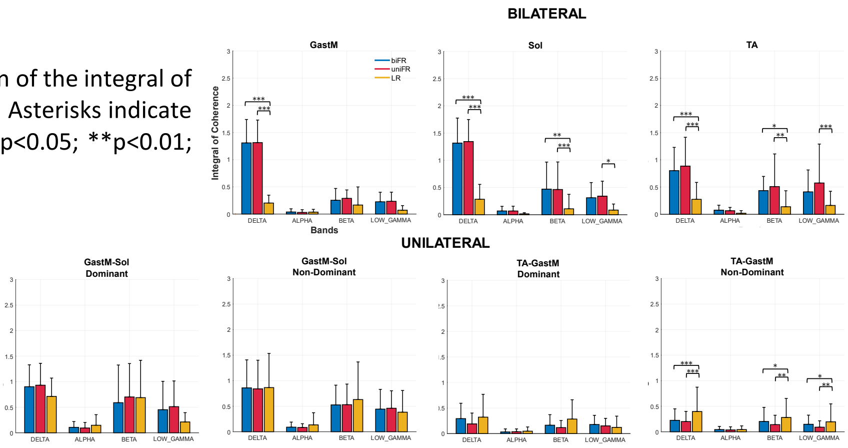

Figure 1. Mean and standard deviation of the integral of the significant IMC across all subjects. Asterisks indicate significant differences across tasks (*p<0.05; **p<0.01; ***p<0.001).

Discussion

The results reveal task-dependent differences in coherence between lower limb muscles during upright reaching tasks suggesting distinct neural strategies depending on movement direction. The increase in IMC in the ND antagonist muscle pair, and reduction in bilateral delta band IMC, suggests greater antagonist coupling and interlimb independence to counter lateral instability during LR. IMC was strongest in the delta band across different limbs, reflecting a more distributed control strategy, whereas a relatively greater contribution of the beta band in intralimb coordination suggests higher synchrony and greater reliance on shared cortical drive.

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Bilateral Muscle Synergies During the 30-Second Sit-to-Stand Test

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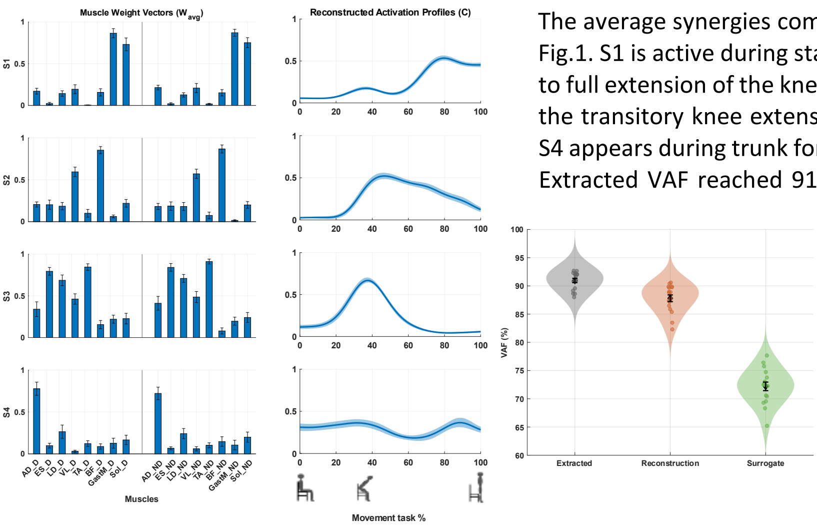
Introduction

The Sit-to-Stand (STS) test is a widely adopted clinical tool for its' ability to effectively indicate lower limb strength, functional capacity, and risk of falls, which are critical for maintaining independence in daily activities [1]. Muscle synergy analysis offers a structured insight into the neuromechanical strategies that drive STS movements [2]. This study aims to characterize the bilateral muscle synergy patterns underlying repeated STS movements by using bilateral surface electromyography (EMG). The objective is to define a common set of synergy vectors and examine their validity in describing the muscle coordination of various healthy individuals.

Methods

Seventeen healthy volunteers (7F, 27.53 ± 3 y.o.) performed three trials of 30-Second STS tests [3]. Surface EMG was used to record activity from 8 muscles on each side of the body (dominant [D] and non-dominant [ND]): Anterior Deltoid (AD), Erector Spinae (ES), Latissimus Dorsi (LD), Vastus Lateralis (VL), Tibialis Anterior (TA), Biceps Femoris (BF), Gastrocnemius Medialis (GastM), and Soleus (Sol). Kinematic measurements isolated the initial sitting-to-standing phase, which was applied to pre-processed EMG data. Amplitude and time-normalized EMG data were concatenated, and random cycles were selected [2]. Muscle synergies were extracted using non-negative matrix factorization, with the number of synergies (N_{syn}) determined by Variance Accounted For (Extracted VAF) [4] and Mean Squared Error [5]. A cross-validation was done by using the averaged muscle weight vectors (W_{avg}) to reconstruct EMG activity for all subjects (Reconstruction VAF). Reconstruction VAF values were compared with the 95th percentile of the distribution coming from the reconstruction with surrogate W matrices, obtained by random shuffling W_{avg}.

Results



The average synergies coming from the identified N_{syn} are shown in Fig.1. S1 is active during stable standing; S2 relates to the transition to full extension of the knee and hip; S3 spans trunk flexion through the transitory knee extension point to maximal ankle dorsiflexion; S4 appears during trunk forward transfer and final stabilization. The Extracted VAF reached 91.0% ± 0.4 (mean ± standard error [SE]), while the Reconstruction VAF was 88.0% ± 0.6. In contrast, the Surrogate VAF dropped to 72.2% ± 0.8.

Figure 1. Muscle weight vectors (W_{avg}), reconstructed activation profiles (C) of the muscle synergies averaged across participants, and cross-validation results (mean and SE).

Discussion

These findings support the robustness and generalizability of bilateral muscle synergies during repeated STS movements, providing a common framework for movement assessment that can serve as a valuable reference for comparisons with other populations.

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Wearable sensor-based analysis of trunk and upper limb movements in bakery: a pilot study

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Introduction

Work-related musculoskeletal disorders (WMSDs) represent a major occupational health issue among bakery workers due to several factors like repetitive nature of the performed tasks, prolonged time spent in standing position, and awkward postures associated with specific processing procedures of the products [1]. However, despite the well-recognized relevant ergonomic risk in this sector, the assessment of the biomechanical variables of interest still mostly relies on subjective evaluations, while the use of instrumental techniques is restricted to lab-based studies. While such lack of real-time, sensor-based monitoring limits the ability to accurately quantify the actual biomechanical exposure, it is noteworthy that the recent advancements in wearable sensor technology provide an opportunity to overcome such limitations in an accurate and continuous manner. Nonetheless, studies applying such technology in actual bakery environments remain scarce. Based on such considerations, this study aims to propose a real-world analysis of posture carried out by means of wearable inertial measurement units (IMU) to quantify trunk and upper limb movement patterns in bakery workers under ecological conditions, namely during regular shifts.

Methods

We employed a simple low-cost, minimally intrusive approach based on a limited number of sensors, previously tested with encouraging results in other productive sectors [2,3]. Trunk and upper limb kinematics of 7 experienced workers (2 dough makers, and 5 bakers, mean age 39±14 years) during a 4-hour actual work shift were obtained by processing data obtained by a single IMU positioned at the first lumbar vertebra level to record trunk movements, and by two accelerometers placed at the deltoid tuberosity to estimate upper arm kinematics [2]. Raw accelerations and angular velocities were processed using a custom routine to calculate trunk inclination and shoulder elevation. Amplitude and frequency of movements were compared with the thresholds defined by the international standards ISO 11226 and EN 1005-4.

Results

Data analysis showed that trunk movements frequently exceeded the recommended thresholds in both worker categories. In particular, dough makers spent more time in moderate (>20°) and extreme (>60°) trunk flexion than bakers (20.2% vs 8.9% and 2.5% vs 1.5%, respectively), also resulting in higher mean flexion angles (34.8° vs 29.2°). Trunk flexion frequency was also higher in dough makers (3/min) than bakers (2.8/min), both above the recommended limit of 2/min. Upper limb analysis revealed that workers spent about 40% of their time with arms flexed, with similar average angles (~30°) for both dominant and non-dominant limb. Percentage of time spent in moderate flexion was 36.0% for dominant and 41.1% for non-dominant, while extreme flexion (>60°) occurred in 4.9% and 7.9% of the time, respectively. Bakers performed more static (lasting more than 4s) upper limb flexions than dough makers (13/min vs 10.5/min), with both exceeding ISO 11226 limits.

Discussion

The obtained results highlight (and quantify) the significant exposure to non-neutral postures and repetitive movements among by bakery workers. Although task-specific differences emerged – with dough makers who experience higher biomechanical load on the trunk and bakers characterized by superior upper limb involvement – both roles frequently exceeded recommended thresholds for trunk and upper limb postures. Such findings emphasize the physically demanding nature of bakery tasks and the importance of role-specific analysis. The integration of wearable sensor technology into workflows could enable real-time ergonomic monitoring, offering continuous and objective evaluation of postural risks.

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Functional Subtypes in Knee Osteoarthritis Using IMU-Based Gait and Balance Analysis with Unsupervised Machine Learning

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Introduction

Knee osteoarthritis (OA) is a leading cause of pain and functional decline in older adults, often associated with altered gait and impaired balance. AI and unsupervised learning methods like PCA and SOM are transforming human movement analysis, enabling the discovery of hidden biomechanical patterns and supporting personalized interventions, especially when integrated with wearable sensor data. This study investigates whether combining wearable sensor data and unsupervised machine learning can identify clinically meaningful subgroups within the OA population, potentially supporting individualized rehabilitation.

Methods

A cross-sectional study was conducted with 40 participants (20 OA, 20 healthy controls, aged 45–80). Gait parameters were recorded using BTS G-Walk® inertial sensors; postural balance was assessed via stabilometric platform under eyes open (OE) and closed eyes (CE) conditions. Statistical analysis compared OA and control groups, followed by a four-step machine learning approach composed of Principal Component Analysis (PCA), Self-Organizing Maps (SOM), and K-means clustering to identify latent subgroups within the OA cohort.

Results

OA subjects showed significantly reduced walking speed (1.05 vs. 1.30 m/s, $p = 0.025$), cadence (101.98 vs. 110.04 steps/min, $p = 0.015$), and propulsion phase (5.3% vs. 7.6%, $p = 0.007$), as well as greater sway ellipse areas under both OE (1656 vs. 427 mm², $p < 0.001$) and CE conditions (2011 vs. 443 mm², $p < 0.001$). PCA extracted four main components in the OA group, capturing gait performance, asymmetry, cadence, and postural control. Machine learning identified three distinct OA subgroups: (C1) patients with severe impairments and 80% having KL grades 2–3; (C2) high-functioning individuals, 50% KL grade 1; and (C3) participants with poor postural stability, 40% KL grade 2.

Discussion

These findings highlight the heterogeneity within the OA population and the limitations of conventional classifications based solely on radiographic grading. The identification of functional subtypes supports a precision rehabilitation approach, tailoring interventions to specific motor profiles. The integration of wearable sensors with machine learning offers a scalable and ecologically valid method to inform clinical decisions. Future studies should include larger samples and real-world assessments to enhance generalizability.

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From gesture to pathology: biomechanical and ultrasound analysis of the shoulder in elite water polo player

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Introduction

Sports involving repetitive overhead movements such as water polo, baseball, and volleyball have been associated with a significantly higher incidence of shoulder pain and injury compared to non-overhead sports (61% vs. 33%) [1]. Water polo is a physically demanding team sport that combines swimming, throwing, and intense physical contact in rapid succession. This repetitive and high-intensity activity places significant stress on various joints and muscles, predisposing athletes to both acute and chronic injuries. Among these, the shoulder is one of the most frequently affected joints [2], particularly structures such as the rotator cuff, the long head of the biceps, and the glenohumeral joint. In water polo, one of the most critical and biomechanically demanding actions is the shot, which requires forceful overhead throwing to score goals. This gesture plays a central role in the onset of shoulder-related issues in players. The goal of the study is to investigate muscle activities during water polo penalty shoot and to characterize this athletic gesture based on different techniques or on shoulder pain.

Methods

We recruited 14 players, mean age 22.9 ± 5.5 years, from the Bogliasco 1951, men's waterpolo team competing in the Italy's top-tier Serie A1. Each player underwent strength tests using a hand-held dynamometer, evocative tests and ultrasound examination of the shooting shoulder. Following these tests, subjects performed penalty shots in the swimming pool, while we recorded surface electromyography (sEMG) from 11 muscles on the body side executing the gesture. Synchronized video footage was captured from frontal, lateral and oblique views to segment the shot into distinct phases. We divided the movement into four distinct phases as part of our analysis: preparation, loading, acceleration, and the release of the ball. The first two phases are characterized by the movement of the upper limb from when he picks up the ball to when the player reaches maximum extra rotation and abduction; the third phase is essential to transmit speed and the right trajectory to the ball, the fourth phase allows to dissipate the force accumulated during the previous phases.

Results

Based on the sEMG we found 2 shooting patterns with different muscle recruitment patterns (G1 and G2): in G1 the strength is developed more using the torsion of the trunk, in G2 there is a greater use of the upper limb muscles. Of the 14 players analysed, 6 subjects used the G1 pattern and 8 the G2 pattern. Many players, even without lesions documented by ultrasound, present episodes of shoulder pain, in some cases chronic. There is a minimal difference in the strength of shoulder movements in the 2 groups, even if these are limited samples. Results of the strength tests with dynamometer shows a greater strength in intra rotation; players under 25 presented a smaller difference between intra and extra rotation compared to players over 25. The strength in extension was greater than that in flexion in both groups. The involvement of the rotator cuff muscles is present in both groups. From an ultrasound point of view, 2 players presented tendinopathy of the supraspinatus in both G1 and G2. 4 players presented chronic pain, 2 in G1 and 2 in G2.

Discussion

G1 group exhibited a broader and more sustained recruitment of proximal musculature consistent with a power strategy emphasizing gradual acceleration and controlled eccentric deceleration. This contrasts with G2 group, who displayed a more phasic activation profile, with concentrated peaks in triceps brachii and wrist flexors, indicative of a high-intensity, rapid-release pattern. G1 strategy observed here may thus offer protective biomechanical advantages by distributing mechanical stress across a broader musculoskeletal base, potentially lowering the risk of distal overuse syndromes. These results may reflect greater mobility or adaptation in athletes who rely more heavily on proximal contribution. While these ROM differences did not meet the threshold for statistical significance, the associated effect sizes suggest clinically meaningful variation that warrants further exploration in larger samples

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Video-based kinematic assessment of lower limbs in paediatric patients with severe neuromotor disorders during hydrokinesitherapy.

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Introduction

Hydrokinesitherapy is a rehabilitation technique performed in water to reduce joint load, relieve pain and spasticity, and improve flexibility, coordination, muscle relaxation, posture, and Range of Motion (ROM) [1]. An observational study at Fondazione TOG (Milan, Italy) developed a new method to analyse lower limb kinematics during water gait in severe paediatric patients with neuromotor disorders, comparing it with gait on land and over time. This non-invasive approach has been evaluated in clinical practice for hydrokinesitherapy assessment and patient monitoring.

Methods

A markerless, video-based method was used for human landmark detection through the AI MediaPipe system, which identifies 33 key-points in video frames [2]. The sample included 10 patients with severe neuromotor disorders able to ambulate in water, with a mean age of 10.25 ± 3.14 years. These patients had different pathologies, such as Infantile Cerebral Palsy and genetic syndromes. Gait was recorded in water and on land using a GoPro HERO10 camera at 30 Hz, positioned 1.5 meters from the subject to capture sagittal plane motion. Recordings were repeated three times at three-month intervals to evaluate temporal trends and preliminary therapy outcomes. Landmark coordinates were used to calculate knee and hip angle as dot products between the vectors representing the anatomical segments. ROM was then computed as the difference between the minimum and maximum angle within a step and averaged over five steps per side of each patient across all three acquisitions.

Results

The ROM differences of knee and hip angles between water and land conditions were computed, considering variations within ±6° for lower limbs as negligible [3]. Out of 174 evaluated ROM differences, approximately 8% were negative, 23% were null, and 69% were positive, indicating greater joint excursion in water compared to land. **Figure 1** shows the adopted convention for calculating the knee angle and an example of a comparison of this angle on land and in water over time during an acquisition session. Time has been normalised to the duration of each acquired gait to make the graphs comparable. Over time, the percentage of positive ROM differences increased from 58.3% in the first acquisition to 91.7% after six months.

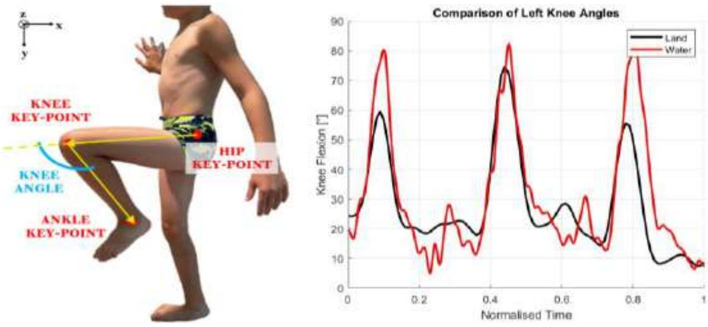

Figure 1. Adopted convention for knee angle calculation and left knee angle over normalised time for patient 9 during the first acquisition, comparing land (black line) and water (red line) gait.

Discussion

For all patients, the aquatic environment facilitated wider, simpler and less painful movements compared to land. The warm water increased joint excursion by reducing muscle contraction and shortening. The greater ROM differences observed in the final recordings compared to the initial ones indicated clear improvements over time. In conclusion, this study proposed a non-invasive method for kinematic assessment in paediatric hydrokinesitherapy, showing promise for clinical applicability.

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An innovative AI software for the biomechanical analysis of lower limb running prostheses from slow-motion videos

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Introduction

In paralympic sprint running, prosthesis fitting influences performance. Key aspects include the selection of the running prosthetic foot (RPF) and the alignment of the prosthetic components relative to the socket [1,2]. These operations affect the socket and foot orientation relative to the ground during running and the foot compression, which are key biomechanical indicators based on our experience. These indicators are typically quantified through manual video annotation or marker-based techniques, leading to operator errors and time-consuming processing. Recently, AI-driven software allow for marker-less motion analysis, but current solutions are not trained to recognize running protheses and to extract the landmarks crucial for calculating the aforementioned parameters. The aim of this study was to develop, train and conduct a preliminary validation of an innovative AI app to fulfill this need.

Methods

The software leverages Convolutional Neural Networks, based on the CenterNet architecture with Hourglass104 backbone, to detect the object "lower-limb prosthesis" and its keypoints. The app development consisted of three phases. The TensorFlow 2 (TF2) Object Detection API [3] was chosen as the main framework to fine-tune the pre-trained model CenterNet Hourglass104 Keypoints 512x512 (TF2 Object Detection Model Zoo) [3]. The second phase includes the annotation of two custom datasets as shown in Figure 1a: 1899 images of J-shaped RPFs gathered from 32 slow-motion videos featuring 8 athletes; 1288 images of C-shaped RPFs extracted from 14 videos featuring 3 athletes. Finally, a graphical user interface was developed to apply the trained AI models on the slow-motion videos and compute the 2D kinematic analysis using the extracted keypoints. A validation procedure was performed on two videos each with over 80 images, one for each RPF type, by comparing the keypoints identified by the software with manually annotated keypoints as gold standard.

Results

Figure 1b shows a paradigmatic output of the trained models applied on a frame of a slow-motion video. The error analysis resulting from the validation procedure is expressed in terms of the distance between the keypoints' positions estimated by the two methods, i.e. manual vs AI annotation, in terms of mean distance and standard deviation. Specifically, for J-shaped RPFs, keypoint 7 exhibits the larger error of (1.1 ± 0.6) cm, while keypoints 4, 5 and 9 show the lowest errors of (0.4 ± 0.2) cm, (0.8 ± 0.2) cm and (0.6 ± 0.4) cm, respectively. For C-shaped RPFs the keypoints 0, 1, 2 and 3 show the larger errors, from (1.4 ± 0.7) to (2.0 ± 1.6) cm, while keypoint 4 shows the lowest error of (0.5 ± 0.2) cm.

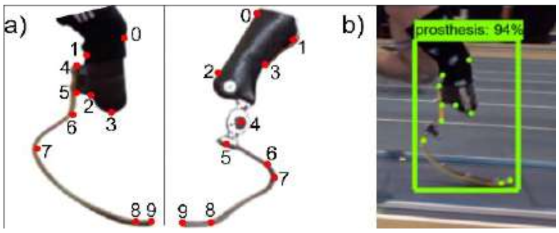

Figure 1. a) Annotation system used for the J-shaped and C-shaped RPFs datasets. b) Example of the result of the application of the AI models to a frame of a slow-motion video.

Discussion

The most inaccurate keypoint in J-shaped RPFs is the 7th. However, its impact on the 2D foot compression angle can be mitigated by the accuracy of keypoints 5 and 9. For the C-shaped RPFs, the most critical keypoints are those of the socket. However, their variability remains acceptable, as they stay along the socket edge, allowing for the calculation of its axis. Results suggest that the chosen architecture and AI implementation offer a promising tool for marker-less biomechanical analysis and running prosthesis fitting support. Our next goal is to complete the AI validation and combine the kinematic analysis with the estimation of ground reaction forces.

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Comparing wearable sensors and optoelectronic systems for estimating lumbo-sacral flexion moment during lifting

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Introduction

Work-related musculoskeletal disorders (WMSDs) are a major occupational health concern, especially in manual lifting [1]. The lumbosacral joint is prone to excessive mechanical loads, increasing the risk of lower back pain [2]. Estimating internal joint moments is crucial for assessing biomechanical risk and preventing injuries [3]. This study hypothesizes that IMU-based moment estimations at the lumbosacral joint, compared to an Optoelectronic system (Opto), during lifting tasks, can be accurate and reliable enough to possibly assess workplace risk evaluation and injury prevention in the future.

Methods

The study was approved by the Ethical Committee of the University of Twente (ref. 240909). Five healthy subjects (4 males, 1 female; 24 ± 2.5 years; 74.9 ± 11.4 kg; 180 ± 6.4 cm) lifted four different loads (0, 5, 10, 15 kg) ten times in two minutes, keeping their knees extended (stooping). Each participant was equipped with 62 retro-reflective markers placed in anatomical positions, acquired at 100 Hz using a Qualisys Opto. Marker placement followed the modified Cleveland Clinic marker set. Additionally, 8 IMUs (Xsens, 60 Hz) were placed on the body to capture kinematic data simultaneously. Four extra markers were placed on the corners of the lifted box to track the external load's motion. OpenSim's *Inverse Kinematics* tool computed joint angles from marker data. The *IMU Placer* and *IMU Inverse Kinematics* tools in OpenSim estimated joint angles from IMU orientation data. OpenSim's Inverse Dynamics tool was used to estimate the flexion moment at the L5-S1 joint. Input for the dynamics analysis included subject and box kinematics along with the external loads. Finally, Pearson's correlation coefficient ($p < 0.005$) and the average difference in peak flexion angle and moment were calculated to compare the two methods.

Results

From the statistical analysis, the correlation between the signals from the two methods was found to be very high ($r>0.8$ and $p<0.005$), both for L5-S1 flexion angle and moment for all subjects and lifted loads. The average and standard deviation from all subjects of the difference in maximum values of L5-S1 flexion angle and of maximum flexion moment estimated by Opto and IMUs are reported in Figure 1.

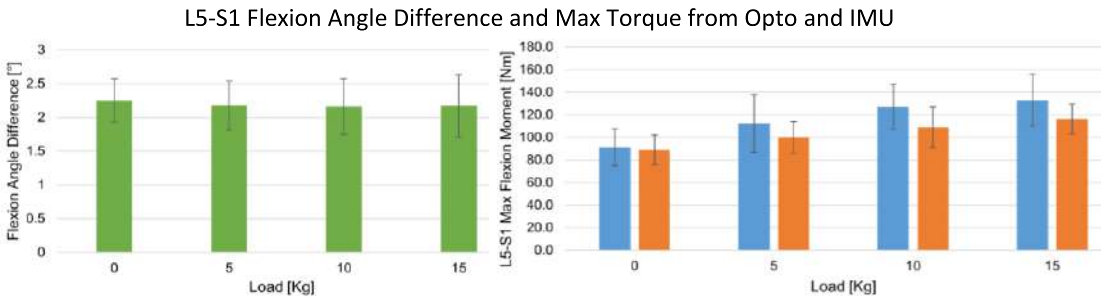

Figure 1. Average difference (and standard deviation) between Opto and IMU of maximum values of flexion angle (a) and maximum flexion moment (b) at L5-S1 joint estimated by Opto and IMU.

Discussion

Correlation analysis found a very high value between the two methods over the entire joint angle and moment values, and, as shown in Figure 1, the mean error in the maximum flexion angle is relatively low. However, because derived quantities are utilized in the inverse dynamics computation, this angular error may contribute to a difference in the maximum estimated flexion moments. Nevertheless, given the small median difference (<7Nm) on maximum flexion moment, this research demonstrates that IMUs can estimate the flexion moment at the joints to evaluate potential risks associated with specific tasks, given the fact that they can detect the increase of the moment with the lifted load. The presented methodology could be utilized to explore any other joint or task outside the laboratory to analyse real case scenarios.

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Delayed muscle onset in athletes after anterior cruciate ligament reconstruction during unplanned change-of-directions

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Introduction

Effective recovery of neuromuscular control after Anterior Cruciate Ligament Reconstruction (ACL-R) is crucial for regaining appropriate mechanical function of the knee joint and preventing further injuries. Muscle onset timing immediately before unplanned Change-of-Direction (CoD) might represent a key parameter for assessing neuromuscular control strategies in Return-to-Sport evaluation. With the growing use of artificial intelligence for electromyography (EMG) analysis, Long Short-Term Memory recurrent neural network for Muscle Activity Detection (LSTM-MAD) [1] proved successful in detecting muscle onsets from EMG signals. This study aims to compare muscle activation onset time in ACL-R and control athletes during an unplanned 90° CoD task, adopting LSTM-MAD for EMG-onset detection.

Methods

Ten ACL-R and 17 control athletes performed 3 unplanned CoD for each leg with speed gates indicating the CoD direction. Foot contact was detected by two force plates [2]. EMG signals of Vastus Lateralis (VL), Vastus Medialis (VM), Semitendinosus (ST), and Biceps Femoris (BF) muscles were acquired bilaterally, band-pass filtered (20–450 Hz) and standardized with zero mean and unit variance. Muscle activation onset times prior to CoD (T_{onset}) were normalized by the duration of the swing phase (T_{swing}) (see **Fig. 1.A**) and then multiplied by 100 to obtain T_{norm}. The median value across three trials was considered for the analysis. For each muscle, a *1-way* ANOVA with Bonferroni adjustment for multiple comparisons was performed to test differences in T_{norm} between ACL-R athletes and controls.

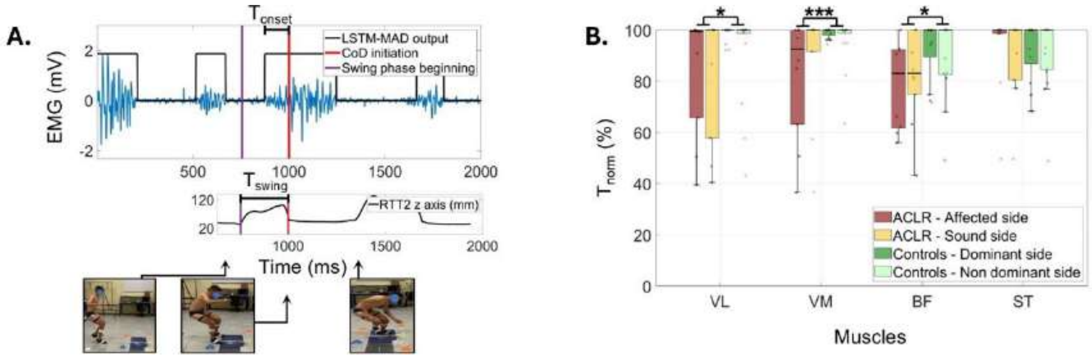

Figure 1. A Detection of EMG activity during an unplanned Change-of-Direction (CoD) task: activation intervals (detected by LSTM-MAD) of the VM muscle of a representative ACL-R athlete and the trajectory along the vertical (z) axis of the marker attached on the distal phalanx of the hallux (RTT2). B Comparison of normalized muscle activation onset times in athletes after ACL-R (affected and sound side) and controls (dominant and non-dominant side). Asterisks represent statistically significant differences (*p<0.05, **p<0.01, ***p<0.001).

Results

Statistically significant differences in T_{norm} between populations were found for the VM (ACL-R: 84±5 % (mean±SE); controls: 95±2 %; p=0.018), VL (ACL-R: 85±5 %; controls: 98±1 %; p<0.001) and BF (ACL-R: 80±4 %; controls: 91±3 %; p=0.013) muscles (see **Fig. 1.B**).

Discussion

Despite being cleared to Return to Sport, ACL-R athletes still exhibit alterations in neuromuscular control during an unplanned task compared to controls, thought to predispose to either re-injury or to contralateral ACL injury. Notably, early muscle activation onset may reflect increased pre-tension, serving as a protective mechanism by increasing joint stiffness in preparation for CoD movement.

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Inverse dynamics comparison of able-bodied and Paralympic elite sprinters using OpenSim

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Introduction

Technological progress has enabled athletes with lower limb amputation to compete in high-level track events. Body-ground interactions, along with joint torques and forces, play a crucial role in performance, training and injury prevention both for able-bodied and amputee athletes [1]. In literature, limited data is available on joint moments and power [2]. In this context, OpenSim, among others, can be used for inverse dynamics. Since the Rajagopal model [3] was originally developed for healthy young runners, it is not directly suitable for both sprinters' categories. In this study two subject-specific musculoskeletal models were developed, one for able-bodied and one for transtibial athletes, to compare their inverse dynamics quantities during maximal sprinting.

Methods

One able bodied (AB: male, 70 kg, 100m PB: 10''65) and one left transtibial Paralympic (left TT: male, 85 kg, 100m PB: 10''64, Ossur Xtreme Cat5.6) sprinters participated in this study. Tests were conducted on the 60m indoor Olympia SmartTrack (Palaindoor, Padova, Italy), using a 6.9m force platform line. Full body kinematics and kinetics are collected using a custom marker-set protocol. Markers trajectories and ground reaction forces (GRFs) are low-pass filtered at 10 Hz and 20 Hz respectively. Joint-specific range of motion adjustments are applied to the able-bodied musculoskeletal model to better represent sprinting mechanics, e.g. subtalar and ankle. In the transtibial model, missing segments are removed, and the residual tibia is adjusted and integrated with a prosthetic socket. Then, inverse dynamics quantities were evaluated at the hip, knee and ankle. In case of the transtibial model, GRFs and transport moment were applied directly on the prosthetic socket-clamp.

Results

Athletes reached different speed during tests (AB: 7.9 m/s; TT: 10.1 m/s). In Figure 1 lower limb internal joint moments are shown for both athletes. Stance phase in the AB is 22% of the right stride for both limbs; while in the TT, it is 23% for the affected limb and 18% for the unaffected one. Unlike AB, TT joint moments exhibited inter-limb asymmetries. The right unaffected limb presents similar trends to the AB at the right knee and ankle, whereas the right hip moment clearly differs. In the affected limb, knee and hip moment trends exhibit some differences compared to the AB.

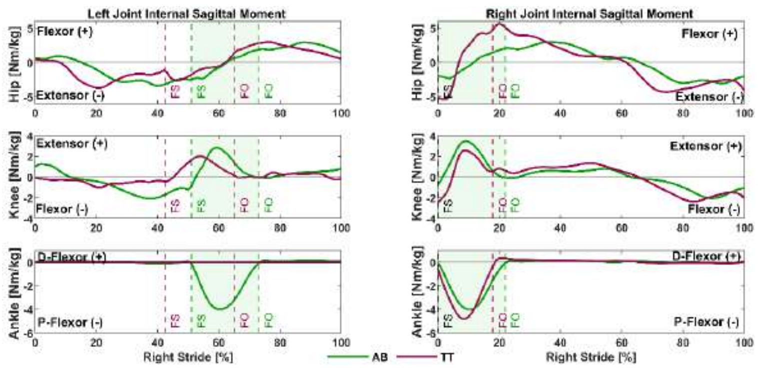

Figure 1. Hip, knee and ankle sagittal internal moments of an AB (in green) and a unilateral left TT Paralympic athlete (in red) normalized over the percentage of right stride. Vertical lines represent foot-strike (FS) and foot-off (FO) events (in green for the able-bodied; in red for the Paralympic athlete; in black whether events are the same for both athletes).

Discussion

AB joint moments trends for both limbs are consistent with previous findings [6]. In the TT, the observed inter-limb asymmetry, with increased right hip moment and decreased knee moment compared to AB, are indicative of compensatory strategies [6]. These promising preliminary results motivate improvements in the accuracy of the TT model.

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The midstance instant definition in sprinting: comparison of different approaches applied to Paralympic athletes with unilateral lower limb amputation

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Introduction

Running is a repetitive movement described by a gait cycle, divided into stance and swing phases. Within stance, midstance is a key instant for describing running biomechanics – crucial for both stability and propulsion [1]. In athletes with lower limb amputation, identifying midstance precisely enables better understanding of running-specific feet (RPFs) behaviour. However, a standardised definition of midstance is missing, leading to data misinterpretation across studies. This study addresses this issue by comparing different kinematic- and kinetic-based definitions of midstance in sprinting.

Methods

Four athletes with unilateral transfemoral (TF) and four with unilateral transtibial (TT) amputations took part in the study. Participants were asked to perform 60 m sprint tests at the Olympia Smart Track [2] at the Palaindoor of Padua (Italy). Kinematic and kinetic data were filtered and analysed in Matlab. Kinetic-based midstance definitions were identified when: (i) the Great Trochanter (GT) and the Centre of Pressure (COP) were vertically aligned; (ii) the anterior-posterior ground reaction force (AP-GRF) crossed zero. Kinematic-based definitions of midstance included the instants: (iii) when the GT was vertically aligned with the FD5 marker (placed laterally on the RPF, 5 cm from its tip); (iv) only for TF athletes, when the GT was vertically aligned with the K marker (placed laterally on the prosthetic knee centre of rotation). These definitions were adopted for the affected limb (AL), while analogous definitions were considered for the unaffected limb (UL), using the marker placed on the fifth metatarsal head (VMH) rather than FD5. Agreement between methods was tested with Bland–Altman (BA) analysis.

Results

Bland-Altman analysis for the AL in TT athletes (Figure) underlined strong agreement between GT-COP and GT-FD5 definitions, with no significant time differences. Instead, a significant mean difference (-9.6 ms; $p<0.001$) was observed between GT-COP and AP-GRF. In contrast to TT, for TF athletes, the kinematic methods (GT-K, GT-FD5) showed a statistically significant difference compared to GT-COP ($p<0.001$), respectively with a median time of -8.3 ms (IQR=4.2 ms) and 4.2 ms (IQR=8.3 ms). For GT-COP and AP-GRF zero-crossing definitions, no significant time difference (median=0.0 ms; IQR=8.3 ms; $p=0.53$) was found. For the UL, the comparison between GT-COP and GT-VMH showed a median time equal to -4.0 ms (IQR=4.2 ms; $p<0.01$) and -4.2 ms (IQR=0 ms; $p<0.01$), in TT and TF respectively.

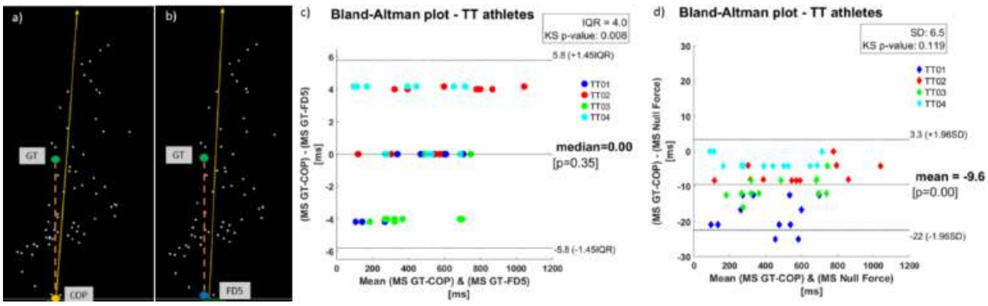

Figure 1: Comparison of midstance (MS) definitions in the AL of TT athletes. a-b) GT-COP and GT-FD5 alignment; BA plot comparing c) GT-COP and GT-FD5 timing, d) GT-COP with zero-crossing of the AP-GRF timing.

Discussion

The findings suggest that for TT athletes GT-COP and GT-FD5 definitions are interchangeable, providing flexibility in method selection depending on the available instrumentation. In TF athletes, further investigation is needed to address discrepancies between GT-COP and kinematic methods.

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Atypical gait cycles from pressure insoles in real-life scenarios in people with gait disorders

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Introduction

The most common sequence of gait phases is Heel-contact, Flat-foot contact, Push-off, and Swing (standard "HFPS" cycle). However, alternative sequences, referred to as "atypical" gait cycles (*AGC*), may also occur [1] and are relevant for evaluating instability and gait efficiency. This study aims to investigate *AGC* in people with different gait disorders during free daily living activities by employing a newly developed open toolbox for detecting gait phases from Pressure Insole (PI) signals.

Methods

PI signals of 70 pathological subjects (from 5 cohorts) and 18 Healthy older Adults (HA), recorded during free-daily-living activities (lasting 2.5 hours) were extracted from the Mobilise-D open database [2]. Gait phases were identified through the PIN2GPI toolbox (https://github.com/Biolab-PoliTO/PIN2GPI) (**Figure 1.A**). *AGC%_norm* was computed as the maximum *AGC* percentage between the left and right sides (i.e., subject-specific "worst side") normalized by the individual's total walking time.

Results

For each subject, we analyzed 1931±609 (mean±SE) gait cycles in CHF, 1068±113 in COPD, 1267±231 in MS, 1916±399 in PD, 1059±201 in PFF patients, and 2076±246 in HA**.** Higher *AGC%_norm* was found in PFF (8.8±4.1 %/min; p<0.001), COPD (1.9±0.2 %/min; p<0.001), and MS (3.7±0.9 %/min; p=0.007) patients compared to HA controls (0.8±0.1 %/min) (**Figure 1.B**).

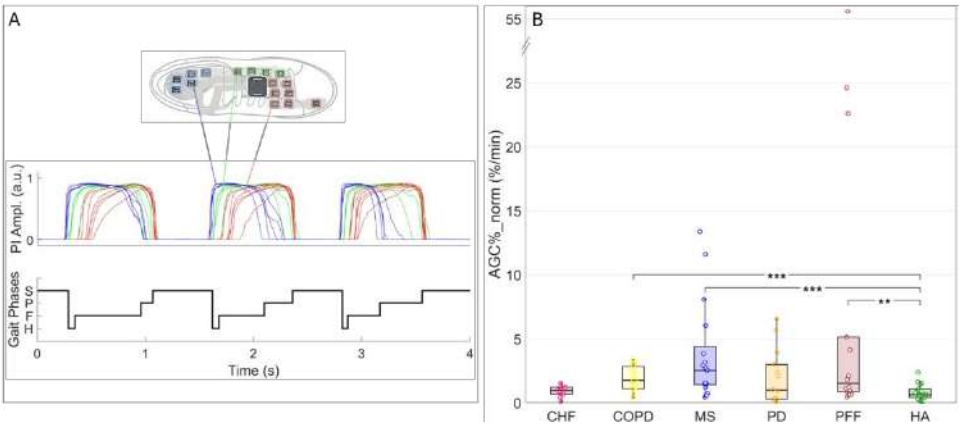

Figure 1. **A** Example of Pressure Insole (PI) signals and extraction of gait phases. **B** *AGC%_norm* comparison on 5 pathological cohorts (10 patients with Congestive Heart Failure (CHF), 15 with Chronic Obstructive Pulmonary Disease (COPD), 17 with Multiple Sclerosis (MS), 14 with Parkinson's Disease (PD), 14 with Proximal Femoral Fracture (PFF)) and 18 Healthy Adults (HA). Outliers are indicated by circles. Significant differences are indicated by asterisks: **p<0.01, ***p<0.001.

Discussion

The increased *AGC%_norm* in specific clinical populations suggests its potential as a quantitative marker of locomotor instability. Notably, this parameter was derived from data collected during unsupervised and free-living activities, underscoring its ecological validity. Its relevance for fall-risk assessment is currently being explored in the ongoing MOVEWISE project [3].

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Characterizing hybrid kinematic-muscular synergies in multi-directional reaching

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Introduction

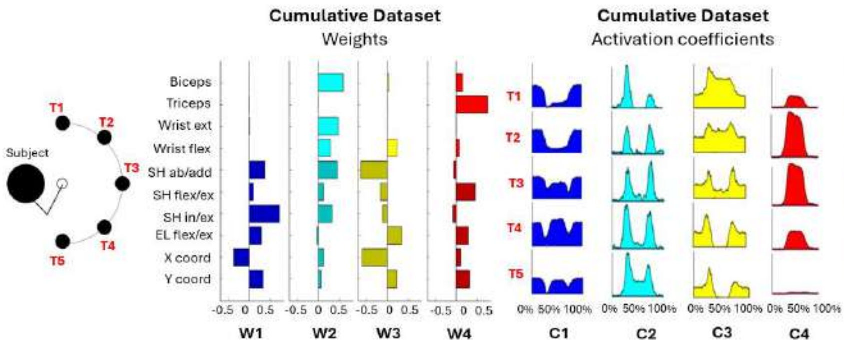
Reaching movements involve complex coordination between muscolo-skeletal structures of the upper limbs. Unlike gait, upper-limb movements are highly variable in both joint kinematics and muscle activation patterns across subjects and repetitions [1]. This variability at the execution level may conceal more structured and stable control mechanisms operating at a higher level of motor organization. To investigate control strategies in planar reaching tasks, hybrid kinematic-muscular synergies were extracted by applying the Mixed Matrix Factorization (MMF) [2].

Methods

Nine healthy subjects (3M6F, 23±2 years) performed a 2D center-out reaching task towards five different positions located in a semi-circle (300 trials, 60 per target), in randomized order. Surface bipolar electromyography (EMG) was recorded from 4 upper limb muscles (biceps brachii, triceps brachii, wrist flexor and extensor) using a Cometa MiniWave system (2000 Hz). Kinematic data were collected with a VICON™ system (100 Hz), using markers located on the trunk, arm, forearm, and manipulandum. Joint angles of shoulder (SH) and elbow (EL) were estimated, together with planar coordinates (X, Y) of the manipulandum. EMG envelopes were obtained with a 50th-order low-pass filter (20 Hz). MMF was applied to the combined EMG-kinematic dataset for each subject to extract hybrid synergies. Synergies were computed both cumulatively, by pooling all trials across the five targets, and separately for each target direction, to assess the consistency of synergy weights across movement directions. Weights similarity between conditions was quantified using the Pearson correlation coefficient (r).

Results

Four synergies were extracted per subject with a reconstruction accuracy of $R^2 \geq 0.8$. As output, the algorithm gives weights (W) and temporal activation coefficients (C) (0%: rest; 50%: target; 100%: rest) for each synergy, as shown in Figure 1. The figure also reports the correlation coefficients (r) between cumulative and target-specific synergy weights for one representative subject.



Target-specific synergies
Correlation coefficients

	Synergies 1	2	3	4
T1	0.84	0.03	0.52	0.85
T2	0.45	-0.01	0.44	0.95
T3	0.90	0.42	0.36	0.96
T4	0.85	0.47	0.56	0.71
T5	0.78	0.52	0.73	0.38

Figure 1. *Left*: Synergy weights (W1-W4) extracted from the cumulative dataset; *Central*: Activation coefficients (C1-C4) of the cumulative synergies across the five reaching targets; *Right*: Correlation coefficients between target-specific and cumulative synergies.

Discussion

Correlation coefficients between target-specific and cumulative synergy weights varied across synergies and directions. The highest similarity was observed for T3 (mean r=0.66). Synergies 4 and 1, mainly active during the hold and rest phases respectively, were the most consistent across targets. Conversely, Synergies 2 and 3, involved in movement transitions, showed weights lower similarity with the cumulative dataset. This suggests that synergies related to static phases (rest and hold) are more stable, whereas those associated with dynamic phases are more target-dependent.

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Kinematical analysis of 135° change-of-direction techniques in basketball

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Introduction

Change of direction (COD) is a fundamental movement in team sports, particularly in basketball, where athletes must rapidly decelerate, reorient their bodies, and reaccelerate in response to dynamic game situations. Among the biomechanical techniques used to perform COD, three primary patterns have been identified: the Side-Step, Crossover Cut, and Split-Step [1]. Therefore, this study aimed to identify the COD techniques naturally adopted by basketball players during pre-planned 135° directional changes, and to compare the associated lower-limb kinematics and execution time using IMU-based motion analysis.

Methods

A total of 130 young basketball players (66 males, 64 females; aged 13–18) from Bàsquet Girona participated in the study. After a standardized 10-minute warm-up, each player performed the V-cut test twice, consisting of a 25-meter sprint with four pre-planned 135° CODs every 5 meters [2], executed as quickly as possible on an indoor court. Kinematic data were collected using the MVN Biomech Link system (Xsens Technologies BV, Netherlands), comprising 17 IMUs operating at 60 Hz. Joint kinematics (hip, knee, ankle) and execution time for each COD were analyzed. Execution time was calculated between automatically identified initial and final frames. The frequency of each COD technique was expressed as a percentage of total CODs. Statistical Parametric Mapping (SPM{t}) was used to compare time-continuous joint kinematics across techniques, while Mann–Whitney U tests assessed differences in execution time. Statistical significance was set at $p < 0.05$.

Results

Two COD techniques emerged: Side-Step and Split-Step. Among 1,038 valid CODs, Side-Step was more frequent (72.1%) than Split-Step (27.9%). Side-Step also showed a significantly shorter execution time (median = 0.55 s; IQR = 0.13) compared to Split-Step (median = 0.67 s; IQR = 0.17) ($p < 0.001$). Kinematic analysis revealed that, in the pivot leg, Side-Step involved greater hip flexion, external rotation, and abduction during braking. Side-step also showed lower knee flexion, higher internal rotation, and greater knee abduction. At the ankle, Side-Step was characterized by higher dorsiflexion and adduction during the pivot and push-off phases.

Discussion

Side-Step was the predominant COD technique, likely due to greater biomechanical efficiency, familiarity, or performance advantages, as reflected in its significantly shorter execution time [1]. For 135° CODs, it may represent a time-efficient strategy. Nonetheless, the optimal technique depends on task demands, game context, and athlete-specific factors. In terms of kinematics, Split-Step showed reduced hip flexion and internal rotation during braking, which may increase ACL loading by shifting stress to the knee [3]. However, its double-leg landing could help distribute forces more evenly compared to the unilateral loading seen in Side-Step [1].

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Instrument-based digital twins for monitoring preterm neuromotor developmental trajectory

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Introduction

Preterm births lead to an increased risk of neuro-developmental disorders (NDDs) [1]. Early longitudinal monitoring of motor development, strongly associated with neurodevelopmental outcome [1], is crucial for a timely identification of NDDs, but it is limited by the lack of longitudinal, quantitative, and interpretative measures for infant motor development, and the need to integrate them with longitudinal comprehensive medical history. Thus, we propose a Digital Twin (DT) Framework [2] integrating instrument-based metrics for motor assessment [3,4] for holistic longitudinal infant monitoring.

Methods

The DT framework integrates i) heterogenous data collection, ii) data processing for motor assessment [3,4] and iii) ML methods for holistic data analysis (Fig.1). Each DT dynamically organizes available data. Longitudinal clinical data (i.e., pregnancy, imaging, growth, nutrition, development) are collected at term equivalent age (T0) and at 3-, 6-, 12-, 18- and 24-months corrected age (CA), matching clinical follow-ups. Longitudinal motor function data are collected at key milestones: i) video-based recordings of spontaneous movements [4] (T0 and 3months), ii) sensor-based assessment [3] (sitting posture, crawling, independent standing posture, gait) from 6 to 24 months CA, when present. Data are stored using FHIR and mapped via a domain-specific knowledge graph. To demonstrate feasibility, a proof-of-concept study was conducted on data from [3] (longitudinal clinical data and sensor-based gait data at 24months, n=46). Data were normalized (Min-Max Scaler) and automatically analyzed using: i) t-distributed stochastic neighbor embedding (t-SNE); ii) clustering (k-means, k=2; Kernel Density Estimation); iii) 5 classification methods (Logistic Regression, Decision Tree, Random Forest, Extreme Gradient Boosting - XGBoost, Support Vector Machine; train/test: 75/25%) and SHAP analysis.

Results

For synthesis, only classification and SHAP results are reported. XGBoost outperformed other classifiers, with the highest scores across evaluation metrics (accuracy 0.92, balanced accuracy 0.95, precision 0.67, recall 1.0, F1 Score 0.80, AUC 0.95, MCC 0.77). SHAP analysis revealed early low motor complexity as a key biomarker of motor delay in preterm toddlers.

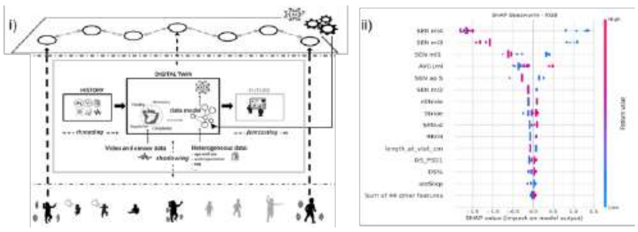

Figure 1. i) DT ecosystem, ii) SHAP values for XGBoost.

Discussion

The multidimensional analysis allowed by the DT framework highlighted the importance of motor assessment in preterms. Results on motor complexity, in agreement with literature on gait [3] and other tasks, reinforced the vision of a longitudinal perspective that overcomes task specificity and considers age-appropriate tasks within a unified motor trajectory. When fed with longitudinal data, the DT will enable the identification of interpretative biomarkers of NDDs, advancing the understanding of precursors of long-term alterations in preterm infants and a timely identification of NDDs.

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Sensor-based gait analysis for clinical monitoring and assessing treatment response in Juvenile Myasthenia Gravis

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Introduction

Juvenile Myasthenia Gravis (JMG) is a rare condition (1.5/million person-years) affecting individuals under 18 [1]. While the clinical presentation is similar to that in adults (fatigable muscle weakness, acute or subacute initial presentation, and a chronic course with remissions and relapses), managing JMG is more complex, given the lack of validated pediatric tools for JMG evaluation, often resulting in the use of adult-based measures [1]. Gait analysis can help fill this gap by offering quantitative insights into locomotor performance and status. IMU-based gait analysis is especially promising for its ease of use in ambulatory settings and its suitability for children with typical and atypical development [2-3]. This work proposes an IMU-based locomotor assessment in JMG patients (i) to characterize their locomotor performance in comparison with typically developing peers, and (ii) to compare it with the Quantitative Myasthenia Gravis (QMG) scale, an adult tool used to monitor generalized JMG. For the latter objective, longitudinal data and comparisons of IMU-based metrics with clinical scale scores were considered.

Methods

Six patients (3F/3M, 10.4–18.1years) with generalized JMG were prospectively enrolled. At each assessment, QMG were administered, and natural (NW) and tandem walking (TW) data recorded using 3 IMUs (MMRL, Mbient, USA) on lower trunk and shanks (200 Hz). Temporal parameters, variability, recurrence quantification analysis (RQA), and multiscale entropy (sample entropy, SEN, $\tau=1\div6$) were extracted and compared with those of a typically developing control group (n = 112, 6–25 years, TD) [2]. The median QMG value was used as threshold. NW and TW IMU data were divided by paired QMG result (below/above threshold) and compared (Kruskal-Wallis test, $\alpha = 0.1$).

Results

Twenty-three gait recordings and paired QMGs were obtained over two years. JMG patients exhibited increased normalized stride time, stance, and double support in NW and TW. In TW, children with JMG showed decreased MSE and increased RQA parameters in the anteroposterior direction. The QMG threshold was 11, corresponding to 13 trials with QMG below the threshold and 9 trials above the threshold. JMG children with QMG above the threshold exhibited significant further alterations in temporal parameters during NW (increased duration of normalized stride, stance, and double support).

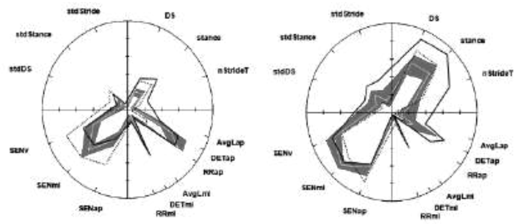

Figure 1. Polar lines from two recordings of a 15-year-old patient with QMG scores above (solid black line) and below (dotted black line) threshold, shown on the age-matched reference polar bands. Parameters normalized to 2nd- 98th percentile range of the full dataset; SEN values shown for $\tau=6$.

Discussion

The proposed sensor-based approach detected and quantified JMG-related motor difficulties both in comparison to typical development (slower gait and less mature motor control in TW) and in relation to QMG scale scores (further alterations of temporal parameters). These results support its promising use as an additional assessment tool for the clinical monitoring of JMG patients and for evaluating their response to treatment. The limited analyzed population is being increased in ongoing patient recruitment and data collection. To characterize fatigue and fatiguability in JMG patients, 6-minute walking test will be included in future acquisitions.

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RE-WALK-EASY: Two Case Studies on Functional Electrical Stimulation for Critical Illness-Acquired Muscle Weakness

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Introduction

Intensive Care Unit-acquired weakness (ICU-AW) is a frequent neuromuscular complication in critically ill patients, characterized by generalized muscle weakness that develops during a stay in the Intensive Care Unit (ICU). It results from factors such as prolonged immobilization, systemic inflammation, and neuromuscular dysfunction. The two main forms are critical illness polyneuropathy (CIP), which primarily affects peripheral nerves, and critical illness myopathy (CIM), which directly involves muscle fibers [1]. Functional electrical stimulation (FES) has proven useful in preventing muscle mass loss, especially in non-cooperative patients [2]. However, the effectiveness of FES in critically ill patients with muscle weakness has not yet been demonstrated, as the two forms, CIP and CIM, are often grouped together under the umbrella term ICU-AW, despite potentially differing clinical courses and responses to treatment. We hypothesize that FES may provide greater benefit in CIP compared to CIM, as it allows for muscle activation while the nerve regenerates, thereby preserving muscle structure and function during neurological recovery.

Methods

Two patients, diagnosed respectively with CIM and CIP, were enrolled and underwent a FES-based rehabilitation program tailored to their residual functional abilities. RE-WALK-EASY program consisted of 15 one-hour sessions and included balance and gait exercises supported by FES. The 6-minute walk test (6MWT) was administered at baseline (T0), after 8 sessions (T1), and at the end of the treatment (T2). The results were then compared with those of other critically ill patients admitted to the cardiac rehabilitation unit, which is the referring department for both subjects. The percentage improvements in the 6MWT between T1 and T0, and between T2 and T0, were calculated relative to T0.

Results

The patient with CIP completed the training, while the patient with CIM was discharged after the intermediate evaluation. Both patients were able to walk at T0 (6MWT, CIP 74 m CIM 360 m). Additionally, 11 patients with acquired muscle weakness who were also able to walk were selected from the hospital records (Matched Group G_M 6MWT at T0 mean (SD) 235.0 (152.2) m), based on admissions in the previous year. At the discharge, the mean recovery of the G_M was 128.2% with SD 111.3%. At T1, the percentage change in the CIM subject was negligible and showed no improvement, whereas the CIP subject had already exceeded the threshold of G_M recovery with a 160% increase. By T2, the CIP subject's improvement reached 250%.

Discussion

This case report highlights the potential benefits of FES as part of a personalized rehabilitation program for critically ill patients with acquired muscle weakness. The observed greater improvement in the patient with CIP compared to the one with CIM supports the hypothesis that FES may be particularly effective when muscle activation can be maintained during nerve regeneration. Although these findings are preliminary and limited to only two cases, they provide valuable insights for future research. The ongoing RE-WALK-EASY project aims to enroll 72 patients by 2027 in a randomized controlled trial (RCT). The study will compare the effects of a rehabilitation program using FES against the same program without FES. This will enable more robust statistical analyses and help validate the effectiveness of FES across different subtypes of ICU-AW.

Acknowledgements

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Activity detection of paralympic athletes with lower limb running-specific prosthesis during extended periods of time: software development and preliminary validation

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Introduction

Monitoring the activities of athletes with amputation using running-specific prostheses is essential to evaluate their training regimes and prosthesis usage and efficiency. Recent advancements in IMUs and activity detection algorithms offer new opportunities for objective assessment, but their application in Paralympic sport remains underexplored. The aim of this work was to design and implement an innovative protocol and analysis software for the short and long term activity detection of athletes with transtibial (TT) and transfemoral (TF) amputation, and test its validity on a sample of elite runners.

Methods

Seven elite athletes of the Italian Paralympic team (3 female, 4 male) participated in the study, which was approved by the University of Padua Review Board. They ranged from 26 ± 7 year-old, 4 with TT unilateral, 2 with TF unilateral, 1 with TT bilateral amputation. For the protocol and software development each subject was involved in a single measurement session. Firstly, an Axivity AX6 inertial sensor weighing 11g was mounted on the prosthesis socket (**Errore. L'origine riferimento non è stata trovata.**) to collect 3D accelerations with a sampling frequency of 12.5 Hz. Then the subject proceeded with their usual training routine, approximately for one hour. The whole session was video-recorded to serve as gold-standard for activity labelling, based on the following categories: 'stop', 'walk', 'jog', 'sprint' and 'other'. A custom app was developed in Python for data segmentation, labelling, subject calibration and activity detection. This last was based on a dual tree algorithm [1,2], exploiting the maximum acceleration amplitude and a set of features from continuous wavelet analysis. To assess the accuracy of the detection algorithm in discriminating the activities with respect to the gold-standard, a stratified Monte Carlo Cross-Validation with 50 iterations was implemented.

Figure 1: Set-up of Axivity AX6 sensor on a prosthesis socket

Results

The activity detection algorithm provided high accuracy, with 94%, 98%, 99% and 100% recall in activity recognition of 'stop', 'walk', 'jog' and 'sprint' respectively based on a confusion matrix analysis. Overall, the accuracy was 97%.

Discussion

The main innovation of this study lies in the possibility to distinguish sport-centred activities with a sampling rate of just 12.5 Hz, which can considerably extend the memory and battery life of Axivity AX6 up to six months of continuous use. Results support improved accuracy performances compared to previous literature on prosthesis users in every-day-life activities [3], and are comparable to performances obtained with complex and computational demanding algorithms based on gyroscope data on healthy individuals [4]. Long term acquisitions have been completed before the Paris Paralympic games and their analysis is underway.

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Human-Machine interaction in clinical practice: the take home messages from a multidisciplinary round-table in La Salle Campus Madrid.

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Introduction

The SIAMOC Conference offers awards for early-career researchers, including the BTS one-week internship at a leading European research center specialized in human movement analysis. In this context, one of the authors (V.A.A.) was awarded during the last conference in Stresa in 2024, completed an internship at "La Salle Campus Madrid" hosted by other co-author (S. L. L.). Given the increasing attention on the topic of human machine interaction (HMI) in clinical settings, particularly rehabilitation [1], and aiming to strengthen the European ecosystem in human movement analysis, S.L.L. proposed a roundtable discussion titled 'The Human and the Machine'. Indeed, here we present preliminary reflections shared by the discussants, intended as a starting point for further dialogue within the SIAMOC community.

Methods

A round table, moderated by S.L.L., brought together four discussants representing different fields: Physical Therapy (S.L.L.), Humanities and Contemporary Culture (J.M.G.P.), Occupational Therapy (M.G.M.), and Bioengineering (V.A.A.). The event lasted approximately an 90 minutes and was attended by nearly 60 participants from the La Salle community including i) students, ii) researchers and iii) faculty members. The moderator initiated the discussion by inviting each discussant to present their general perspective on the central theme of the round table. He then guided the dialogue through two additional key questions: firstly the 'past, present, and future' of HMI, and secondly, reflecting on 'The Good, the Bad, and the Ugly' aspects related to the integration of technology into clinical practice.

Results

The discussants collectively acknowledged several advantages of integrating machine-based technologies into clinical practice, particularly in the areas of i) clinical decision-making support, ii) robotic rehabilitation, and iii) artificial intelligence applications.

Discussion

Nevertheless, they also voiced common concerns regarding the need for qualified personnel to effectively implement these tools—highlighting not only the importance of a solid technological background but also the broader challenges posed by the high costs, which continue to limit their widespread adoption in clinical settings. Moreover, the panel emphasized the importance of maintaining an anthropological perspective in both the development and use of these technologies, underscoring the necessity of keeping the human being at the center of care [2]. Ultimately, the discussants agreed that the greatest potential lies in the integration of all three technological domains—when guided by a patient-centered perspective [3].

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Usability and acceptability study of a Functional Electrical Stimulator controlled by electromyographic signal for people post-stroke

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Introduction

Upper limb motor deficits following stroke, such as muscle weakness, hemiparesis, and spasticity, severely limit the activities of daily living [1]. Improving upper limb function is therefore essential to overcoming the loss of independence, and Functional Electrical Stimulation (FES) plays a key role in rehabilitation approaches [2]. Exploiting the residual voluntary myoelectric activity (EMG) of paretic muscles to trigger and modulate stimulation can enhance the subject's volitional involvement in rehabilitation exercises, provide proprioceptive feedback, and boost motor recovery. This technique, known as Myoelectrically Controlled FES (MeCFES), allows direct control of stimulus intensity, timing, and duration [3]. A new user-centered MeCFES device, called FitFES, was developed and optimized for effective EMG-controlled stimulation. This study aims to assess the usability, acceptability, and satisfaction of FitFES by people post-stroke and healthcare professionals.

Methods

Twenty persons were enrolled in this study, including ten persons post-stroke (age 52.9 ± 16.8 years) and ten healthcare professionals (age 35.4 ± 13.6 years). Participants performed one-hour sessions of reaching, grasping, and manipulation exercises while wearing the FitFES. Through surface EMG electrodes, FitFES recorded the EMG signal generated during muscle contraction while executing a task, processing this information in real-time to produce a stimulation proportional to the recorded muscle activity. The stimulus was then applied to the muscle of the affected arm that needed assistance, or the dominant arm for clinicians. At the end of the session, participants completed the System Usability Scale (SUS), the Unified Theory of Acceptance and Use of Technology 2 (UTAUT-2), an ad-hoc survey on the main features of FitFES, and ad-hoc semi-structured interviews. A Likert scale from 1 to 5 points was used, naming the answers from "completely disagree" to "completely agree" for SUS and UTAUT-2, and from "completely unsatisfied" to "completely satisfied" for the FitFES questionnaire.

Results

Healthcare professionals reported a mean total SUS score of 69.8 ± 6.8, above the threshold for acceptability, while post-stroke subjects had a SUS score slightly below it (65.5 ± 9.6). Regarding the UTAUT-2 scale, all clinicians scored above 65/100, with 40% exceeding 75/100, while 60% of post-stroke subjects scored above 75/100, and the remaining 40% scored over 55/100. The FitFES questionnaire focused on the practical aspects and functionality of the device, showing a mean total satisfaction value of 83.3/100. The semi-structured interviews used open questions to explore participants' perceptions of the FitFES and its stimulation. Clinicians valued its wearability and real-time EMG-based customization, highlighting how biofeedback increased user engagement. However, they also noted the need for longer training. Post-stroke participants considered FitFES effective for supporting and enabling movement, though they experienced slight discomfort from the stimulation.

Discussion

Preliminary results of usability questionnaires indicated general acceptability and satisfaction regarding the FitFES device. Both subject groups demonstrated a positive attitude towards this technology, indicating a willingness to incorporate it into their rehabilitation routines. Furthermore, the ad-hoc questionnaire revealed that clinicians were satisfied with the primary features and attributes of the device, such as size, wearability, and functionality. Although not all participants were experts or found electrical stimulation comfortable, they believed the FitFES device could be a valuable and effective tool for upper limb rehabilitation, with potential integration with other therapeutic techniques. Nevertheless, a more thorough examination of the questionnaire subcategories will be conducted to better understand the impressions on the FitFES and identify possible aspects for improvement.

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Quantitative assessment of the impact of physical therapy on lower limb muscles activity and coactivation in individuals with ankle injuries

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Introduction

Lateral ankle sprains and ankle fractures are common among physically active individuals, with the need to undergo specific physiotherapy treatments, [1]. The assessment of the effect of physical rehabilitation currently relies on subjective evaluation scales, highlighting the need for objective measurement methods, such as surface electromyography (sEMG). This study aims to assess the efficacy of physical rehabilitation treatments on the lower limb muscle activity and coactivation in these people. We hypothesize ankle muscles' reinforcement and coactivation reduction during the gait cycle.

Methods

Nine participants (4 males, 5 females, age: 41.1(±13.6) years, weight: 66.7(±11.2) Kg, height: 1.66(±0.06) m) affected with lateral ankle sprains or ankle fractures walked barefoot alongside the 10-m laboratory pathway at self-selected speed before (T0) and after (T1) a specific rehabilitation program, which included RoM exercises, and muscle strenghtening. sEMG data from the vastus lateralis (VL), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius medialis (GM) were recorded unilaterally on the affected side. After sEMG processing, we computed the time-varying multi-muscle co-activation function (TMCf), [2, 3] and the following parameters on muscle activity and TMCf: i) maximum (max) and ii) full width at half maximum (FWHM). The paired t-test test was applied to detect significant differences between T0 and T1. P values lower than 0.05 were considered statistically significant.

Results

The statistical analysis revealed a significant increase of the max of the GM and TA muscles (p=0.041, and p=0.022, respectively), and a significant decrease of the FWHM of the TMCF computed on full leg (considering VL, BF, TA and GM), knee (VL and BF) and ankle (TA and GM) muscles (p=0.047, p=0.005, and p=0.018, respectively) between T0 and T1, Figure 1.

Discussion

Our findings support the positive impact of physical therapy in strengthening the effector muscles of the ankle (increase of GM and TA max value). The reduction in the FWHM of full-leg, knee, and ankle coactivation can be explained because of the restoration of the correct timing of the lower limb muscles after the rehabilitation treatment. Overall, our findings demonstrate the benefits of physical rehabilitation of people with ankle injury, as well as the parameters' usefulness both in programming rehabilitation interventions as well as in designing future clinical trials.

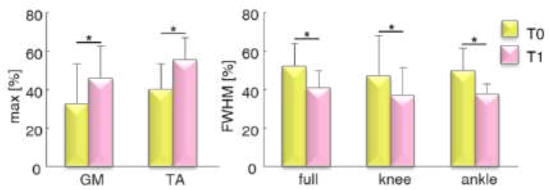

Figure 1. Mean (bar height) and standard deviation (error bar length) of the max value of the GM, TA and of the FWHM of the TMCf before (T0) and after (T1) the rehabilitation program.

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Cutting technique of ACL-Reconstructed professional handball players: on-field kinematic assessment using IMUs

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Introduction

Anterior cruciate ligament (ACL) injury is common among handball players, mostly occurring in non-contact cutting maneuvers [1]. While lab-based studies have identified several biomechanical risk factors, real-game duels in court settings remain unexplored [1]. In this regard, wearable technologies (IMUs) enable on-field assessments during dynamic tasks and ecologically detect potential injury risk factors. The aim of this study was to compare the biomechanics of ACL-reconstructed (ACLR) and healthy handball players using IMUs during on-field sport-specific injury-related tasks.

Methods

Twenty-five professional (first division) handball players (age: 23.7 ± 3.9 years; 14 males), including 7 ACLR players (cleared for RTS>24 months), were tested in their home-team handball court. Players were asked to perform two high-dynamic cutting tasks, one mimicking a change of direction with passive opponent and one in response to a real-game opponent (Figure 1). Both tasks were performed six times (three per limb) per player, with an overall of 300 trials collected. Based on dominant hand and movement direction, each trial was classified as either a classic sidestep change of direction (SSC) or a crossover (XOVER). Lower limb and trunk kinematics were recorded using eight IMUs (100 Hz, MTw Awinda, Movella), validated for high-dynamic movement analysis [2]. Joint kinematics was assessed in the three anatomical planes at key events of the cut foot contact window: initial contact (IC), peak of knee flexion (pKF), peak values (maximum and minimum), and range of motion (ROM). Analysis was conducted separately for movement type (SSC and XOVER), comparing healthy and ACLR players in active and passive movements. Two-tailed Student's t-tests were used to assess between-group differences for each of the 75 extracted features, with Cohen's d effect size reported alongside p-values.

SSC, PASSIVE | XOVER, PASSIVE | SSC, ACTIVE | XOVER, ACTIVE

Figure 1. Players performing passive and active tasks in each change of direction: SSC and XOVER.

Results

During XOVER, 23/75 variables differed significantly between ACLR and healthy players, and 26/75 during SSC. A greater pelvis and trunk flexion (forward bending) was noted for the ACLR group, both during XOVER (p<0.001, d=0.57-0.70) and SSC (p<0.001, d=0.42-0.95). ACLR players exhibited a pronounced pelvis contralateral drop at pKF in XOVER (p=0.013, d=0.50), and at IC in SSC (p<0.001, d=0.90). ACLR players showed a greater tendency to knee valgus in both movements (p<0.017, d=0.47-1.27), and an increased ankle plantarflexion at pKF (p<0.031, d=0.40-0.60). Larger effect size in significant differences and more frequent ACL injury-related patterns [1] were observed in active compared to passive tasks.

Discussion

ACLR handball players adopted different cutting techniques compared to healthy controls, with an altered trunk-pelvis strategy, increased frontal/transverse rotation, and consistent knee valgus tendency during two typical cut maneuvers. These findings highlight the need for sport-specific assessments using wearable sensors to detect residual impairments, supporting data-driven return-to-play decisions.

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Foot plantar distribution and kinematic analysis of low dive in soccer goalkeepers: a case study

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Introduction

The role of goalkeepers in soccer requires rapid, precise movements that combine explosive strength with finely tuned neuromuscular coordination. Although previous studies [1,2] have examined diving techniques using force platforms and optical motion capture, they lack detailed insight into how forces are distributed across different regions of the foot during a dive. To address this gap, we investigated plantar pressure distribution and lower-limb kinematics in an elite female goalkeeper performing low-corner dives, using wearable inertial sensors and sensorized pressure insoles.

Methods

An 18-year-old goalkeeper from an elite youth team performed four randomized low dives (two per side) intercepting balls launched at approximately 30 cm height and 70 cm from the post. Kinematic data were recorded at 60 Hz with the Xsens MVN Biomech Link system (17 IMUs) and plantar pressures at 100 Hz using XSENSOR® smart insoles. A distinctive foot-strike acceleration peak was used as a synchronization marker across all devices. Time series were normalized from peak hip flexion to ipsilateral foot take-off, and analysis focused on stance width (normalized to leg length), joint angles (hip, knee, ankle), vertical ground reaction forces, and regional plantar pressures at four key instants: preparatory phase, ipsilateral foot initial contact (IFIC), contralateral peak force (CPF), and ipsilateral peak force (IPF). Given the exploratory nature and small sample size, data are presented descriptively without inferential statistics.

Results

During the preparatory phase (0% of the movement), the total vertical ground reaction force was about 640 N and evenly distributed. Peak pressures occurred under the metatarsals (≈ 136 N) and toes (≈ 126 N). Stance width was 44% of the leg length. Hip flexion measured 105°, knee flexion 59°, and ankle dorsiflexion 17°. At initial foot contact (IFIC; ~48% of the movement phase), contralateral force increased to 341 N. The load shifted toward the midfoot and metatarsals. Stance width increased to 56%. Hip flexion dropped to 93°, and ankle dorsiflexion to 11°.At contralateral peak force (CPF; ~76%), vertical force under the forefoot peaked at 470 N. Stance width reached 84%, and ankle dorsiflexion peaked at 27°. Finally, at ipsilateral peak force (IPF; ~84%), loading on the ipsilateral foot peaked at 403 N beneath the metatarsals. Hip and knee reached maximal extension (118° and 114°, respectively), and ankle dorsiflexion was 28°.

Discussion

The sequential loading patterns identified in plantar pressure distributions support existing models of coordinated limb involvement, particularly highlighting the distinct roles of contralateral and ipsilateral limbs. The contralateral foot's dominance in initial lateral propulsion, followed by the ipsilateral foot's role in trajectory control, emphasizes the complexity of neuromuscular coordination required during dynamic goalkeeper movements. The capability of sensorized insoles to provide detailed pressure distribution data across specific foot regions offers biomechanical insights beyond those obtained through traditional force platforms alone. The observed high plantar pressures in the metatarsal and toe regions highlight the forefoot's significant role in propulsion. However, the rapid shifts in plantar pressure, combined with ankle dorsiflexion and abduction, may increase stress on ankle structures, potentially predisposing goalkeepers to sprains or chronic instability [3]. Despite these insights, this study presents some inherent limitations. Firstly, it was conducted as a single-case analysis, limiting the generalizability of the results. Moreover, the limited number of trials and the exclusive focus on low dives further restrict the applicability of these findings. These findings highlight the feasibility of wearable sensor technologies for optimizing forefoot loading strategies and ankle stability.

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Assessing the correlation between pain, fatigue, and load during the 10-meter walk test using sensorized crutches after total hip arthroplasty

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Introduction

Total Hip Arthroplasty (THA) is a common surgical procedure to relieve pain and restore mobility in patients with severe hip joint degeneration [1]. Postoperatively, patients face challenges such as reduced muscle strength, abnormal gait patterns, and altered proprioception, leading to uneven weight distribution [2], where crutches are essential in this phase. Although several wearable sensors have been adopted to objectively estimate spatiotemporal gait parameters, no commercially available instrumented crutches currently exist, and their role in load distribution and pain management is unclear. This study explores the correlation between crutch use during the 10MWT and post-discharge Borg (exertion) and VAS (pain) scores.

Methods

A prospective cohort study was conducted on THA patients discharged from the Istituto Ortopedico Rizzoli (Bologna, Italy). Assessments were performed after discharge (T0) and 20 days (T1) post-surgery. At baseline, 20 participants (10 females, 10 males; mean age 53.2 ± 9.1 years; BMI 23.98 ± 2.6 kg/m^2) were enrolled. Participants completed 10MWT trial in three-point gait pattern while using the mCrutch system [3], which records acceleration, angular velocity, and ground force via instrumented crutches. A custom Android app collected data, and an algorithm segmented swing and stance phases. Key metrics included crutch load AUC (% body weight) and mean stance/swing durations. VAS and Borg scores were recorded, and Spearman's correlation was used for analysis in Python 3.11.

Results

Among the extracted parameters, mean stance duration showed a moderate and statistically significant correlation with VAS ($\rho = 0.49$, $p = 0.030$), and a weaker, non-significant correlation with Borg ($\rho = 0.35$, $p = 0.126$). In contrast, AUC force percentage was weakly associated with both VAS ($\rho = 0.32$, $p = 0.166$) and Borg ($\rho = 0.17$, $p = 0.483$), without reaching statistical significance.

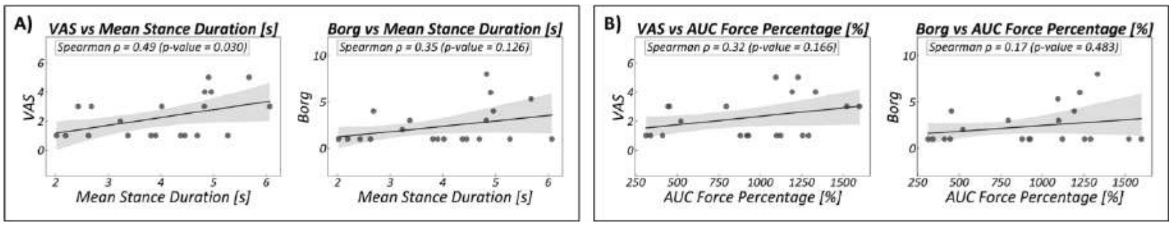

Figure 1. Correlation of clinical scales with mCrutch parameters: (A) AUC Percentage and (B) Mean Stance Duration.

Discussion

This preliminary study shows a moderate correlation between mean stance duration and VAS/Borg scores, suggesting that greater pain or fatigue leads to longer crutch contact during the 10MWT. AUC force showed weak correlations, indicating that measuring the load applied to the crutch accounts for only a portion of the user's perceived exertion and pain. Results suggest mCrutch's potential to assess post-discharge pain. Future work will validate findings in larger cohorts and compare follow-up sessions.

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Assessment of plantar pressure patterns during early postoperative walking after total hip arthroplasty

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Introduction

Total Hip Arthroplasty (THA) reduces pain and restores mobility in patients with degeneration hip osteoarthritis. Unilateral load management and gait symmetry are critical after surgery to prevent complications such as dislocation or joint overload [1,2]. Wearable sensors allow continuous, real-time monitoring of gait patterns and load distribution, supporting personalized rehabilitation plans [3,4]. This prospective cohort study evaluates the usage of insole pressure sensors to objectively track postoperative recovery in THA patients by assessing load distribution across the lower limbs, spatiotemporal gait parameters, and changes in loading patterns during the early postoperative phase.

Methods

The prospective cohort study was conducted on THA patients discharged from Istituto Ortopedico Rizzoli (Bologna, Italy). Assessments occurred after discharge (T0) and 20 days (T1) post-surgery, without intervening rehabilitation advice. At each assessment session, participants performed a 30 second Standing Test, three 10-m walking trials. Subsequently, they reported their levels of pain and fatigue via visual analogue scale (VAS) and Borg scale. Twelve patients (five females) were recruited, with a mean age of 51.3 ± 9.6 years, and mean BMI of 23.8 ± 2.6 kg/m^2. Kinetic parameters (mean, peak and impulse loads), center of pressure (COP) gait-line parameters and temporal parameters (stance, swing, stride durations) were extracted. Statistical analyses were conducted using a linear mixed-effects model, with experimental time (T0 vs. T1) and z-standardized covariates specified as fixed effects, and subject-specific intercepts and time slopes as random effects. P-values were adjusted via the Benjamini–Hochberg false discovery rate. All analyses were implemented in Python.

Results

In the operated limb, significant post-intervention improvements were observed in COP gait-line parameters. Gait-line chord increased from 11.3 ± 4.7 cm to 15.5 ± 2.9 cm (p=0.005, d=0.87) and gait-line velocity from 6.4 ± 2.9 cm/s to 15.7 ± 3.8 cm/s (p<0.001, d=3.7). All load and temporal metrics changed significantly (p<0.001): stance time decreased by approximately 50%, from 2119 ± 535 ms to 1040 ± 183 ms (d=–2.4); swing time fell from 632 ± 217 ms to 406 ± 106 ms (d=–1.3); and stride time was reduced from 2749 ± 556 ms to 1446 ± 240 ms (d=–2.7). Concurrently, average and peak loads increased by about 80%, with large effect sizes (d=2.2 and 2.5, respectively). No significant changes were detected in the COP excursion and length, and load impulse (all p>0.05). In the contralateral limb, only COP velocity and chord-length difference increased and both stance time and stride time decreased (all p<0.001).

Discussion

The three-week follow-up showed significant improvements in operated-limb gait mechanics, notably in foot rollover and load-bearing, with large effect sizes (d>0.8). In particular, enhanced foot rollover and propulsion (gait-line chord and velocity) alongside increases in load-bearing capacity suggest real gains in stability and walking efficiency, which in practice may translate into faster achievement of functional milestones such as independent ambulation and stair negotiation. The small cohort size, short follow-up, and absence of a standardized rehabilitation protocol limit this study.

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Exploring upper-limb cortico-muscular coherence based on muscle synergies during prehension movements

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Introduction

Cortico-muscular coherence (CMC) assesses functional coupling between the sensorimotor cortex and muscles during isometric contractions [1]. However, real-life voluntary movements result from the coordinated activation of multiple muscle groups (muscle synergies, MS), mediated by complex cortico-cortical and cortico-spinal circuits [2]. This study aimed to evaluate coherence between brain activity and muscle synergies (CMSyn) during ecologically valid prehension movements.

Methods

A 3D-printed grasping box with sensors was developed to detect movement phases. An Arduino board controlled a LED "go" signal and synchronized EEG-EMG recordings. Four right-handed healthy subjects performed grasps using three grip types. The 62-channels EEG and 8-ch EMG signals were preprocessed, muscle synergies extracted, and coherence analyses performed: CMC was computed using magnitude-squared coherence, while wavelet coherence was used to compute CMSyn.

Results

The movement was divided into a phasic phase (reaching and grasping) and an isometric phase (holding). Preliminary results from one subject (Figure 1) showed that C3 (sensorimotor cortex) exhibited significant coherence with two main synergies. Synergy 1: coherence peak during the hand configuration phase just before the contact with the object. Synergy 2: coherence during the holding phase and even before movement onset, suggesting involvement in motor planning.

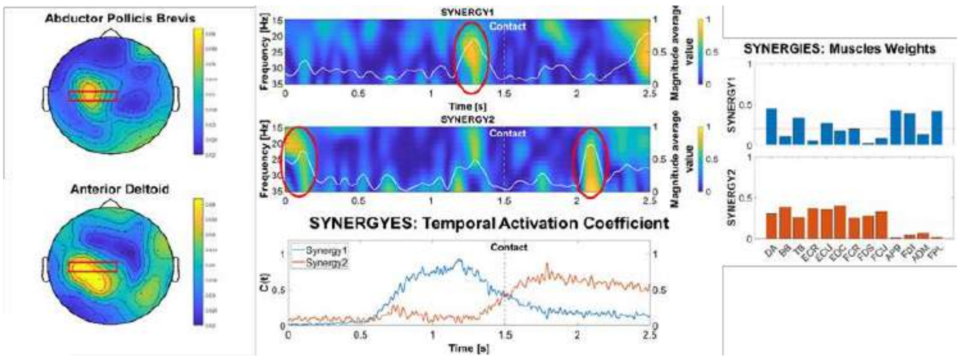

Figure 1. LEFT: Significative CMC computed over the isometric phase of the movement. Red square highlights motor area in EEG channels (left to right = C5, C3, C1, Cz). CENTER: Time-Frequency significative CMSyn computed between C3 and synergies temporal activation coefficient over the phasic phase of the movement. White line represents the average value among beta band in that specific time instant. The vertical dotted line at 1.5s indicates the contact instant. RIGHT: Muscles weight coefficients of the synergies.

Discussion

This study demonstrates the feasibility of assessing CMSyn during dynamic movements. C3 localization was consistent with known hand-arm cortical representation, confirming data validity. Unlike studies limited to isometric tasks, this approach provides insight into neural control of voluntary movements in unconstrained non-isometric real-life conditions. These findings may inform brain-computer interface (BCI) development aimed at predicting or assisting movement.

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Safety and functional benefits of a 6-Month adapted exercise program in adults with haemophilia

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Introduction

Haemophilia, a genetic disorder caused by a deficiency in clotting factors, often leads to musculoskeletal complications such as arthropathy, which reduces function and can induce kinesiophobia. Regular physical activity, as recommended by the World Federation of Haemophilia, supports musculoskeletal health, coordination, weight control and psychological well-being. This study explores the safety and the changes in functional capacity, strength, and balance following a 6-month adapted exercise program in adults with haemophilia.

Methods

The study employed a single-arm, within-subjects design with assessments at baseline (T0) and two follow-ups at 3 months (T1) and 6 months (T2); during the period between T0 and T2, participants completed a twice-weekly, individually tailored physical-activity program supervised by qualified specialists. Functional capacity was assessed using the Six-Minute Walk Test (6MWT) with the BTS G-WALK system. Perceived fatigue and dyspnea were recorded after each 6MWT using the Borg and VAS scales, respectively. Secondary outcomes included the 30-second Chair Stand Test (30″CST) to assess lower-limb strength, the Single-Leg Stance Test (SLST) for static balance, and the Timed Up and Go (TUG) test for dynamic balance. Data were analysed using nonparametric tests: the Shapiro–Wilk test assessed normality; Friedman test evaluated repeated measures, with Wilcoxon signed-rank tests and Bonferroni correction for post hoc comparisons ($p < 0.05$).

Results

Participants showed significant gains in functional capacity and balance over six months, while mean TUG duration remained stable. Improvements were most marked in 6MWT distance ($p<0.001$), 30″ CST ($p = 0.003$) and single-leg stance (both $p<0.01$), with smaller but significant reductions in fatigue and dyspnea at 6 months. No significant change was observed for mean cadence or TUG time. See Table 1 for full details. No adverse events were recorded during the exercise program period.

Table 1. Description of statistical results.

Outcome	χ^2	p-value	Significant Comparisons
6MWT distance (m)	17.64	< 0.001	T0–T1, T0–T2*, T1–T2*
6MWT dyspnea	11.64	0.003	T0–T2*
6MWT fatigue	8.46	0.015	T0–T2*
30″ CST (reps)	11.44	0.003	T0–T1*, T0–T2*
Single-leg stand dominant (s)	12.05	0.002	T0–T1*, T0–T2*
Single-leg stand non dominant (s)	16.05	< 0.001	T0–T1*, T0–T2*
TUG (s)	2.18	0.336	–

Discussion

This study supports the safety of a 6-month supervised adapted exercise program for adults with haemophilia. Significant improvements were observed in functional capacity, lower-limb strength, and balance, along with reduced perceived fatigue and dyspnea. The absence of adverse events further reinforces the safety of such interventions in this population. Despite the single-arm design and small sample, findings endorse adapted exercise as a safe, effective adjunct in haemophilia care, in line with systematic reviews on resistance and aerobic benefits [1,2]. Further randomized trials are warranted to confirm these benefits and to establish optimal exercise dosing.

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The influence of training data quantity on CNN-LSTM generalization in gait laterality detection

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Introduction

Recent deep learning advances enable accurate stride segmentation from a single wearable inertial sensor, even in challenging real-world conditions [1]. However, detecting gait laterality—a crucial step before segmentation—remains understudied. Existing works often rely on controlled settings and standard sensor placements (e.g., waist), limiting real-world applicability [2, 3]. Recent studies show that head-worn inertial measurement units (H-IMU) can also provide reliable gait information despite motion-related noise [4], making them suitable for integration in everyday devices like smart glasses. A key challenge is determining the training dataset size needed for robust, generalizable models. This study analyzes how training data size affects CNN-LSTM performance for gait laterality detection using a H-IMU and identifies the minimum number of subjects needed to reach acceptable generalization (test accuracy > 85%). Findings support data-efficient study design and faster model development.

Methods

Fifteen adults (50% female, 26±3 y.) completed a 2.5-hour free-living session wearing a H-IMU (100 Hz) and the INDIP multi-sensor reference system [5]. Mediolateral acceleration and vertical and anteroposterior angular rate in the sensor frame were segmented into 1 s windows centered on initial contacts, labeled "Left" or "Right" by INDIP. A CNN-LSTM was trained in Matlab via 5-fold cross-validation on growing training sets (2–10 subjects) and a fixed 5-subjects test set. Splits were stratified by hierarchical clustering on handcrafted features. Accuracy and AUC were used for evaluation.

Results

Both accuracy and AUC improved consistently with the increase in training data size (Figure 1). Accuracy values improved by +38.6% and +12.7% when increasing the training set from 2 to 4 participants, and from 4 to 10 participants, respectively.

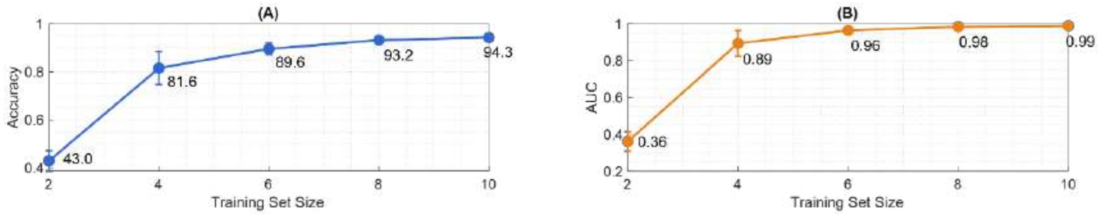

Figure 1. Average A) test accuracy (%) and B) AUC across different training set sizes, with error bars representing standard deviation computed across five folds.

Discussion

This study demonstrates that a CNN-LSTM model can effectively detect gait laterality using a head-worn IMU in real-world conditions. While prior studies addressed this task using sensors in standard positions (e.g., lower back) and in controlled environments, we show that high performance (accuracy >89%) is achievable even with a challenging head-mounted sensor and with as few as 6 training subjects. This suggests strong generalization from limited data, making the approach suitable for real-world applications where collecting large datasets is often not feasible. Head-mounted sensors also offer practical benefits, as they can be integrated into everyday consumer devices like smart glasses or earbuds, allowing for more standardized and repeatable sensor placement. These insights are especially relevant for clinical mobility studies, where recruiting large cohorts can be difficult. Understanding how dataset size impacts performance supports more efficient study planning and algorithm development. Future work should investigate the generalizability of these findings in pathological populations and across more diverse subject groups.

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The role of Adapted Physical Activity in the Rehabilitation Project for Children and Adolescents with intellectual and Motor Disabilities. "OPBG Sport per tutti" Project: preliminary results.

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Introduction
Adapted Physical Activity (APA) has proven to be an effective tool in the rehabilitation of pediatric neurological patients [1]. The department of Neurorehabilitation of the Bambino Gesù Children's Hospital has launched an innovative project, "OPBG Sport per tutti", with the purpose of investigating the effects of APA on motor function—including performance, coordination, balance, and endurance—as well as to assess the level of fatigue experienced during aerobic sports activities. Additionally, the program explores the impact of APA on personal autonomy in daily living activities, changes in the psychological profile and social participation of the participants, and any improvements in the Quality of Life (QoL) of both the individuals involved and their families.

Methods
A one-week structured rehabilitative training program was implemented by a multidisciplinary team (i.e., PMR doctors, Physiotherapists, Occupational Therapists, an Athletic Trainer, and a Bioengineer) for 54 children (ages 4–18) with intellectual and motor disabilities, including genetic syndromes (50%), cerebral palsy (20,37%), neurodevelopment disorders (24,56%), significant malformations (3,7%). Clinical assessment — Movement ABC, Level of Sitting Scale, 6MWT, WeeFim, Abilhand Kids, Pediatric Quality of Life Inventory (PEDsQL), and periodical phone calls –as well as instrumental assessment— Stabilometry, and COSMED K5 (for those over 14)— were conducted at baseline (T0), after three months of independent training at a specialized structure for APA (T1), and three months post-training (T2). Follow-up evaluations (T1, T2) will be stablished singularly for each patient, in consideration of the effective time of their enrolment in said program. Baskin and frame running sessions were held individually or in small groups to support motor skills and social participation, while dynamic adaptive cycling was delivered one-on-one to enhance therapeutic engagement.

Results
Preliminary results for the baseline (T0) were completed for all 54 patients. Of these, 31 trained in both Baskin and cycling, 19 in Baskin only, and 7 in cycling only, with 15 also trying frame running. From October 2024 to May 2025, 49 out of 54 patients have completed at least one month of adaptive sports training and were contacted for follow-up. Among them, 28 (49.12%) have reported regular participation in sports, including Baskin, swimming, football, hippotherapy, dance, skiing, and frame running. While 13 patients received and used adaptive bicycles, 11 others are awaiting authorization. A three-month follow-up has been scheduled for those who began adaptive activities or received equipment, in line with the study protocol. K5 parameters (e.g., VO_2max, VO2/kg, HR, RQ) were extracted for 7 patients during a 6-minute walk test (6MWT) and the subsequent post-exercise rest period.

Discussion
The impact of sports on pediatric neurorehabilitation is being studied in a heterogeneous group of 54 neuropathic children, through a one-week training program, which involves Baskin, Frame Running, Athletica, and Dynamic Adaptive Cycling. A baseline evaluation (T0), conducted prior to independent training within an appropriate sports facility, has been completed in seven months. Outcome measures will be collected following the upcoming T1 and T2 evaluations.

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From Prodromes to Gait-Based Screening: Explainable AI Unveils Preclinical Risk Signatures of Parkinson's Disease.

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Introduction

Non-motor prodromes frequently precede the clinical onset of Parkinson's disease (PD), but it remains challenging to determine which individuals will later develop the disease [1]. Subtle gait changes may already be present in the prodromal phase, possibly encoding early biomechanical correlates of disease risk [2]. Wearable sensors and explainable artificial intelligence may enable the detection of a motor signature unique to high-risk prodromal profiles.

Methods

We analyzed gait data from 175 Parkinson's patients enrolled in a multicenter study across two clinical institutions (Mondino Institute of Pavia and ICOT of Latina). Gait was measured using a single lumbar-worn inertial sensor (L5 level) during a 30-meter straight walk at a self-selected speed. Each patient was evaluated for the presence or absence of four prodromal symptoms: hyposmia, REM sleep behavior disorder (RBD), constipation, and depression. A multiclass target variable was created to represent all possible binary combinations of these prodromes. To solve class imbalance, we created synthetic data with a conditional tabular GAN (ctGAN). After stratified feature selection and lazy prediction, the Random Forest model was optimized for recognizing the prodromal triad (hyposmia, RBD, and depression). The SHAP analysis identified crucial biomechanical traits, which were used to develop clinical ranges for screening healthy subjects with motor profiles similar to PD.

Results

The optimized RF model achieved a cross-validated accuracy of 97.0% ± 0.9%, with an F1 score of 0.648, and precision of 0.883 in detecting individuals with the prodromal triad hyposmia, RBD and depression. The model consistently identified high-risk subjects across folds (F1 range: 0.50–0.75), supporting its robustness and generalizability. The most informative features, according to SHAP analysis in Figure 1, yielded a biomechanical risk profile, with cadence (89-125 steps per minute), %det ML (25-75%), and single support (10-43%) emerging as characteristic ranges for individuals exhibiting these high-risk prodromal profiles.

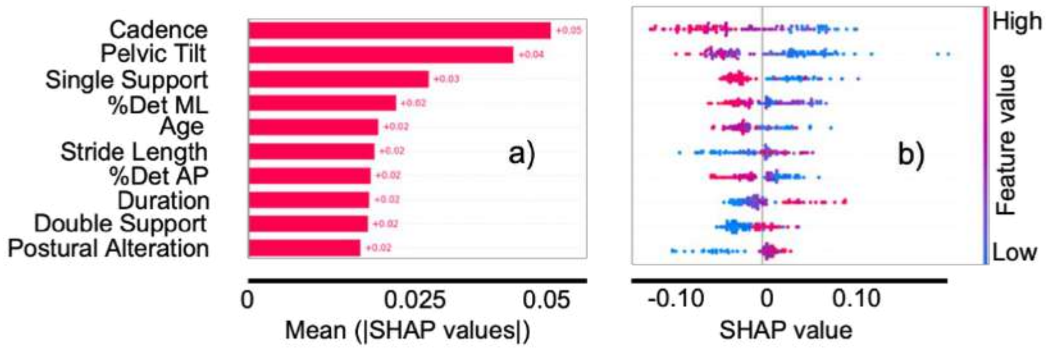

Figure 1. Shap summary (a) and beeswarm (b) plots highlight key predictors of the prodromal triad.

Discussion

These findings show that a specific combination of prodromal features (hyposmia, RBD, and depression) is associated with subtle but identifiable gait changes in PD patients. Training explainable AI models on this target subgroup revealed a reproducible biomechanical signature that included lower cadence, longer stance time, and decreased gait regularity. This signature can be used as a reference profile to screen clinically healthy individuals with the same prodromal profile, providing a new tool for identifying those at higher risk of developing Parkinson's disease.

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From EMG to Insight: Explainable Deep Learning Identifies Muscle Drivers of Stiff-Knee Gait in Hereditary Spastic Paraparesis.

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Introduction

Hereditary spastic paraparesis (HSP) is a rare pyramidal disorder causing progressive lower-limb stiffness and gait impairment [1]. Standard EMG and gait analysis often fail to identify phase- and muscle-specific spasticity markers. We propose an interpretable deep learning approach combining surface EMG, SHapley Additive Explanations (SHAP), and a novel Muscle-Entropy Ratio (MER) to detect stiff-knee gait determinants.

Methods

26 HSP and 18 healthy subjects underwent 3D gait analysis with bilateral EMG from 16 lower-limb muscles. Patients were clinically grouped into three severity levels (HSP1–3). For each of >1000 gait cycles, normalized amplitude and sample entropy were extracted per muscle. These features fed a hybrid BiLSTM–CNN model for binary and multiclass classification (Fig.1). SHAP was used for interpretability, and MER quantified the balance between activation magnitude and modulation complexity.

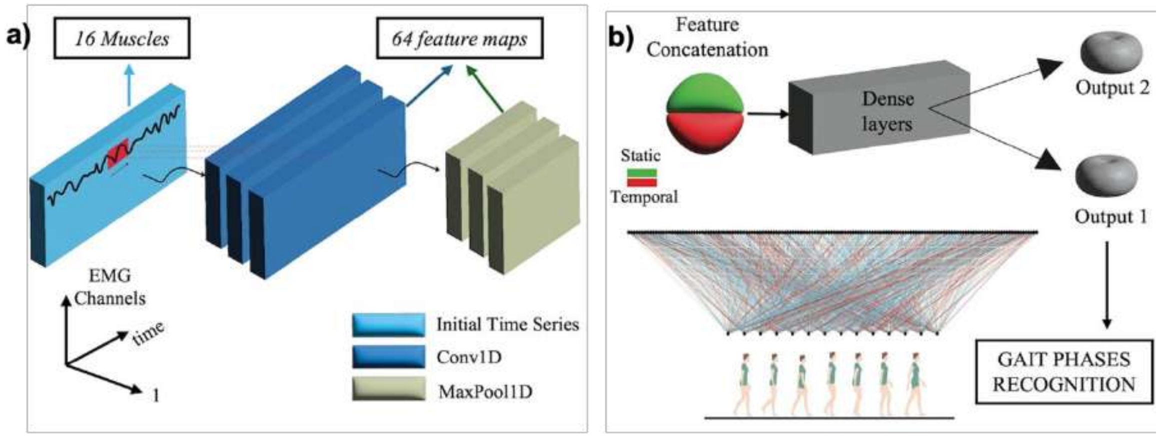

Figure1. a) Convolutional layers extract spatial features from EMG; b) Dense layers after BiLSTM predict binary (HS vs HSP) and multiclass (HS vs HSP1–3) outcomes.

Results

The model achieved 91% accuracy and F1-score in both tasks. SHAP identified quadriceps muscles, rectus femoris, vastus lateralis and vastus medialis, as key in loading response and midswing. MER was higher in more impaired patients, suggesting amplitude-dominated, stereotyped patterns. Elevated MER correlated with reduced joint angular velocity/acceleration ($\rho < -0.65$, $p < 0.001$).

Discussion

Our findings confirm and expand on previous research [1,2] by demonstrating that the quadriceps, play a primary role in the stiff-knee gait in HSP. These muscles made the most SHAP-based contributions during loading response and midswing, which are critical for shock absorption and limb advancement. Their prolonged and stereotyped activation indicates corticospinal dysfunction and reduced motor adaptability. The MER index also revealed reduced modulation complexity in more impaired patients. In conclusion, these insights enable clinicians to identify muscle-phase-specific spasticity, supporting personalized interventions such as botulinum toxin or phase-specific gait retraining in pyramidal syndromes.

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Estimating lower limb kinematics in walking with minimal input approach: preliminary validation on four surfaces and two slopes

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Introduction

Experimental measurement set-up simplification is an important factor for fostering clinical applications of quantitative movement analysis. This preliminary work explored the feasibility of estimating joint kinematics (hip, knee and ankle) using a minimal input approach (MIA), exploiting only information on pelvis and foot orientation and position. To investigate the feasibility of the proposed approach, measurement input were derived from marker-based stereophotogrammetry (SP) as it is considered the reference in clinical movement analysis.

Methods

Five healthy adult participants walked across four standardized configurations of surfaces (flat, up-down profile, soft, and irregular with holes) under two slope conditions (0 deg; 15 deg) [2]. Kinematic data were collected using a marker-based SP system with 12 infrared cameras (Vicon Vero, fs = 100 Hz) and 16 markers (Davis protocol). A lower limb biomechanical model was built using the Denavit–Hartenberg convention [1], including 21 revolute joints (3 for the pelvis and 9 for each lower limb) and 7 rigid segments. The model was scaled using the subject-specific segment lengths. Hip, knee, and ankle joint angles were estimated through an optimization process by fitting the model to the positions and orientations of pelvis and feet. Reference joint angles were obtained from the full markerset. Joint angle errors were evaluated in terms of root mean square difference (RMSE) between the MIA and SP time series as well as range of motion (|ΔROM|) difference for each angle. ROM errors were statistically evaluated using a Two-Way ANOVA.

Results

Mean RMSE values were 1.6 ± 0.3 deg, 5.4 ± 0.6 deg, and 6.9 ± 0.7 deg for the hip, knee, and ankle, respectively. Mean absolute errors in ROM between MIA and SP were 0.9 ± 0.6 deg for the hip, 4.7 ± 2.3 deg for the knee, and 6.2 ± 1.7 deg for the ankle. We found that the estimated ROM statistically significantly differed both between the two methods (MIA vs SP, $p < 0.0001$) and across different terrains ($p < 0.0001$), however with no significant interaction between method and terrain ($p = 0.8064$).

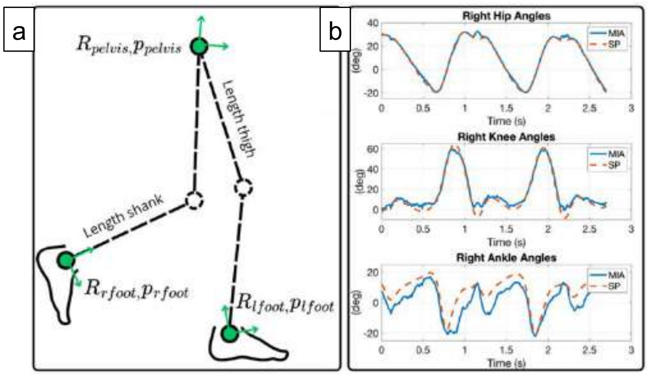

Figure 1. *a)* MIA *b)* Examples of the flexion – extension angles.

Discussion

All mean RMSE values were below 7 deg, with the hip and knee showing lower errors. Mean |ΔROM|) were below 7 deg across all joints, with the hip showing minimal deviation. Statistical analysis indicated that model performance remained consistent across the different terrains. These findings encourage future extension to IMU-based wearable systems.

Acknowledgments

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Telemedicine to provide an adapted physical activity program to pediatric oncology patients undergoing active oncological care: a preliminary feasibility study.

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Introduction

Survival rates for pediatric hematological malignancies have improved significantly over the past 50 years. However, children undergoing cancer treatment face long-term health challenges, including musculoskeletal impairments and reduced physical activity levels, which contribute to a poorer quality of life (QoL) and elevated cardiovascular risks. Barriers to accessing traditional physical activity and rehabilitation programs necessitate innovative approaches, like telemedicine-based interventions. The aim of this study was to assess the feasibility of a telemedicine-integrated adapted physical activity (APA) program for improving functional and clinical outcomes in pediatric oncology patients.

Methods

The study included children and adolescents (5–18 years) with onco-hematological conditions. Participants underwent baseline (T0) and six-month (T1) assessments using the PedsQL system [1] to assess various functional and QoL evaluation tools (PedsQL), as well as functional tests such as the 6-Meter Walking test (6MWT), Turn test (TT), Time Up&Go, and 7-Meter Walking test. Functional tests were performed through a single IMU (G-Sensor, BTS Bioengineering) positioned at the sacral level. IMU data were processed using the G-Studio software and imported into a database for statistical analysis. The APA intervention comprised personalized exercise regimens targeting strength, aerobic capacity, flexibility, and balance. Supervised training sessions were conducted both in-person and remotely via a telemedicine platform (Cisco Webex). Statistical analyses employed the Wilcoxon Rank Sum Test to calculate the T0–T1 differences, mixed regression models to assess the impact of telemedicine on the pre- and post-intervention changes, and a graphical prediction model was used to predict the effect of telemedicine sessions on the parameters that resulted as significant in the mixed regression models.

Results

A total of 12 subjects completed T0 and T1 assessments (sex: 5 M and 7 F, age: 11 ± 3). During the study period, significant improvements were observed. Specifically, several parameters of the PedsQL scale demonstrated substantial improvements ($p < 0.05$). Regarding the data retrieved from the IMU, several parameters showed significant improvement after treatment. Several parameters demonstrated a significant and clinically meaningful correlation between IMU parameters and the number of telemedicine sessions performed. In particular, the 6MWT speed and distance, as well as the total time of the TT, showed significant improvements ($p < 0.05$). The graphical predictive model of 6MWT speed and telemedicine sessions is presented in Figure 1.

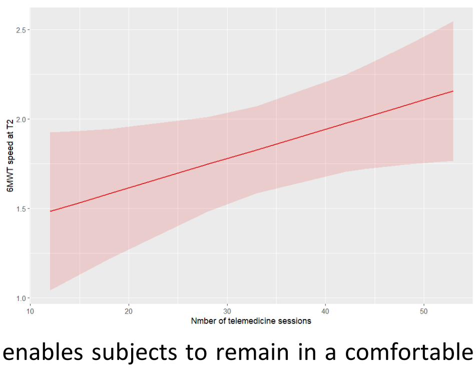

Figure 1. Predictive model of 6MWT speed improvement concerning the number of telemedicine sessions.

Discussion

The recruited sample is too small to draw definite conclusions. However, this is one of the first studies on pediatric patients with onco-hematological conditions that are still undergoing active treatment. In contrast, APA interventions typically commence at the end of the treatment period. This study implemented APA treatment while the treatment was still ongoing. Moreover, the adoption of telemedicine enables subjects to remain in a comfortable setting (i.e., at home), which is significantly different from the inpatient setting. Exercise medicine in the oncology setting has already proven its efficacy for adults [2]; this work opens interesting insights also in the pediatric context.

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Automatic identification of postural transfers within an IMU signal by dynamic time warping: a study on healthy and subjects with Parkinson's disease.

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Introduction

The ability to perform Postural Transfers (PTs) safely plays a pivotal role in rehabilitation, and the assessment of PTs is a cornerstone of clinical examination. However, the automatic instrumental identification for monitoring and evaluation is inadequately addressed in the literature, except for the sit-to-stand transfer[1]. A recent study developed a preliminary assessment algorithm that distinguishes between healthy and pathological PTs[2]. Nevertheless, the relationship between the proposed parameters and clinical outcomes remains unclear. In this study, we propose a method for automatically identifying PTs from IMU signals using Dynamic Time Warping (DTW) in a sample of healthy subjects (HS) and subjects with Parkinson's Disease (SwPD).

Methods

5 PTs (Sit to Stand, Stand to Sit, Supine to Sit, Sit to Supine, and Roll) were performed by HS and SwPD while wearing a single chest-mounted IMU (BTS G-Sensor). Data from the IMU triaxial accelerometer was processed within the Delphi environment. For each postural transition (PT), a mean acceleration profile was computed as a reference pattern. Baseline values and thresholds were defined to distinguish movement from rest. Using a moving window, the distance between each signal segment and the reference patterns was calculated via Dynamic Time Warping (DTW). Each PT was classified by the minimum DTW distance.

Results

A Total of 265 signals have been processed from 5 HS and 5 SwPD. The DTW algorithm has identified 100% of PTs performed by HS and 93% of PTs performed by SwPD (Table 1).

Table 1. Identification rate in Healthy subjects and subjects with PD

Group	**Healty**, N = 118[1]	**SwPD**, N = 147[1]
Success	118 [100%]	136 [93%]
Error	0 [0%]	11 [7.5%]

[1] n [%]

Discussion

The DTW algorithm achieved 100% PTs identification in healthy subjects and 93% in SwPD, highlighting its robustness against kinematic variability, particularly in Parkinsonian motor fluctuations. The 7.5% error rate in SwPD likely stems from disease-related inconsistencies in movement initiation or velocity. The single IMU setup provides practical monitoring advantages for both clinical and home use. This approach bridges a critical gap in instrumental PT assessment, enabling objective evaluation and potential links to clinical outcomes. While small sample size limits generalizability, future studies should validate findings in advanced PD stages, integrate real-time monitoring systems, and reduce the error rate.

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Analysis of muscle synergies to evaluate the impact of robotic rehabilitation on trunk control in individuals with SCI

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Introduction

Spinal Cord Injury (SCI) often causes paralysis, weakness and spasticity of trunk muscles and loss of postural control (both static and dynamic) severely compromising the ability to perform activities of daily living (ADL) and reducing the quality of life of the affected individuals [1]. Furthermore, deficits in postural trunk muscles often lead to incorrect compensatory muscle activation patterns in individuals with SCI. Therefore, improving trunk mobility and strengthening trunk control are primary rehabilitation goals. Nowadays, robotic rehabilitation can be added to conventional rehabilitation to improve trunk control, balance and proprioception in the seated position, playing a key role in promoting motor learning and muscle coordination while providing real-time feedback. The aim of this preliminary study is to evaluate the effects of intensive robotic therapy with the Hunova® device (Movendo Technology, Italy) on trunk control and muscle coordination in individuals with acute SCI analysing synergies extracted from surface electromyography (sEMG) signals of trunk muscles recorded during the execution of a dynamic reaching task.

Methods

Twenty SCI patients (4F, 44.5±17 y.o.) with acute (<6 months post-injury) motor complete (C, n=10) or incomplete (I, n=10) lesions were instructed to perform a reaching trunk evaluation test on the robotic device Hunova. They were seated upright on Hunova chair with their feet on the ground and their hands on their thighs and they had to lean their trunk as far as possible in one of three directions, in a random order, following a trajectory showed on Hunova screen, and return to the starting position. Bilateral sEMG was recorded from eight muscles during the test: Erector Spinae (ES), Latissimus Dorsi (LD), Trapezius (Tr) and Pectoralis Major (PM). 10 patients (5C, 5I) underwent 10 sessions of robotic trunk rehabilitation via Hunova (1h/day, 5d/week, for 2 weeks), while the others completed 20 sessions (1h/day, 5d/week, for 4 weeks). Each patient was tested before (T0) and after (T1) robotic treatment. Hunova data were used to segment the reaching task and were applied to the recorded EMG data. Muscle synergies were extracted from the pre-processed, segmented, and time-normalised EMG dataset using a non-negative matrix factorisation. The number of synergies was chosen as the minimum to explain at least 80% of the data variation, as calculated by variance accounted for (VAF). To compare the extracted muscle synergies, a *k-means* clustering algorithm was applied to the normalized weight vectors [2]. ANOVA was performed to analyse changes in the number of extracted muscle modules before and after rehabilitation, considering the completeness level and the number of robotic sessions. Similarity of weight coefficients was evaluated using two indices of similarity: Cosine Similarity (CS) and Similarity Index (SI) [3].

Results

The mean number of extracted synergies was 4±1. The results showed that it was independent of the level of completeness or the number of sessions, with no statistically significant differences observed. For this reason, we set the number of synergies to 4 for all subjects and conditions. All patients showed a high degree of similarity in the synergies involved, with indices ranging from 0.86 to 0.98. However, comparison between patients with the same level of completeness who underwent a different number of robotic sessions revealed a lower mean SI value (C 0.73±0.05, I 0.73±0.05). This suggests that robotic rehabilitation influences the restoration of trunk muscle synergies.

Discussion

After neurological disorders such as SCI, impaired muscle coordination is generally linked to changes in muscle activation patterns. However, the way in which trunk muscle synergies change after SCI is still unclear. Our results suggest that robotic rehabilitation could influence them. Future studies could acquire the same sEMG data from healthy subjects, enabling a comparison of physiological muscle activation. Furthermore, more individuals with SCI could be recruited and results stratified according to the neurological level of the lesion.

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Walking through frailty: a prospective observational study on the rehabilitation path of subjects after total knee arthroplasty with and without frailty.

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Introduction

The number of total knee arthroplasties (TKAs) is steadily increasing, and patients undergoing this procedure are getting older. As a result, more frail individuals are being included, which raises the risk of perioperative and postoperative complications. However, the assessment of frailty in patients who are candidates for surgery is rare. The existing evidence on frail subjects who undergo TKA showed an increased length of stay and an enhanced burden for national health systems due to frailty [1]. However, there is little to no evidence regarding how postoperative rehabilitation affects the clinical and functional outcomes (i.e., gait) of frail and non-frail subjects differently. This study examines the differences in rehabilitation paths between frail and non-frail patients following total knee arthroplasty (TKA) during inpatient conventional rehabilitation, with a specific focus on gait changes.

Methods

This study is part of a larger project aiming to include up to 62 participants. For the present analysis, we recruited individuals who met the inclusion criteria and were able to walk independently, with or without walking aids. Participants were stratified into a frail group (FG) or non-frail group (NG) based on the Primary Care Frailty Index (PC-FI), assessed using pre-operative anamnestic data. At admission (T0) and discharge (T1) from the rehabilitation ward, clinical outcome measures were collected, including the modified Barthel Index, Numerical Pain Rating Scale, and International Knee Society Score. Patient satisfaction was evaluated with the Oxford Knee Score at both time points. Gait analysis was performed at T0 and T1 using an optoelectronic system (BTS Smart DX-400) with the Davis-Heel protocol. Subjects walked at a self-selected speed, completing one standing and three walking trials.

Results

12 subjects have been recruited and assessed at T0 and T1, 8 frail and 4 non-frail patients. The two groups have a similar age. Both groups improved during the rehabilitation period. In the between-group comparison, only cycle length and step length at admission showed significant differences (Table 1). Even if non-significant, most of the gait parameters showed a similar tendency between FG and NG. Temporal parameters increased in the FG, while spatial parameters decreased. These differences appear to have diminished by the end of the rehabilitation period. (T1).

Table 1. Significant differences at admission between FG and NG.

Outcome	FG - mean (SD)	NG - mean (SD)	pValue
Cycle length affected side [m]	0.71 (0.17)	0.95 (0.11)	0.022
Normalized cycle length affected side [%]	44.13 (9.21)	56.95 (6.37)	0.048
Step Length non-affected side [m]	0.31 (0.09)	0.46 (0.06)	0.027

Discussion

This study is still ongoing, and additional results will be presented at the upcoming congress. Nonetheless, in the context of a scientific landscape increasingly oriented toward precision medicine, it is crucial to consider each patient's clinical history and pre-operative status in order to tailor rehabilitation strategies effectively. While it is well established that TKA is associated with a higher rate of complications in frail patients compared to non-frail individuals [2], the specific impact of frailty on the rehabilitation process following TKA remains underexplored. Preliminary findings from this study suggest that rehabilitation has led to improvements in clinical outcomes, some gait parameters, and quality of life in both the FG and the NG. Interestingly, despite the limited number of statistically significant findings, a trend seems to emerge: while FG and NG present different scores at baseline, these differences tend to diminish by discharge. Continued recruitment and data collection may clarify how frailty influences post-operative rehabilitation trajectories in TKA patients, providing valuable knowledge that lays the groundwork for advancing precision medicine.

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Can we discriminate between indoor and outdoor environments during daily life activities using barometric signal alone?

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Introduction

Distinguishing between indoor and outdoor (I/O) environments is relevant, as it provides essential context for interpreting mobility patterns in clinical applications [1]. Current approaches rely on GPS, GNSS, Wi-Fi, light sensors, Bluetooth, and magnetometers, achieving accuracy of about 90% with machine learning techniques [2]. Barometric signals are sensitive to external factors such as temperature fluctuations, weather conditions, and airflow variations [3], which are generally considered as sources of noise. But what if this noise could become an asset to discriminate against patient movement across different environments? In this study, we investigate whether the barometric signal can discriminate I/O settings, proposing a novel strategy using only a high-resolution barometric pressure signal.

Methods

Ten healthy subjects wore a barometer on their lower back (sample frequency= 100Hz). Subjects performed daily activities in the city of Turin, including walking inside a building, walking along the street, and entering a supermarket, for a total of 2 hours of recording without supervision. Ground truth labels were obtained through manual annotation of entry and exit times from indoor environments via video analysis. Three different Machine learning techniques, i.e., random forest (RF), multi-layer perceptron (MLP), and Convolutional Neural Network – Long Short-Term Memory (CNN-LSTM), has been applied. The barometric signal underwent preliminary preprocessing, and the effect of different window sizes was evaluated. Data from seven participants (≈14 hours) were used for training, while the remaining three (≈6 hours) formed the test set. The split was executed based on k-means clustering (k = 3) performed on feature distributions to ensure cluster-level diversity in all sets. Leave-one-subject-out (LOSO) cross-validation was employed to assess generalization across individuals. Classification performance was evaluated with accuracy, F1-score, and the area under the receiver operating characteristic curve (AUC-ROC) on the test set.

Results

Table 1. Performances (mean values and standard deviation) of the models across test set, in terms of accuracy, F1-score and AUC ROC. The MLP and RF models were trained on 10 features extracted from the low-pass filtered barometric signal and 7 features extracted from the high-pass filtered barometric signal. The CNN-LSTM models were trained on the low-pass and high-pass filtered barometric signals, including their first and second derivatives.

window size 10s				window size 100s			
%	**Accuracy**	**F1-score**	**AUC**		**Accuracy**	**F1-score**	**AUC**
MLP	86 (2)	77 (3)	94 (3)	**MLP**	**92 (2)**	**85 (7)**	**98 (2)**
RF	87 (2)	78 (3)	87 (4)	**RF**	92 (2)	85 (2)	92 (3)
CNN-LSTM	85 (1)	74 (4)	92 (3)	**CNN-LSTM**	88 (6)	73 (12)	91 (3)

Discussion

The results indicated that increasing the window size improves classification performance across all models. The MLP model yielded the highest performance in both configurations, suggesting its effectiveness in capturing relevant patterns from the extracted features. However, the F1-score remained lower than both accuracy and AUC for all models, mainly due to the misclassification of the outdoor class, which is underrepresented in the dataset. Overall, the findings are promising, and, to the best of our knowledge, this is the first approach introducing a methodology based solely on barometric data to discriminate between indoor and outdoor environments. Acknowledgements: part of the project NODES, MUR – M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (ECS00000036 – CUP E13B22000020001).

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A benchmark analysis of fall detection algorithms with chest- and wrist-worn IMUs on public datasets

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Introduction

Falls are a major health concern among older adults and require rapid assistance to prevent serious consequences. Accordingly, the development of automatic fall detection systems has gained significant attention. Due to the limited availability of clinical data involving real falls, most studies rely on simulated falls recorded with inertial measurement units (IMUs) placed on various body locations and performed by healthy volunteers [1]. Recent approaches use machine learning techniques and multiple IMUs, achieving great accuracy (above 99%) [2]. In contrast, this work proposes a rule-based method that operates with a single IMU and is designed to operate regardless of sensor placement. Additionally, we explore the feasibility of relying solely on accelerometer data to ensure compatibility with devices that do not incorporate a gyroscope.

Methods

221e S.r.l. has developed the MAD (Man Down) software library to detect man-down alert events across a variety of physical activities. The library features two algorithmic versions: *6DoF*, which leverages both linear acceleration and angular velocity data, and *3DoF*, based solely on linear acceleration signals. The MAD library employs a rule-based approach to identify potential falls and trigger escalating alerts independently of sensor placement. Inertial signals are continuously monitored to identify impacts, free falls, or static conditions. Upon detection of an impact or free fall followed by a static posture, the system triggers the initial alert level. If the condition persists and the user's orientation confirms a horizontal posture, the alert escalates. A final confirmation stage may trigger the highest alert level, corresponding to a man-down condition. Orientation and motion features are continuously evaluated to confirm or dismiss alert states. The input signals are sampled at 50Hz. To evaluate the performance of the library, five publicly available datasets containing simulated fall events with chest- and wrist-mounted IMU data were analyzed: CGU-BES, SisFall, FallAllD, UMAFall, and Up-Fall [3]. The chest-mounted data included a total of 7702 recordings, comprising 4903 non-fall events and 2799 fall events. For the wrist-mounted data, 1284 recordings were analyzed, consisting of 821 non-fall events and 463 fall events. The library employs a uniform set of parameters for all datasets instead of using customizable thresholds tailored to specific use cases. The recordings were classified as true positives, true negatives, false positives, and false negatives, from which accuracy, precision, sensitivity, and specificity were derived.

Results

Table 1. Algorithms performance in detecting falls and non-fall events using data from chest- and wrist-mounted sensors.

Chest			**Wrist**		
	6DoF	*3DoF*		*6DoF*	*3DoF*
Accuracy	98%	97%	Accuracy	92%	92%
Precision	97%	95%	Precision	90%	90%
Sensitivity	97%	97%	Sensitivity	88%	88%
Specificity	99%	98%	Specificity	95%	95%

Discussion

The proposed algorithms achieved excellent performance with chest-mounted IMU data, reaching accuracy levels comparable to those reported in literature, while maintaining significantly lower complexity and computational cost. The wrist-mounted configuration yielded promising results, and the corresponding decrease of performance is reasonable considering the higher variability and less predictable movement patterns of the wrist during fall events. The comparable performance of *6DoF* and *3DoF* algorithms highlights the reliability of the acceleration-only approach, supporting its potential for simplified and energy-efficient solutions.

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Gait analysis via markerless OpenCap: comparison with state-of-the-art skin-marker based kinematics

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Introduction

Several markerless technologies have been introduced to measure joint kinematics during human movements. However, the accuracy with respect to standard marker-based gait analysis tools is seldom reported [1]. The open-source web-based platform OpenCap [2] uses two iPhone cameras to estimate joint kinematics. This system automatically identifies the 3D coordinates of several anatomical landmarks based on a predefined marker set. This study aimed at assessing the accuracy of OpenCap in measuring lower-limb joint kinematics during gait with respect to a traditional skin-marker based protocol, considered as gold standard.

Methods

Ten healthy individuals were recruited for this study. Each participant was instrumented with 31 skin markers according to the IOR gait protocol [3] and walked barefoot over a 10-meter walkway. Simultaneously, two iPhone cameras video-recorded the walking sequences. Markerless and skin-marker based hip, knee and ankle 3D joint kinematics were time-normalized over the gait cycle. The effect of the measuring technique on joints ROM was assessed via paired non-parametric Wilcoxon signed rank test. Differences in temporal profiles of joint rotations were assessed via RMSE, Pearson correlation coefficient and Statistical Parametric Mapping.

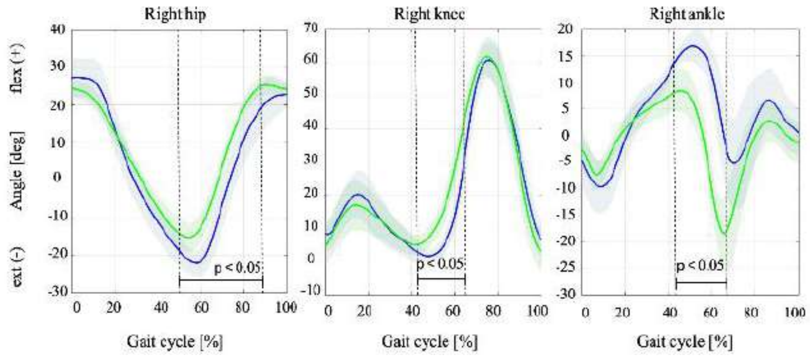

Figure 1. Inter-subject mean profiles (±1SD) of joint flexion/extension rotations during normalized gait duration for OpenCap (blu) and skin-marker based measurements (green). SPM differences are highlighted.

Results

In the hip and knee joints, Pearson's R between OpenCap and skin-marker based temporal profiles of flexion/extension rotations was larger than 0.94 across all participants. The average R for the ankle joint was 0.52. Negative correlations were observed for the internal/external rotations of the hip joint. Statistical differences ($p<0.05$) were found in ROM and in the temporal profiles of joint rotations (fig. 1).

Discussion

While flexion/extension rotations of the hip and knee joints were rather consistent between stereophotogrammetry and markerless technology, internal/external rotation of the hip and flexion/extension rotation of the ankle appeared to be significantly affected by the measurement system. Other motor tasks, and more diverse populations, will be investigated.

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Pre-operative gait analysis and clinical evaluation of a population affected by hallux valgus

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Introduction

Hallux valgus (HV) is a progressive deformity of the first ray of the foot, characterized by a lateral deviation of the hallux and a medial deviation of the first metatarsal bone (Fig. 1, left). HV alters foot biomechanics and may cause pain, difficulty in ambulation, and reduced functionality [1]. The aim of this study was the functional characterization of a HV population pre-operatively.

Methods

Twenty-one patients, recommended for surgical correction of HV at the authors' Institution, were recruited for the study (M/F = 1/20; age = 53±24 yrs). Functional impairment, quality of life, and pain were assessed using MOxFQ, AOFAS, and VAS scales. Foot and lower limb kinematics were analysed with validated skin-marker based kinematic protocols [2, 3]. Wireless surface EMG was used to record the activation of the main ankle dorsi/plantar-flexor muscles. Five walking trials at self-selected speed were collected for each participant. Data from healthy controls (n=27) were used for comparison. Non-parametric tests (Wilcoxon, Mann-Whitney) and Statistical Parametric Mapping (SPM1D) [4] were used to assess spatio-temporal and kinematic differences.

Results

A significant reduction in the median [25% 75%] step length (%height) was observed between the HV group (stepL HV = 76.6 [72.3 81.0]; stepL control = 80.1 [80.0 80.3]; p=0.03). No differences were found in any other spatio-temporal parameter. The mean static-posture valgus angle between hallux and first metatarsal bone was significantly larger in the HV group compared to controls. This difference was also observed across the whole gait cycle (Fig. 1, right). An increased ankle inversion in the affected side with respect to controls was present during midstance. An earlier and shorter activation of the medial gastrocnemius in the HV group was observed with respect to controls.

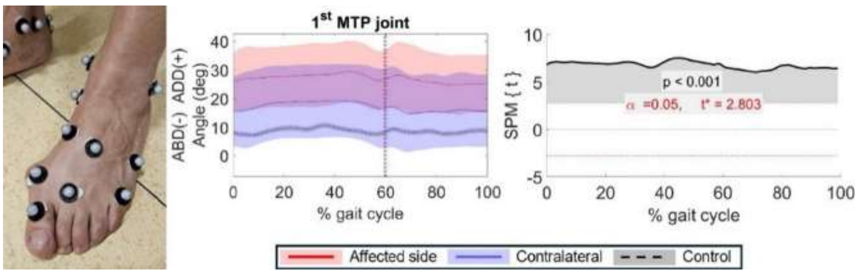

Figure 1. Left, an exemplary HV patient instrumented with skin markers according to the Rizzoli Foot Model. Right, mean temporal profiles (±1SD) of the 1st metatarso-phalangeal (MTP) joint varus/valgus angle during gait in HV patients and controls, and outcome of the SPM test.

Discussion

HV patients exhibited reduced step length compared to controls, likely due to the perceived pain and limited postural stability. HV deformity appeared to affect the kinematics of the whole foot-ankle complex, especially in the frontal and transverse planes. Ankle inversion appears to be a compensatory mechanism to shift the load laterally during stance. Earlier medial gastrocnemius activation leads to a premature push-off phase, likely due to decreased propulsion efficiency resulting from structural changes in the first ray. The effect of surgical corrections will be reported in future endeavours.

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Hybrid robotic-assisted rehabilitation for post-stroke gait recovery: development of a combined exoskeleton and wearable FES system

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Introduction

Gait impairments are among the most disabling consequences of stroke, often resulting in foot drop, asymmetry, and reduced mobility. Two well-established strategies in neurorehabilitation are robotic-assisted rehabilitation (RAR) and functional electrical stimulation (FES). Robotic devices provide safe, repetitive, task-specific training, while FES enhances voluntary activation and sensory feedback, essential for motor relearning [1]. However, their combined use remains underexplored. This project aims to develop and test a hybrid system (H-RAR) integrating a lower-limb exoskeleton (TWIN) with a wearable, EMG-controlled FES device (FitFES) to support gait recovery in post-stroke people.

Methods

TWIN, developed at the Istituto Italiano di Tecnologia (IIT), actuates hip and knee joints via brushless motors, while the ankle joint is a passive and rigid ankle-foot orthosis (AFO), equipped with elastic elements that can be preloaded to control the range of motion limits [2]. FitFES, developed by IIT and Fondazione Don Gnocchi (FDG), is a wearable FES system delivering electrical stimulation proportional to real-time surface electromyographic (EMG) signals [3,4], amplifying residual muscle activity to support functional movement. Here, the two systems were integrated as follows: the AFO was unlocked, and stimulation was delivered to the muscles of the paretic leg. TWIN-Acta, an assist-as-needed control strategy jointly developed by IIT and FDG [5], was accordingly upgraded to include stimulation of the tibialis anterior during the swing phase, to promote voluntary ankle dorsiflexion and prevent foot drop. A unified graphical user interface (GUI) was developed to allow clinicians to configure and monitor both systems simultaneously. To test the efficacy of such system for gait training, 25 post-stroke people will undergo 15 one-hour sessions using H-RAR, over 3-5 weeks. Stimulation and robotic parameters are calibrated individually at each session, based on clinical evaluation and patient feedback. Clinical outcomes will be compared with those of 25 matched patients undergoing identical training using a CE-marked commercial exoskeleton without FES, to assess the added value of hybrid rehabilitation.

Results

The H-RAR system successfully underwent safety and electromagnetic compatibility (EMC) tests according to EN 60601-1 and EN 60601-1-2 standards. Moreover, FitFES complies with particular safety standards, IEC 60601-2-10 for stimulators and IEC 60601-2-40 for EMG. Both devices' software complies with EN 62304 requirements. The experimental protocol received approval from the regional Ethical Committee and the Italian Ministry of Health, and the clinical trial is currently ongoing.

Discussion

This trial will provide insights into the clinical impact of integrating FES with RAR for post-stroke gait rehabilitation. Comparing the hybrid system with a conventional exoskeleton without FES integration will help evaluate FES's role in enhancing recovery outcomes. Preliminary findings in healthy subjects already showed that FES improved ankle kinematics during walking: greater dorsiflexion and plantarflexion during terminal stance, and increased dorsiflexion during swing with the AFO unlocked. The ongoing study will determine whether the H-RAR is an effective tool for rehabilitation and whether it offers additional benefits compared to the RAR approach alone.

Acknowledgment

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Preliminary results on the relative mechanical stability of the TWIN exoskeleton-user interaction during functional use

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Introduction

Exoskeletons have gained increasing attention in various fields, with a notable rise in their use for rehabilitation, especially for people with neurological or musculoskeletal impairments. Lower-limb exoskeletons are primarily designed to facilitate the restoration of a physiological gait pattern by providing stability and movement support throughout the walking cycle. Importantly, their therapeutic efficacy strongly depends on the active participation of the user, as such engagement fosters motor recovery and neuroplasticity, especially in individuals with residual motor function. A critical aspect to consider is the human-robot interaction, as it impacts safety, ergonomics, and overall system usability [1]. It is important to ensure that the exoskeleton delivers the intended assistance while also preventing joint overload, as well as injuries and skin abrasions that could occur from prolonged use. To maximize system functionality and minimize discomfort, the mechanical stability between the brace and the body must be optimal and the relative movements between them minimal. In the present work, an experimental trial was conducted on healthy volunteers that performed several tasks while wearing the TWIN exoskeleton, developed at the IIT-INAIL Rehab Technologies Lab [2]. The purpose of the study was to assess the quality of the mechanical stability between the device and the user through the analysis of the relative displacements between the exoskeleton braces and the corresponding body parts (thigh and shank) during walking and sit-to-stand.

Methods

Five healthy adults were enrolled for the study. They were asked to perform several tasks – including sit-to-stand (STS) and gait trials – while wearing the TWIN exoskeleton. Lower limbs kinematic were analyzed using an optoelectronic motion capture system equipped with 10 infrared cameras detecting and recording spherical passive markers placed on specific points on both the subject and the exoskeleton. Four of them were placed on the thigh and the shank (anatomical markers), while the remaining ones were attached to the exoskeleton (technical markers). From the collected data, the standard deviation of the relative displacements (RDstd index) between the markers placed on the orthotic brace and those placed on the correspondent anatomical segments was computed for each trial. As a reference value, the noise level of the experimental setup was used, computed as the relative displacement between the technical markers (rigidly connected) calculated across all trials.

Results

Data are reported as mean (standard deviation). The RDstd between the brace and the anatomical segment was 4.6 (1.5) mm at the thigh and 1.4 (0.1) mm at the shank during the STS task. During walking, it was 3.3 (0.4) mm at the thigh and 2.7 (0.2) mm at the shank. The RDstd between rigidly connected technical markers was 0.4 (0.1) mm.

Discussion

The resulting RDstd values were consistently less than 1 cm, threshold above which pain and skin damage may occur [3]. This is verified for both motor tasks and for either the thigh and the shank segments. The relative displacements between the brace and the thigh were smaller during walking than during STS task, as it might be expected since walking implies smaller excursions at hip and knee joints than sit-to-stand. Conversely, at the shank the relative displacements were larger during walking than during STS, likely due to the destabilizing effects on the lower leg associated with foot strikes of walking, that are not present during STS. Compared to results from D'Elia study [4], which showed RDstd values at the thigh between 4.0 and 6.3 mm during walking with a hip active orthosis, TWIN showed smaller values (3.3 mm), confirming a greater mechanical stability at that level. Moreover, none of the participants of the present study reported any discomfort or pain, suggesting an excellent body-TWIN interface.

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Event related spectral perturbations analysis of sensory-motor activity during visuomotor and imagery tasks performed with a prosthesis by an amputee

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Introduction
Neural plasticity, supported by oscillatory modulation in theta, alpha, and beta bands, plays a key role in motor learning and movement planning/execution. Event-Related Spectral Perturbations (ERSPs) analysis allow investigation of these brain dynamics.

Methods
The study [1] involved a 36-year-old male with a sensorized robotic hand, performing a visuomotor task under three conditions: using the healthy hand (HH), the robotic hand (RH), and imagining the robotic hand (IH) movement. EEG data were recorded with a 64-channel system. ERSPs in theta, alpha, and beta band were examined in task-related brain regions -Left (FC5,FC3,FC1,C5,C3,C1) and Right (FC6,FC4,FC2,C6,C4,C2) ROIs- to assess oscillatory changes across the three conditions.

Results
Results (Figure 1) revealed stronger desynchronizations in theta (4–7 Hz) and alpha (8–12 Hz) bands during RH movement compared to the HH. Theta synchronizations after Cue and Go1 stimuli were observed in both conditions, while in the IH task desynchronizations were reduced and synchronizations more prominent. Alpha desynchronization was marked during RH and IH conditions. Low-beta (12–20 Hz) desynchronizations were stronger in the HH task, while high-beta (20–30 Hz) desynchronizations during Go1 and Go2 appeared only for the HH, with synchronizations in the RH and IH tasks.

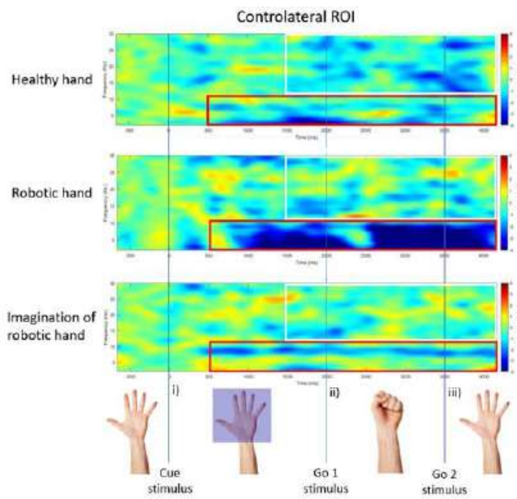

Figure 1. ERSP results in Contralateral ROI during healthy, robotic and imaginary hand movement. At the bottom a single trial of the experimental task was represented.

Discussion
Theta and alpha desynchronizations were stronger in the contralateral hemisphere during RH movement compared to the HH, reflecting greater mental effort and supporting the idea that increased brain activity compensates motor difficulty. Theta synchronizations after Cue and Go1 stimuli may indicate enhanced attentional processing. Alpha desynchronization began before Go1, linking it to movement preparation. Beta desynchronizations were more evident during HH movement, aligning with better motor performance. Similar alpha modulations during IH were also observed in previous studies. In conclusion, the study highlights specific EEG rhythm modulations in an amputee using a prosthesis, suggesting neural plasticity-driven reorganization in the contralateral hemisphere.

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Assessing a beacon-based UWB system for home-based patient movement tracking

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Introduction

In recent years, the rapid development of telemedicine and IoT-based has given rise to a growing interest in the monitoring of individuals' movements within their home environments, with a particular focus on patients suffering from neurological disorders. In such cases, particularly in instances of cognitive impairment or dementia, the identification of wandering behaviour is imperative for ensuring patient safety and providing support to caregivers. To address these needs, continuous, non-invasive monitoring systems—such as the beacon-based prototype proposed in this study—should be integrated directly into patients' homes [1]. These systems must ensure privacy by avoiding intrusive solutions like video recordings. In addition to tracking patient movement, they can localize everyday objects, which is especially useful for individuals with memory deficits who may misplace essential items. This study validates a prototype beacon-based Ultra-Wideband (UWB) system for indoor localization, designed for domestic healthcare. Its performance is compared with the Vicon system with a focus on the agreement and consistency between the two systems under controlled conditions.

Methods

A comparison was made between two tracking technologies: the Vicon optoelectronic system (Culver City, CA, USA), which uses infrared cameras for high-precision 3D tracking, and a prototype Ultra WideBand (UWB) beacon system developed by Medinok S.p.A. (Casoria, NA, Italy), enabling localization via triangulation from fixed anchors and a mobile tag. Tests were conducted at MARLab (Telese Terme) in a controlled 25 m^3 environment (11.52 m^2 area), equipped with six Vicon cameras and three beacon antennas in a triangular layout. A mobile tag with three asymmetrical Vicon markers was simultaneously tracked by both systems. Static acquisitions were performed in five positions (centre and corners), each repeated three times for one minute. Beacon data, initially in a local frame, were transformed to the Vicon reference system. The distances from the marker centroid to the beacon anchors were then compared with UWB estimates. The statistical analysis performed in Python included Bias, MSE, Spearman correlation, and Passing-Bablok regression with confidence intervals.

Results

Table 1 reports the statistical results of the five dynamic tests (1: upper left, 2: upper right, 3: lower right, 4: lower left, 5: center of volume). All tests show bias below 1 m, with higher relative errors in tests 2 and 5. Correlation is generally strong, though lower in tests 3 and 5.

Table 1. Results of statistics conducted on static tests.

Test	Bias (m)	MSE	Spearman	Slope	95% CI Slope	Intercept	95% CI Intercept
1	0,756	0,652	0,936	1,570	[0,670 – 42,50]	-2,540	[-242,98 – 0,870]
2	0,892	1,200	0,920	0,740	[0,460 – 1,990]	1,880	[-7,320 – 2,290]
3	0,709	0,555	0,481	1,059	[-0,007 – 1,669]	0,230	[-3,996 – 4,202]
4	0,883	0,981	0,983	1,430	[0,520 – 4,260]	-1,870	[-20,78 – 1,510]
5	0,923	0,896	0,410	1,120	[-0,130 – 5,870]	-1,410	[-20,88 – 6,130]

Discussion

The static tests show a measurement difference ranging from a maximum of 92 cm to a minimum of approximately 71 cm, with an average bias of about 83 cm. The Passing-Bablok results indicate that both the slope and intercept intervals contain the unitary and null values, suggesting no significant systematic or proportional error between the two methods. Spearman's test reveals strong correlation, except for tests 3 and 5, likely due to increased variability in those trials. Although confidence intervals are wide—likely due to the limited number of trials (15) and high variability—no evidence contradicts the hypothesis of a linear relationship. In conclusion, the beacon technology shows good agreement with the Vicon system, demonstrating its potential in controlled settings and its seamless integration with telemedicine systems for clinical monitoring, mobility assessment and positional tracking.

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Investigation of an IMU-based metric for monitoring motion symmetry during telerehabilitation with ARC intellicare

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Introduction

Rehabilitation is essential for managing conditions that impair physical, neurological, respiratory, and other functions [1]. Growing demand and the need for remote care have driven the development of telerehabilitation technologies [2], such as ARC intellicare (ARC). ARC allows patients to perform rehabilitation exercises exploiting the use of 5 inertial measurement units (IMUs) and an artificial intelligence algorithm to supervise the patient remotely. However, an objective and quantitative assessment of motor performance is still missing, hindered by the variety and complexity of rehabilitation tasks prescribed in clinical practice. To address this gap, the present study: i) introduces a symmetry metric designed as a digital mobility outcome to objectively assess telerehabilitation outcomes; ii) performs a preliminary clinical validation of the proposed metric.

Methods

We analyzed acceleration and angular velocity signals recorded by the 5 IMUs of ARC (positioned on wrists, ankles and the back of the neck) during the execution of rehabilitation exercises. Data were collected from the RICOMINCIARE [3] clinical study, involving 18 participants with Parkinson's disease (PD) and 13 with Long COVID (Cov-19) syndrome using ARC at home for 1 month, and from an internal acquisition of 30 healthy subjects conducted by HENESIS. A subset of exercises was selected, specifically those characterized by movements predominantly occurring within a single anatomical plane and without inter-limb constraints. In these cases, analyzing just one component of the angular velocity was sufficient, as it did not lead to a loss of significant information. For these, we computed a symmetry metric adapted from the literature: mTADS-SI, a modified version of TADS-SI [4]. It is specifically tailored to quantify the percentage of symmetry between left and right limbs, based on the area under the curve of their angular displacement signals along the predominant angular velocity axis. An average score was then computed for each subject per exercise. For the selected exercises, correlation analyses were performed including only those with a sample size greater than 5 individuals. This criterion was applied due to individual differences in rehabilitation plans. Specifically, we correlated the computed average mTADS-SI with the 6-Minute Walk Test (6MWT) in both PD and Cov-19 patients, and with the MDS-UPDRS Part III in PD patients. Finally, the statistical significance of inter-group differences was assessed using Mann-Whitney test.

Results

Analyses were conducted on 15 exercises (40% of the total), selected according to the criteria outlined above. Regarding correlations with clinical scores, for the 6MWT (available for 10 PD and 11 Cov-19 subjects), a positive association was observed in 5 out of 7 exercises for PD subjects and in 7 out of 12 for Cov-19 subjects. As higher symmetry scores reflect better motor performance, a negative correlation with MDS-UPDRS Part III (available for 8 subjects) was expected. This was observed in 4 out of 7 exercises. Additionally, statistical analysis of mTADS-SI revealed a significant difference ($p < 0.05$) between healthy and both Cov-19 and PD subjects in 60% of the 15 exercises.

Discussion

The metric exhibited clinically relevant correlations with established functional scales in most exercises and successfully distinguished healthy individuals from pathological subjects in more than half of them. These findings support the use of mTADS-SI as a promising tool for the objective assessment of motor performance in telerehabilitation settings. Future work will focus on extending the applicability of the metric to a broader range of subjects and exercises, including those involving more complex movement patterns across multiple anatomical axes.

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Baropodometrical and kinematic assesment in type 1 diabetic patients

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Introduction
Constant physical activity has a protective effect against diabetic neuropathy and a positive effect on metabolic control, and can also increase walking performance in diabetic subjects. The objective of the investigation is to observe and quantify the biomechanical parameters that describe the dynamic behavior of the foot in type 1 diabetics who perform regular physical activity compared to sedentary patients.

Methods
21 patients were evaluated, 10 active (A) and 11 sedentary (S) in good metabolic control. The kinematic and pressure data collection was carried out using a baropodometric insole system (Pedar-Novel) to obtain the plantar pressure data and a Gait Analysis system (Technobody) to collect the kinematic and inertial data.

Results
As regards the Gait Analysis, significant differences were observed for stride length; A=69 cm vs S=51 cm ($p<0.05$). Vertical oscillation significantly lower in sedentary people; A= 2.3 mm vs S= 1.4 mm ($p<0.05$). The baropodometric analysis revealed pressure peaks in forefoot support that were significantly greater in the active population; A= 1450 kPa vs S= 1260 kPa ($p<0.05$). The support area significantly greater A= 133 cm\q vs S= 103 cm\q with ($p<0.05$).

Table 1: Statistically significant kinematic and baropodometric differences in patients aged > 51 years, neuropathic and active compared to the control group.

Kinematics data	AGE > 51	PND	IPAQ2
VERTICAL OSCILLATION cm	<0.47	< 0.44	<1.0
SPEED p\s	ns	<0.6	ns
KNEE ROM °	< 8.5	ns	<7
LENGTH STEP cm	ns	<10.70	<10

Baropodomerics data	AGE > 51 a	PND	IPAQ 2
PP FOREFOOT	<148 kPa	< 179 kPa	>150.57 kPa
AREA	ns	ns	>12.34
PP FULL STRIKE	ns	<76	ns

Discussion
The kinematic and baropodometric data of this study show significant differences in terms of mobility and foot support between sedentary vs active patients, with improvements in gait propulsion performance.

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Organizing Degrees of Freedom through Kinematic Synergies in Functional Reaching

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Introduction

Dynamic equilibrium maintenance is a very complex process, involving interaction between visual, vestibular, proprioceptive and nervous systems [1]. Fluidity in systems' communication and actuation can be investigated with balance tests. The Functional Reach (FR) test [2] allows to evaluate the limits of stability in a self-perturbed situation. As the kinematic analogue of muscle synergies, kinematic synergies enable the study of coordinated control across multiple degrees of freedom (DoF) during dynamic balance tests [3]. The aim of this study is to extract kinematic synergies from kinematic data of young adults performing forward and lateral FR tests.

Methods

Fifteen healthy volunteers (6F; 27.5 ± 3,1 y.o.; 1.7 ± 0.1 m; 65.7 ± 9.0 kg) performed 10 repetitions of three reaching tasks: Unilateral and Bilateral Forward FR (moving the dominant arm or both arms in the sagittal plane), and Lateral Reach (moving the dominant arm in the frontal plane). A 3D motion capture system (9 cameras, VICON®, Oxford Metrics, Oxford, UK) recorded kinematic data applying a full PiG model. Kinematic synergies were extracted from 12 DoF: Non-Dominant (NDSh) and Dominant Shoulder (DSh) elevation plane angles; Spine (Sp_1 and Sp_2), Non-Dominant (NDH_1 and NDH_2) and Dominant Hip (DH_1 and DH_2) sagittal and frontal planes; as well as Non-Dominant (NDK_1) and Dominant Knee (DK_1), Non-Dominant (NDA_1) and Dominant Ankle (DA_1) sagittal plane. Synergies were extracted using the *SynergyAnalyzer Toolbox* [4] in MATLAB, applying Principal Component Analysis (PCA) and determining the number of synergies based on the R^2 error. For the same task, synergies were extracted individually, clustered across participants, and then averaged to obtain representative group-level patterns. Statistical analysis included the Shapiro-Wilk test for normality of synergies weights (W). Synergies were compared through repeated measures ANOVA for normally distributed data, and Friedman test for non-normal ones. Post-hoc comparisons included Bonferroni corrections.

Results

The overall kinematic synergies extracted are shown in **Fig. 1**. In W1, the Lateral Reach is primarily characterized by a positive component of shoulder elevation, whereas Unilateral and Bilateral FR are dominated by positive components in the sagittal plane at the hips. In contrast, W2 exhibits a positive component of shoulder/s elevation during Unilateral and Bilateral FR, and a positive component in the frontal plane at the spine during the Lateral reach.

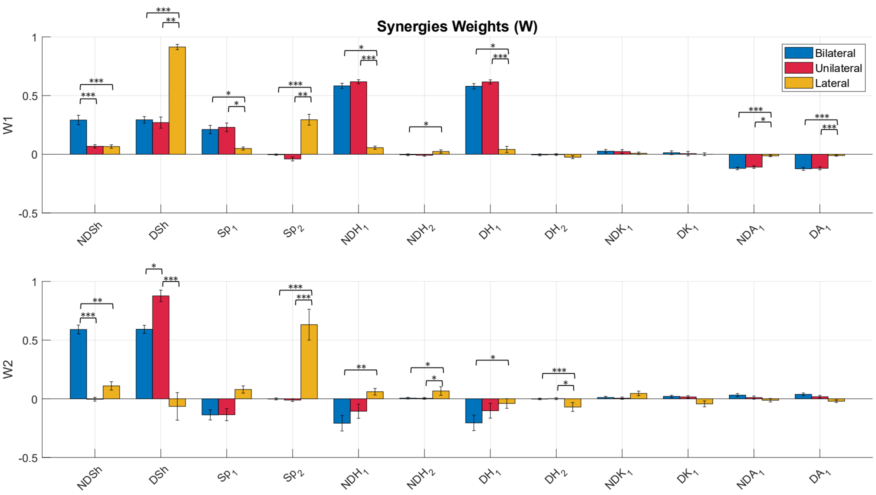

Fig.1 Synergies Weights (W) averaged across individuals (mean and SEM). Significant differences across tasks (*p<0.05; **p<0.01; ***p<0.001).

Discussion

Sagittal plane movements of forward FRs share the motor coordination, in addition to the weight of the unused arm for the Bilateral task. Conversely, FRs along different planes of motion induce specific biomechanical demands which, likely, entails distinct motor strategies.

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U-Turn detection from angular velocity: effects of device location

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Introduction

Remote smartphone-based assessment of motor capacity via structured tests such as six-minutes walking or a U-Turn test is gaining traction within clinical trials, especially in patients with neurodegenerative diseases [1]. One of the challenges of this unsupervised approach is that participants might not always follow the instructions given regarding the phone positioning, alternating across longitudinal observations among front or back pockets, belts, etc. This study presents and evaluates an algorithm for isolating turns within a five U-Turn test able to provide consistent results when applied to data from different devices and positions.

Methods

Ten healthy controls (Age: 21-31, BMI:18.3-22.9 kg/m2) performed two repetitions of a 5 U-Turn test consisting of walking five-steps and then performing a U-turn for five times consecutively. No instructions were provided in terms of turning directions (clockwise, CW, or counterclockwise, CCW) or strategy (pivoting versus following an arc trajectory). Triaxial accelerometer and gyroscope data were simultaneously collected from two smartphones (iPhone 12, 50Hz): iP_{FP} worn in the right front pocket and iP_{BE} worn over the lower back in a running belt. One IMU (INDIP [3], 100Hz) was worn in the right back pocket (IMU_{BP}) by 8 of the 10 participants. The Discrete Turn Algorithm [2], was applied to iP_{BE} data following its previously validated configuration [2]: a 0.8 Hz low-pass filter is applied to the angular velocity along the vertical axis (ω_z) to identify turns having peaks > |15| deg/s. The start/end of these turns is then detected by applying a 3 Hz low-pass filter to the original ω_z and identifying those instants when this filtered signal crosses a ± 5 deg/s threshold. For iP_{FP} and IMU_{BP} the frequency of the latter filter was instead set to 1.5Hz to account for the different patterns and level of noise in the signals (Figure1). The median turn duration (T), estimated using data from each device (T_{BE}, T_{FP}, T_{BP}) over the first four turns recorded in each trial, was used as an outcome measure for the test. A Wilcoxon signed-rank test was used to compare T data from different positions. Furthermore, the agreement between iP_{BE} and iP_{FP} and IMU_{BP} was assessed via a Bland Altman analysis in terms of bias and limits of agreement (LOA) of the individual turn durations estimate.

Results

The median turn duration over a trial was robust to the device positions (T_{BE}=2.27s±0.25s, T_{FP}=2.22s±0.28s, T_{BP}=2.24s±0.29s, Wilcoxon test: T_{BE} vs T_{FP} p=0.66, T_{BE} vs T_{BP} p=0.93). When isolating individual turns, more similar durations were observed between iP_{FP} and iP_{BE} in the CCW turns (n= 62, bias: 0.04s, LOA: [-0.50s, 0.59s]) than in the CW turns (n=26 Bias: -0.14 LOA: [-0.93, 0.64]). The estimates from IMU_{BP} showed similar bias as iP_{FP} for the CCW turns (n= 46, bias: 0.04s, LOA:[-0.46s, 0.54s]) with higher agreement in the CW turns (n= 18, bias: -0.06s, LOA: [-0.34s, 0.21s]).

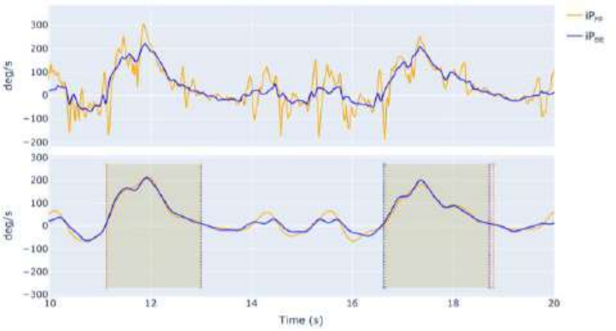

Figure 1: examples of filtered (A) and unfiltered (B) signals from the two phones. The grey bands in (B) represent the identified turns.

Discussion

These preliminary results suggest the feasibility of consistently estimating turn durations from devices worn on the lower back and in a trousers pocket. Further work is warranted to increase comparability in the estimates in both turning directions. More data from healthy controls and patients with PD are being collected to allow for this development and to confirm the generalizability of the reported results.

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Gait analysis methods in patients with spinal cord injury: a systematic review

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Introduction

A spinal cord injury (SCI) disrupts motor, sensory, and autonomic pathways, resulting in disability and decreased quality of life. The recovery of ambulation represents an utmost priority for SCI patients. Lower limb muscle strength, muscle tone, sensory input, and autonomic function are central factors to walking recovery [1]. Unlike conditions like stroke or cerebral palsy [2], little is known about the kinematic and kinetic characteristics of gait in persons with SCI. A better understanding of these biomechanical aspects is essential for designing and monitoring personalized rehabilitation strategies. Therefore, this systematic review aims to summarize the gait analysis tools and biomechanical parameters used in previous SCI research.

Methods

We included articles in English from inception through 1st May 2025 from five databases: PubMed/Medline, Embase, Web of Science, Scopus, and the Cochrane Library. A priori inclusion and exclusion criteria were defined according to the Population (P), Exposure (E), Comparison (C), Outcomes (O), and Study design (S) (PECOS) framework. Inclusion criteria were the following: P: Adult patients with spinal cord injury (men and women) able to walk independently and without aids; E: Gait analysis or gait measurements with computer-based tools; C: Healthy subjects; O: Gait parameters (spatiotemporal, kinematics, kinetics, sEMG); S: Review articles, case reports, key journals, conference proceedings, trials registers and book chapters. Exclusion criteria were the following: P: Adolescents (under 18 years of age), patients with other neurological diseases and spinal disorders that do not cause spinal cord injury; O: Gait parameters not measured with computer equipment; S: Review articles, case reports, key journals, conference proceedings, trial registers and book chapters. The methodological quality of the included studies was assessed and the Level of Evidence (LOE) score was determined using the 2011 Oxford Centre for Evidence-Based Medicine Levels of Evidence scale.

Results

The database research yielded 475 articles. After selection, 30 articles fulfilled the inclusion and exclusion criteria and were selected for further analysis. The methodological quality was high in 5 studies, fair in 16, and low in 9. Twenty-two studies were classified as LOE 2, while 8 studies were classified as LOE 3. Among selected studies, spatio-temporal parameters were the most frequently measured and reported variables (see Table1). In particular, gait speed emerged as the most frequently assessed parameter (n=22), followed by cadence (n=17), step length (n=15), step width (n=15), stride length (n=16), and double support time (n=15).

Table 1. The total count of biomechanical parameters.

Parameters	Total
Spatio-temporal	160
Kinematic	82
Kinetic	11
sEMG	28

Discussion

Gait speed emerged as the most frequently assessed parameter in SCI gait analysis, not solely for its clinical relevance but also for its practicality and ease of standardization. However, its predictive value for functional recovery is limited when considered alone. Kinetic measures and sEMG offer deeper insights into gait mechanics and muscle activation but require integration with spatio-temporal and functional outcomes to fully assess rehabilitation progress [3]. Instrumental gait analysis enhances the detection of subtle abnormalities and supports more precise, patient-specific interventions. This review is the first to systematically identify and evaluate biomechanical gait parameters specific to SCI, providing clues for optimizing assessment protocols in both clinical and research settings.

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Improving Orthopedic Patient Stratification Using Instrumented Timed Up and Go and Machine Learning Techniques

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Introduction

In orthopedic rehabilitation, timely assessment of functional mobility is essential to support clinical decision-making, individualize treatment, and optimize resource use. This is especially relevant after total knee (TKA) or hip arthroplasty (THA), where early recovery influences discharge planning and long-term outcomes [1]. While PROMs are widely adopted, they are subjective and may not capture actual performance [2]. Conversely, the Timed Up and Go (TUG) test provides an objective assessment of functional mobility but is limited by its reliance on total time alone. The introduction of wearable inertial measurement units enables the Instrumented TUG (iTUG), which segments the task and extracts detailed biomechanical metrics. These parameters have potential for patient stratification and prognosis, though their application in orthopedic settings remains limited. This study investigated whether selected iTUG-derived features can accurately classify patients with TKA, THA, or surgically treated hip fractures during inpatient rehabilitation, comparing their performance with stopwatch-based TUG and randomly selected variables through supervised machine learning.

Methods

Twenty-five iTUG metrics were selected based on our previous study, including walking, turning, sit-to-stand, and stand-to-sit transitions. To date, data were collected from 130 inpatients diagnosed with THA, TKA, or surgically treated femoral fractures. After a 70/30 train-test split, multiple classifiers (Random Forest, GBM, Logistic Regression, and LDA) were trained using 5-fold cross-validation. Performance was assessed via accuracy, F1-score, balanced accuracy, Mattew's correlation coefficient (MCC) and Receiver characteristics Area under the curve (ROC AUC). The best model was further analyzed using feature importance techniques to identify the most discriminative kinematic variables.

Results

Random Forest was the best model, achieving an accuracy of 0.68, F1-score of 0.67, balanced accuracy of 0.63 and ROC AUC of 0.76. GBM also performed well (accuracy: 0.68, F1-score: 0.65).

Table 1. Model Performance.

Model	Accuracy	F1 Score	MCC	ROC AUC
Random Forest	0.69	0.68	0.54	0.76
GBM	0.62	0.61	0.41	0.71
Logistic Regression	0.65	0.64	0.48	0.60
LDA	0.62	0.60	0.43	0.76

Traditional classifiers like LDA and Logistic Regression underperformed (~0.65 accuracy) compared to others. Stopwatch-based TUG time yielded an accuracy of only 0.51, confirming the added value of sensor-based metrics and dimensionality reduction. Feature importance analysis from the Random Forest model identified the "Range of the Medio-Lateral Angular Velocity during Walk" as the most discriminative variable, followed by other medio-lateral and antero-posterior kinematic features during walking and transition phases. Group-level analysis of this top-ranked feature revealed significantly higher medio-lateral angular variability in TKA patients compared to both THA ($p<.05$) and hip fracture groups ($p<.001$). These differences remained consistent when stratified by affected side (left vs. right), type of assistive device (crutches vs. walker), and turning direction, suggesting this metric captures robust diagnosis-specific postural control deficits.

Discussion

A structured subset of iTUG-derived variables significantly outperforms stopwatch TUG duration in classifying orthopedic diagnoses. The "Range of the Medio-Lateral Angular Velocity during Walk" appears to be a robust clinical marker of diagnostic group, particularly sensitive to the postural challenges of TKA. These findings support the integration of iTUG and machine learning into orthopedic rehabilitation path to enable more precise functional assessment and personalized care planning.

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Communicative accessibility and inclusive sports: the use of augmentative and alternative communication in baskin to promote participation and self-regulation in children and adolescents with complex communication needs (CCN)

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Introduction
Communicative accessibility is a fundamental right and a key element in promoting the participation and inclusion of individuals with Complex Communication Needs (CCN), particularly in recreational and sports contexts. In educational and social settings, Augmentative and Alternative Communication (AAC) aims to compensate for communication disabilities and facilitate interaction, expression of needs, and self-determination in individuals with impairments in speech, language, or comprehension. Baskin, an inclusive sport inspired by basketball and designed to allow participation of individuals with diverse abilities, provides a particularly suitable context for the implementation of AAC tools. This study explores the effectiveness of introducing symbolic AAC supports to enhance participation and self-regulation in children and adolescents with CCN within a Baskin program.

Methods
The intervention involved a group of sports professionals (secondary users) and a heterogeneous sample of children and young adults aged 6 to 19 years old, with diagnoses that range from autism spectrum disorder, intellectual developmental disorder, language disorder to genetic syndromes with communicative impairments. Customized AAC tools (visual schedules, behavioral rule charts, task analysis boards, and post-activity reflection books) were designed using the Pictoselector software and ARASAAC pictographic symbols. The perceived effectiveness of the intervention was measured using the IPPA (Individual Prioritised Problem Assessment), administered to the professionals before and after the introduction of the AAC supports, to assess changes in perceived difficulties during sports activities.

Results
Pre-intervention data revealed recurrent difficulties in several domains, including understanding and following game rules, turn-taking, emotional regulation, and comprehension of instructions. Following the implementation of AAC supports, a significant reduction in perceived difficulties was observed, particularly in areas related to participation, emotional regulation, and understanding of structured activities. The introduction of visual and symbolic supports facilitated comprehension, improved behavioral regulation, and supported transitions between different phases of the game, promoting greater autonomy and creating a more predictable and inclusive environment.

Discussion
The findings from this pilot study suggest that the integration of AAC tools in Baskin may be an effective approach to promote communicative accessibility, active participation, and self-regulation in children and adolescents with CCN. The approach demonstrated particular effectiveness in supporting emotional and behavioral regulation and improving understanding of game dynamics. However, the effectiveness of the intervention varied depending on individual profiles and the timing of support implementation. Some AAC tools were developed and adapted progressively in response to emerging needs during the course of the sports program. Limitations of the study include the absence of a control group, the small sample size, and the qualitative and subjective nature of the data collected. Further research is needed, involving larger samples, a broader range of settings, and evaluation tools directly accessible to participants with communication disabilities, in order to better understand and validate the impact of AAC in inclusive sports environments.

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Comparison of algorithms for stride width estimation using wearable-based methods in straight and curvilinear walking: validation on healthy controls

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Introduction

Stride width (SW) is a fundamental parameter in gait analysis, particularly useful for assessing postural control and fall risk [1]. Currently, SW is measured using in-lab instrumentation like stereophotogrammetry or instrumented mat, limiting out-of-lab and more complex analyses. Moreover, no existing methods have been validated in real-world scenarios involving trajectories more complex than simple straight walking. This preliminary work aims to assess and compare the performance of two different recent methods for SW estimation using wearable systems [2-3] during both straight and curvilinear paths, thus investigating the feasibility of their application to free-living walking analysis.

Methods

Five healthy subjects performed twice a 5-m straight path at three self-selected speeds (slow, comfortable, fast) and a 2-min walking test along a 4-m closed-loop path. Inertial sensors were fixed to the pelvis and feet, and infrared distance sensors to a single foot [2] (Figure 1a). SW was estimated through two different methods. Rossanigo et al. [2] (M1) estimated footprint poses during stance phases exploiting foot inertial data and inter-foot distances, and computed SW as the mediolateral distance between consecutive footprints. Wang at al. [3] (M2) implemented and made open-source available a LSTM RNN-based model to estimate SW from pelvis and shank inertial data. SW errors were computed as the difference between estimates from M1-M2 and the stereophotogrammetric gold standard data. Friedman test and pairwise comparisons were used to assess both methods during straight walking and turnings.

Results

A total of 873 strides width (371 in straight walking and 502 in turning) were analyzed (Figure 1).

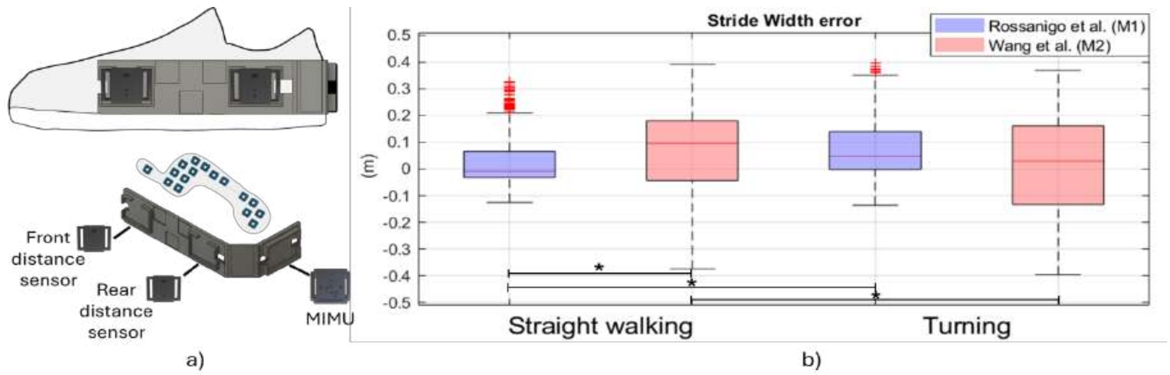

Figure 1. a) Foot-mounted wearable system; b) Comparison of SW errors for each wearable-based method and each walking condition. * Significant difference between SW error distributions ($p<0.05$).

Discussion

This study assessed the performance of two wearable-based methods for SW estimation in straight walking and turning. The performance of both methods was significantly affected by walking conditions ($p<0.05$). M1 significantly outperformed M2 in straight walking: median errors equal to 1 cm (6%) vs 9 cm (70%) ($p<0.05$) and provided more precise estimates (doubled error IQRs in straight and curvilinear walking using [3]). In conclusion, M1 is suggested as a promising and effective solution for SW estimation in free-living walking. It has to be underlined that the degradation of performance of M2 can be due to the adopted setup (foot-mounted inertial sensors instead of shank-mounted ones as in [3]) and to the fact that the LSTM model was not trained on curvilinear paths. Part of the project NODES, MUR – M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (ECS00000036 – CUP E13B22000020001).

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Predicting functional recovery after stroke through eeg connectivity analysis and machine learning approaches.

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Introduction

Stroke is a leading cause of long-term motor disability and dependency worldwide. The early post-stroke phase is a critical window for initiating targeted neurorehabilitation. However, outcomes vary widely even among patients with similar initial severity. Electroencephalography (EEG) offers a non-invasive, affordable solution with excellent temporal resolution. Functional connectivity metrics such as total coherence (TotCoh) and Small World (SW), when combined with artificial intelligence (AI), can provide valuable insights into the functional integrity of motor-related brain networks [1,2]. Here, we developed and validated an AI-based framework to classify stroke status, lesion side, and forecast recovery potential using EEG-derived features and baseline clinical evaluation.

Methods

We enrolled 127 patients with first-ever subacute ischemic stroke (<15 days post-onset) and 90 healthy controls matched for age and sex. All participants underwent resting-state EEG. EEG connectivity metrics (TotCoh and SW) were computed for each hemisphere across Delta (2–4 Hz), Theta (4–8 Hz), Alpha1 (8–10 Hz), Alpha2 (10–13 Hz), Beta1 (13–20 Hz), Beta2 (20–30 Hz), and Gamma (30–40 Hz) frequency bands. NIHSS was administered at baseline (T0) and after 40 days of standard rehabilitation (T1). Quadratic support vector machine (SVM) algorithms were developed to: (1) classify stroke patients vs controls (Healthy vs Stroke), (2) identify the side of the lesion (Left vs Right Hemisphere), and (3) predict functional recovery. EEG features from the affected and unaffected hemispheres, alongside clinical severity at admission (NIHSS0) for the latter, were used. A forward feature selection procedure optimized classifier inputs. All models were validated on an independent sample of 26 individuals (12 controls, 14 stroke patients).

Results

After feature selection, each classifier retained a minimal yet highly informative set of EEG connectivity features. Stroke detection relied mainly on TotCoh values in the right hemisphere across Delta, Theta, and Gamma bands. Lesion lateralization was best captured by right hemisphere Theta TotCoh and SW indices from both hemispheres, highlighting interhemispheric asymmetries. For recovery prediction, the most relevant features included baseline NIHSS, TotCoh in Beta2 and Gamma bands, and SW in Delta and Alpha2 bands within the affected hemisphere, reflecting motor network integrity and plasticity potential. With these selected features, model performance improved substantially. The Healthy vs Stroke classifier reached 99.1% accuracy (100% sensitivity, 98.5% specificity, AUC = 0.99), the Lesion Side classifier reached 86.8% accuracy (91.4% sensitivity, 80.3% specificity, AUC = 0.87), and the Functional Recovery Prediction achieved 94.8% accuracy (96.3% sensitivity, 92.3% specificity, AUC = 0.95). Notably, in patients with moderate-to-severe symptoms (n=38), the recovery prediction model maintained excellent performance (accuracy = 89.2%, AUC = 0.90). The validation results strongly confirmed the generalizability of our approach, reaching high performances in all of the three tasks.

Discussion

Our findings confirm the utility of EEG-based functional connectivity as a reliable, early biomarker of motor recovery potential in subacute stroke. These findings highlight the robustness of the approach and the clinical relevance of the selected connectivity features, particularly those in the beta and alpha frequency ranges, which are tightly linked to motor function and plasticity mechanisms. The AI-driven approach allowed the development of accurate and interpretable models, easily applicable in clinical settings. By leveraging the neurophysiological fingerprints of motor network reorganization, this study highlights a clinically viable method for stratifying stroke patients based on expected recovery, thus promoting a shift toward precision neurorehabilitation.

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An automatic approach for estimating stride length at different running speeds using foot-mounted inertial sensors

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Introduction

Running stride length (SL) is a fundamental parameter linked to injury risk and recovery. Its computation in-the-field commonly requires determining foot accelerations by subtracting the gravity vector projection from the accelerations recorded by an inertial measurement unit (IMU) through ad hoc methods, whose parameter(s) setting is usually affected by speed variations [1]. To avoid parameter(s) adjustment and to expand the applicability of inertial-based methods to sport with variable stride speeds, this study aimed to compare different methods for the selection of orientation estimation parameter(s) and to propose an automatic speed-independent method to estimate SL across 8-30 km/h.

Methods

Thirty runners were enrolled (dataset A: 400-m trials at 8 and 10 km/h, dataset B: trials at 14 km/h with stereophotogrammetric system as reference, and dataset C: sprints at 19-30 km/h with labelled videos as reference) and instrumented with an IMU on to the instep of each foot (fs = 100 Hz for A and 200 Hz for B and C). SL was computed through the double integration of foot acceleration between two consecutive contacts with the ground. The latter instants were derived using a threshold-free template-based approach [1-2]. To remove the gravity contribution, foot orientation was estimated using Madgwick's method relying on a single parameter (β) [3]. Two different approaches to set β were investigated. β was fine-tuned minimizing SL errors to find a constant trade-off β suitable for all analyzed speeds (method M1). To explore the potential of stride-by-stride parameter adjustment, optimal stride-by-stride β setting was investigated first by minimizing each SL error. Then, β was automatically selected stride-by-stride using an optimization framework imposing constraints of running cyclicity (null foot velocity at each integration instant) and horizontality (constant vertical foot displacement at each integration instant) (M2). A one-way ANOVA with Bonferroni correction was performed on SL error distributions to assess the effect of speed, of used approach for β selection, and of changing β values.

Results

More than 56,000 SL errors were computed. SL errors were significantly affected by changes in β ($p < 0.05$) and a suitable trade-off β was 0.29-0.36 rad/s across speeds. Adjusting β stride-by-stride minimizing each SL error halved SL errors up to 14 km/h with respect to M1 ($p < 0.05$). Results obtained using β=0.3 rad/s (M1) and automatically stride-by-stride selected β (M2) are reported in Table 1.

Table 1. SL percentual errors (mean±std) at different speeds and using methods M1-M2 for β selection.

Dataset (Speed)	Stride length errors (%)	
	Fixed tuned β (M1)	Stride-specific β (M2)
A (8-10 km/h)	2.8 ± 1.3	5.1 ± 6.5
B (14 km/h)	3.2 ± 1.5	4.9 ± 2.2
C (19-30 km/h)	11.8 ± 4.4	12.4 ± 7.0

Discussion

This study highlighted the importance of stride-by-stride parameter setting in inertial-based methods for SL estimation during running: stride-specific selection of the optimal orientation estimation parameter β significantly outperformed the use of an optimal fixed β value (M1) ($p < 0.05$). Furthermore, a completely automatic method despite the speed (M2) was proposed. SL errors achieved with both M1-M2 were speed-independent, ranging between ~3-5%, at 8-14 km/h ($p > 0.05$). M2 provided comparable or slightly worse performance than M1 ($p > 0.05$), but without tuning any parameter, which is time-consuming and often needs a reference, thus being suggested in running at variable speed. The significant degradation in performance in sprinting ($p < 0.05$) was due to the adopted fs (200 Hz). This study was funded, in part, by Diadora S.p.A.

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Gait alterations in post-stroke patients: the impact of type of stroke, lesion location, cognitive and language impairments

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Introduction

Stroke, a cerebrovascular event caused by arterial blockage (ischaemic) or vessel rupture (haemorrhagic), leads to neuronal damage and functional deficits due to reduced oxygen and nutrient supply to brain tissue. The clinical impact varies depending on which part of the brain is affected: lesions in the left hemisphere may result in language impairments such as aphasia, as well as impairment of the right side of the body, while lesions in the right hemisphere can cause neglect, visuospatial deficits, and problems on the left side of the body. Stroke often impairs walking ability through compromised muscle control, coordination and balance, resulting in altered gait patterns While many individuals regain the ability to walk, their gait remains abnormal, which affects their quality of life. This study aims to quantitatively analyse gait alterations in relation to stroke type and lesion location, and investigate whether cognitive impairments or language disorders affect gait parameters differently.

Methods

Twenty-eight stroke patients (mean age: 59.5 ± 13.7 years; 11 females) were analysed: 10 haemorrhagic and 18 ischaemic; 16 with left and 12 with right hemisphere lesions. 9 had aphasia and 10 cognitive impairments. Kinematic analysis was conducted using the Mobility Lab system (APDM Inc., Portland, OR, USA;) 0 and the ISAW protocol, which involved placing three inertial sensors on the lower back and both feet. The normality of the data was assessed using the Shapiro–Wilk test. To examine how lesion location, stroke type and cognitive impairment and language disorders influence gait parameters, the Kruskal–Wallis test was applied to non-normally distributed data.

Results

Table 1 shows the results, descriptive statistics and Kruskal–Wallis results in terms of p-values.

Table 1 Results of the statistical analysis.

Condition	Parameters	Mean±Std		P-Value
		Right	Left	
Site of Lesion	APA Peak ML (g)	0.0401±0.0181	0.0246±0.0161	0,0117 (*)
		Not compromised	Aphasic	
Not compromised vs aphasic	Gait Stride Length L [Mean] (%stature)	79.8±6.81	59.9±19.4	0.0269 (*)
	Gait Stride Length R [Mean] (%stature)	79.1±6.70	58.5±20.2	0.0269 (*)
	APA First Step Length (degrees)	40.8±7.51	27.3±7.78	0.00457 (**)
	Turn Duration [Mean] (seconds)	3.12±0.70	5.90±3.02	0.0305 (*)
	Turn Number Of Steps Mean	5.33±1.52	8.62±2.64	0.0115 (*)
		Not compromised	Cognitive disorders	
Not compromised vs cognitive disorders	APA Peak AP (g)	0.0562±0.0282	0.0335±0.0161	0.0410 (*)
	APA First Step Length (degrees)	40.8±7.51	32.0±7.35	0.0263 (*)

ns: p-value>0.05; *: 0.01<p-value<0.05; **: 0001<p-value<0.01; ***: p-value<0.001.

Discussion

The Kruskal–Wallis analysis revealed several significant motor differences between the clinical groups. No differences emerged between stroke types. Individuals with right hemisphere lesions showed higher APA Peak ML values, suggesting altered lateral postural control, consistent with the right hemisphere's key role in balance, spatial attention, and body awareness. Aphasic patients, typically with left hemisphere damage, showed shorter stride lengths, reduced first step angles, and increased difficulty turning, indicating impaired motor planning beyond language dysfunction. Similarly, patients with cognitive impairments exhibited lower APA peak values in the antero-posterior direction and shorter first steps, reflecting difficulties in movement initiation and suggesting cautious, compensatory gait strategies linked to reduced executive and postural control.

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Stride width in laboratory versus real-world walking: preliminary evidence in people with multiple sclerosis and healthy controls

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Introduction

Stride width (SW) has been observed to correlate with severity of multiple sclerosis (MS) [1]. Accurate estimation of SW requires simultaneous knowledge of both feet's positions to determine their mediolateral distance [2]. Thus, SW is mainly assessed in laboratory settings using motion capture systems, limiting its evaluation in the real-world and during motor tasks more complex than straight walking. This study aimed to monitor SW using a novel, validated wearable system [2] in both healthy subjects (HS) and people with MS (pwMS) during a structured clinical in-lab test, in-lab simulation of daily activities, and in the real-world, and to preliminarily explore how different contexts influence SW.

Methods

Five HS and five patients with mild to moderate MS (EDSS=1-6) performed 1) a 2-min walking test (2MWT) along a 4-m closed-loop path, 2) an in-lab simulation of daily activities (SDA) including curvilinear walking, setting a table for a meal, and picking up objects from the floor, and 3) a 2.5-h unsupervised free-living session. Participants wore a wearable system, based on inertial and infrared sensors, designed and validated to estimate SW through a dedicated method [2]. To evaluate the impact of walking condition (2MWT, SDA, and free-living) and groups (HS vs pwMS) on SW, a linear mixed-effects model (LME) was employed, with walking condition and its interaction with participant group specified as fixed effects, and participant included as a random intercept.

Results

Over 4050 and 570 SWs were computed in HS and pwMS, respectively, and their distributions across walking conditions are reported in Figure 1, along with individual SW trends.

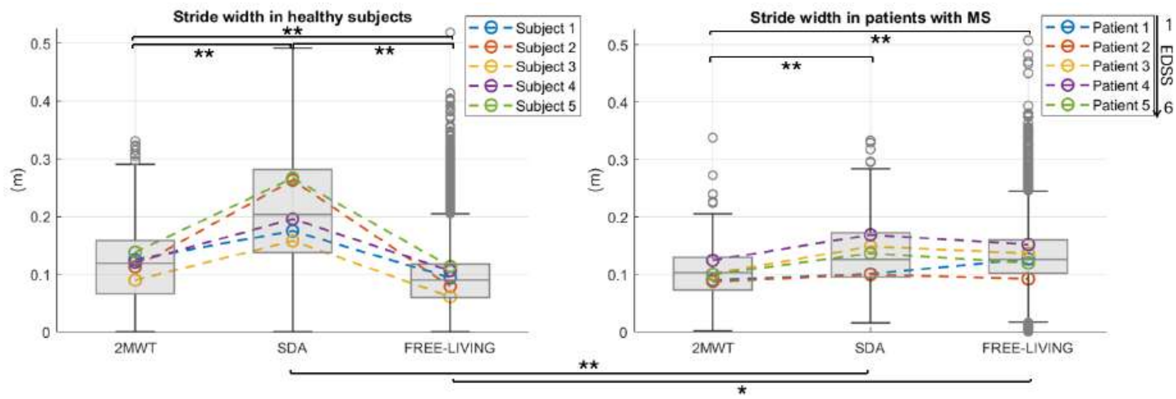

Figure 1. SW in HS (left) and MS (right) across different walking conditions. * p < 0.05; ** p < 0.001.

Discussion

Walking conditions significantly influenced SW in both groups ($p < 0.001$): all HS and pwMS showed narrower SW during 2MWT compared to SDA ($p < 0.001$). While HS and pwMS had comparable SW during 2MWT ($p > 0.05$), pwMS showed a narrower and less variable SW than HS during SDA ($p < 0.001$), and a wider SW during free-living ($p < 0.001$). These preliminary findings suggest that pwMS may have reduced ability to modulate SW with task demands. In contrast, HS adjusted SW in SDA, reflecting greater gait flexibility. Results in free-living support the idea that the more efficient gait of HS can rely on a narrower SW than the more unstable gait of pwMS. Structured tests (e.g., 2MWT) may not fully capture gait variability or group differences seen in more ecological settings, highlighting the value of context-sensitive assessments. Part of the project NODES, MUR – M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (ECS00000036 – CUP E13B22000020001).

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Uncovering Terrain-Induced Instabilities in Parkinson's Disease with Wearable Sensors

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Introduction

Falls are a major health concern among the elderly, with one-third experiencing at least one fall annually. Of these, up to 50% suffer recurrent falls, and 10–20% result in serious injuries, including fractures (2–6%). Beyond physical harm, 19% of older adults who fall subsequently avoid daily activities, leading to reduced autonomy and quality of life [1]. Current clinical assessments of gait stability and fall risk are predominantly based on subjective measures, including the Timed Up and Go (TUG), the Tinetti Test, and the Berg Balance Scale. [2,3]. These methods are limited by their dependence on the clinician's expertise. Despite the good inter-rater and test-retest reliability reported by studies such as Faber et al. [4], the predictive validity of these assessments remains limited, with sensitivity and specificity ranging between 62.5% and 66.1%, respectively. Moreover, traditional assessments are typically conducted in controlled environments, which do not reflect real-world conditions. In this sense, Li et al. found that approximately 73% of falls occur outdoors on uneven surfaces [5], underscoring the need to evaluate gait stability under disturbed conditions. The Spanish project NEUROMARK investigated objective and ecological tools to assess gait stability in vulnerable populations such as older adults and individuals with Parkinson's disease (PD).

Methods

We analyzed gait under ecological conditions to comprehensively capture the motor symptoms experienced by patients in their daily lives. Kinematic gait data were collected from 83 participants: 41 individuals with PD (27M/14F, 67.1 ± 8.6 years) and 42 age-matched healthy controls (18M/24F, 66.9 ± 7.8 years). Participants walked over four different terrains: flat, soft, irregular, and unstructured, while wearing 17 inertial sensors (Xsens MVN, Movella, Netherlands) configured according to MVN Analyze full-body biomechanical model. We evaluated gait stability using the anteroposterior Margin of Stability (MoS_{AP}) at three key points in the gait cycle: heel strike, swing phase, and toe-off. Additionally, we examined the arm swing, a critical component of balance and postural control.

Results

Individuals with PD demonstrated greater gait instability compared to controls—especially during heel strike and swing phase on flat ground, during swing phase on soft surfaces, and throughout all key gait phases on irregular and unstructured terrains. Furthermore, an asymmetrical reduction in arm swing was noted on flat terrain, evolving into a more symmetrical but accentuated pattern on irregular terrain.

Discussion

Our findings emphasize the critical role of irregular terrains in revealing gait instability, particularly in individuals with PD. Compared to flat or soft surfaces, these terrains consistently led to greater instability. Changes in arm swing further reflected the elevated motor demands of uneven terrain. Moreover, surface instability may contribute to increased muscular stiffness, potentially reducing arm swing on the less affected side in individuals with PD. This may explain the observed arm swing symmetry on irregular terrains, which appears to result not from improved function on the more affected side, but from a compensatory reduction on the less affected side. This highlights the importance of evaluating gait in conditions resembling real-life environments, where most falls occur. By using a full-body inertial sensor setup, we objectively measured subtle gait alterations that traditional clinical tests might overlook. These results demonstrate that assessing patients on irregular terrains yields a more precise and meaningful evaluation of gait stability and fall risk, offering valuable insights that can enhance diagnostic accuracy and guide more effective rehabilitation strategies in aging and PD.

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Towards MobGap 1.0, a computational pipeline for real-world digital mobility assessment: Technical Validation across different patient cohorts

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Introduction

The Mobilise-D project has developed and technically validated a computational pipeline for estimating digital mobility outcomes (DMOs) from wearable sensor data [1]. Mainly implemented in MATLAB, these algorithms were recently re-implemented in Python and released as MobGap, an open-source toolbox aiming to support broader accessibility and long-term sustainability [2]. This study presents the full validation of MobGap on the entire Mobilise-D Technical Validation Study (TVS) dataset and compares its performance to the original implementation.

Methods

Data from 101 participants from a range of patient groups and healthy controls were analyzed with MobGap. The dataset comprised data from a single wearable device at the low back and a multisensor reference system [4] during a range of walking tasks in laboratory and free-living settings [3]. MobGap's performance was compared to that of the original implementation. Validation metrics included the absolute relative error |ΔE| and intraclass correlation coefficient (ICC) for several DMOs. For the sake of brevity, results are reported for walking speed only - being the final and most relevant primary DMO derived from DMOs estimated earlier in the pipeline (e.g., initial contacts, cadence, stride length).

Results

In free-living settings, MobGap performance consistently outperformed the original implementation, showing lower |ΔE| (10.4 - 34.1%) and higher ICCs (0.42 - 0.65) for walking speed estimation. In laboratory settings, MobGap matched or exceeded the original performance in most cohorts (|ΔE|: 12.5 - 22.7%, ICC: 0.63 - 0.89). Notably, MobGap exceeded the predefined Mobilise-D validation thresholds (|ΔE| < 20%, ICC > 0.7) in nearly all laboratory conditions and demonstrated improved robustness in free-living contexts (Table 1).

Table 1. Absolute relative error (%) and ICC for walking speed estimated by MobGap and the original implementation across all TVS cohorts in both free-living and laboratory conditions. Results refer to aggregated performance, i.e., median estimated VS reference walking speed.

		HA		CHF		COPD		MS		PD		PFF	
		|ΔE|	ICC	|ΔE|	ICC	|ΔE|	ICC	|ΔE|	ICC	|ΔE|	ICC	|ΔE|	ICC
Free-living	MobGap	**10.4**	**0.65**	**16.5**	**0.61**	**15.9**	**0.63**	**20.8**	**0.42**	**29.3**	**0.63**	**34.1**	**0.62**
	Original	16.9	0.45	32.2	0.52	21.1	0.49	28.0	0.27	38.3	0.49	47.7	0.47
Lab	MobGap	13.6	**0.76**	**13.5**	0.74	12.7	0.63	**12.5**	**0.88**	**13.8**	**0.88**	**22.7**	**0.89**
	Original	**12.9**	0.74	13.8	**0.83**	**10.9**	**0.74**	14.7	0.84	16.2	0.83	30.4	0.83

HA: Healthy Adults; CHF: Congestive Heart Failure; COPD: Chronic Obstructive Pulmonary Disease; MS: Multiple

Discussion

MobGap consistently matched or outperformed the original implementation across diverse clinical cohorts, particularly in challenging free-living conditions. Combined with its scalability and open-source nature, these results position MobGap as the new benchmark for digital mobility assessment. Some limitations remain: in a few cases, especially under free-living conditions, ICC values fell below the 0.7 threshold, suggesting room for improvement in algorithm tuning or preprocessing. The official release of MobGap 1.0, incorporating the validated implementation, is planned by July 2025 and will represent a key milestone for the Mobilise-D initiative, promoting reproducibility and accessibility in gait analysis.

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Non-invasive follow up of AIS using AI and 3D surface analysis with INBODY 3D scanner

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Introduction

Adolescent Idiopathic Scoliosis (AIS) is a 3D spinal deformity that emerges in early adolescence, involving lateral curvature and vertebral rotation. If left untreated, progressive curves can lead to chronic pain, reduced lung function, and disability in up to 25% of cases [1]. Beyond radiographic signs, AIS affects posture and movement: patients often display postural asymmetries, slower gait with shorter stride length, and altered muscle activation in the trunk and legs [2]. Monitoring progression is essential, but repeated radiographs raise concerns about cumulative radiation. The INBODY Instant Body Scan™ by BEYONDSHAPE [3] is a full-body 3D photogrammetric scanner that captures external morphology instantly. It generates high-resolution surface models, enabling precise, radiation-free assessment of trunk asymmetries. This approach enables customized orthopedic device design and ensures consistent, non-invasive follow-up of scoliosis, enhancing the ability to monitor changes in spinal morphology and postural balance throughout the course of treatment. We present a study protocol to assess the usability and acceptability of the INBODY system, with the aim of improving AIS management while reducing dependence on radiographic imaging.

Methods

The study consists of two phases: (1) development of a 3D analysis and clinical decision support pipeline; (2) validation of the protocol and clinical evaluation. In phase 1, a method will be created to analyze 3D reconstructions of the torso and describe trunk deformities across three planes, enabling follow-up of AIS progression. The INBODY Instant Body Scan™ by BEYONDSHAPE [3], a full-body 3D photogrammetric scanner, will be used to acquire high-resolution scans. An AI-based approach combined with shape analysis will be used to extract the external back morphology and calculate clinically relevant indices. Clinicians will use the 3D models and these indices to design the most suitable spinal orthosis for each patient. A clinical advisor will support the testing and evaluation of the overall protocol. In phase 2, the protocol will be validated using frontal and sagittal radiographic images as ground truth. Medical professionals will be involved to assess the reliability and clinical effectiveness of the entire process.

Results

3D shape-derived parameters were compared with those obtained from frontal and sagittal radiographs, used as ground truth. The mean error in thoracic Cobb angle estimation was 0.46°, and 1.9° for the lumbar region. Additionally, the average error for kyphosis and lordosis angle measurements was 3.31° and 3.21°, respectively. Using the 3D models and quantitative indices derived from shape analysis, more than 400 personalized spinal orthoses have been developed to support the clinical treatment of AIS.

Discussion

The Shape-based estimations of spinal alignment showed strong agreement with radiographic measurements. In particular, thoracic and lumbar Cobb angle errors remained low (0.46° and 1.9°, respectively), supporting the method's reliability for clinical use. Kyphosis and lordosis evaluations also demonstrated accurate results, reinforcing the value of surface-based without radiation. The INBODY Instant Body Scan™ [3] enabled rapid and precise 3D acquisition of body morphology. Clinician involvement ensured that the protocol meets real-world needs, confirming its potential as a decision-support tool for non-invasive scoliosis monitoring.

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Automatic recognition of smartphone location with machine learning for real-world gait analysis

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Introduction

Smartphones are increasingly used in human activity recognition and gait analysis due to their widespread availability, user-friendliness and embedded inertial sensors [1]. However, in daily life, smartphones can be carried in various body locations (e.g., pockets, bags, hand), which can change dynamically over time. This variability introduces changes in the inertial signals, potentially compromising the reliability of mobility metrics derived from these data [2]. To address this, we developed and evaluated supervised machine learning models to automatically recognize the smartphone's body location during walking.

Methods

Fifteen healthy subjects (67% male, aged 22-57 years) performed indoor gait tasks and participated in a 2.5-hour free-living acquisition. Each subject wore: a) the multi-sensor system INDIP [3] used as a reference to derive walking intervals, b) six Android 10 smartphones placed simultaneously at six locations: Lower-Back, Coat Pocket, Hand-Held, Shoulder Bag, trouser Back and Front Pocket. All devices sampled at 100 Hz. Inertial data recorded by each smartphone during walking intervals were used to derive 15 features in time (e.g., mean) and frequency domains (e.g., peak frequency). These data were used to train and test five classification models—Random Forest, Decision Tree, XGBoost, Artificial Neural Network, and Logistic Regression—across three tasks: (i) 6-class classification, (ii) 5-class classification after merging Back Pocket and Front Pocket into a single class, and (iii) binary classification (Lower-Back against all other positions). All models were evaluated using 5-fold cross-validation, and performance was assessed using balanced accuracy and per-class recall.

Results

In all tasks, XGBoost outperformed the other models, achieving average accuracy values of 0.67, 0.73 and 0.94 for the task with two, five and six classes, respectively. For XGBoost, Lower-Back was consistently the most accurately recognized class (recall >0.90), while Coat and trouser pocket-related classes showed lower performance (Table 1). Merging Back Pocket and Front Pocket into a single class to reduce misclassification of trouser pocket locations led to a modest improvement in performance for the new pocket class (recall rising from 0.57 to 0.76), while Coat Pocket remained the most challenging class (recall: 0.47). In the binary task, XGBoost achieved excellent performance (Lower-Back recall: 0.98), confirming that the lower-back produces highly distinctive inertial patterns.

Table 1. (A) Per-class recall of the best model (XGBoost) across the three tasks. Results are reported as mean ± standard deviation.

<table>
<tr><th></th><th>6-classes</th><th>5-classes</th><th>2-classes</th></tr>
<tr><th>Lower-Back</th><td>0.91 ± 0.05</td><td>0.92 ± 0.02</td><td>0.98 ± 0.00</td></tr>
<tr><th>Coat Pocket</th><td>0.47 ± 0.09</td><td>0.47 ± 0.11</td><td rowspan="5">0.90 ± 0.06</td></tr>
<tr><th>Hand-Held</th><td>0.73 ± 0.12</td><td>0.74 ± 0.11</td></tr>
<tr><th>Shoulder Bag</th><td>0.80 ± 0.09</td><td>0.80 ± 0.13</td></tr>
<tr><th>Back Pocket</th><td>0.55 ± 0.18</td><td rowspan="2">0.76 ± 0.04</td></tr>
<tr><th>Front Pocket</th><td>0.57 ± 0.19</td></tr>
</table>

Discussion

The proposed framework demonstrates the feasibility of accurately detecting smartphone placement during gait, particularly when class overlap is minimized. These findings support its use as a preprocessing step in smartphone-based gait analysis systems. Although based on a limited number of participants (n=15) with similar demographics, the dataset included over 100,000 gait cycles from long (2.5 h) recordings, providing robust input for model training. Future work should explore whether frequent changes in phone position, as might occur in daily life, could impact classification performance.

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Exploring correlates between EEG brain network connectivity and postural sway during an eyes-closed balance task

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Introduction

Posturography is a diagnostic technique employed to evaluate human balance and postural stability, mainly evaluating the center of pressure (CoP) variability during quiet stance. Nevertheless, posturography has some limitations since not directly capture the underlying neurological mechanisms that contribute to human balance and postural stability. The simultaneous acquisition of postural sway data and electroencephalographic (EEG) signals can offer a more comprehensive view of this multi-level mechanism at the base of postural control [1]. Hence, this study aims to investigate the interaction between brain organisation at the cortical level and the actual mechanism of postural stability by correlating global network graph theory (NGT) features derived from EEG signals with postural sway parameters, calculated from the stabilogram in the acceleration domain.

Methods

Ten healthy volunteers (5 males and 5 females) performed an eyes-closed postural sway task while standing on a stable surface for 30 seconds. Three postural sway parameters (jerk, path length, and range) were acquired by using a single inertial measurement unit placed on the lower back and computed using the Mobility Lab system (APDM, USA). EEG signals were simultaneously recorded using a 64-channel EEG cap (Brain Products, Germany) and then preprocessed to perform source reconstruction using minimum-norm estimation method. By resorting to the 100-Schaefer atlas, a 100 x 100 functional connectivity matrix was estimated for each subject, applying the Phase Locking Value as statistical coupling method and then thresholding at 10% to avoid spurious connections. Four NGT metrics were extracted from the functional connectivity matrices: clustering coefficient (CC), global efficiency (GE), participation (P), and assortativity (R). Pairwise relationships between sway parameters and EEG-based NGT metrics were evaluated using Spearman's rank correlation.

Results

In Table 1, the Spearman correlation coefficients between postural sway parameters and EEG-based NGT metrics are reported, and statistically significant values (p-value < 0.05) are reported in bold.

Table 1. Spearman's correlation coefficient between postural sway and EEG-derived NGT metrics

	CC	**GE**	**P**	**R**
Jerk	0.219	**-0.669**	0.055	**0.827**
Path length	0.334	-0.456	0.085	**0.705**
Range	0.624	0.272	0.224	0.636

Discussion

As shown in Table 1, positive correlations emerged between the R and the path length (ρ = 0.705) and the jerk (ρ = 0.827), while the GE negatively correlated with range (ρ = - 0.669). Even when other external stimuli are absent, such as in the case of the eye-closed condition, an adequate and long-lasting balance condition should be associated with a reduced CoP excursion (small path length values) and limited variation of CoP acceleration (small jerk values) [2]. On the other hand, an increased GE indicates that the brain efficiently transmits and elaborates information, whereby an increased R indicates that it continuously adapts the functional topology to respond to the external stimuli [3]. Thus, the negative correlation suggests that an efficient brain rapidly provides an appropriate postural control mechanism, determining better stability over time, as indicated by the reduced jerk values. By contrast, the positive correlations suggest that the brain has to continuously adapt the functional organisation during the task, being able to explore different balance conditions, as indicated by the higher path length and jerk values, before selecting the more appropriate postural control strategy.

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Preserving functional autonomy in multiple sclerosis through adapted physical activity: preliminary data

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Introduction
Adaptive Physical Activity (APA) has a central role in the management and maintenance of quality of life in subjects with Multiple Sclerosis (SwMS). Several studies have already highlighted the importance of this kind of intervention [1, 2]. Aim of this study was to test the effectiveness of an APA program to preserve function in subjects with MS.

Methods
The intervention was carried out in collaboration with the patients' association (i.e., AISM). The APA program lasted ten months, but the presented data refers only to the first 4 months. The intervention consisted of biweekly, 50-minute APA sessions tailored to individual abilities. Subjects were assessed before starting the APA program (T0), and at four moths (T1), through clinical outcome measures (i.e., handgrip strength, Arm Curl Test, 30s Sit-to-Stand, Chair Sit and Reach, and Back Scratch) and functional tests (i.e., 6-minute walking test, Time Up&Go, and 7-Meters walking test) performed with an IMU (G Sensor, BTS Bioengineering), positioned at the sacral level, to analyse gait spatio-temporal parameters. We performed the statistical analysis with RStudio (ver. 4.4.0).

Results
In this preliminary study, we recruited 22 SwMS (age: 62.50±15.22, EDSS level: 4.45±2.26). None of the considered parameters showed a significant decrease in the period considered. Instead, some outcomes significantly improved, as shown in Table 1. Concerning the analysis of gait spatio-temporal parameters, no substantial changes were observed in the intervention period.

Table 1. Outcomes that showed a significant improvement in the four-month period.

Outcomes	T0 Median [I Qrt – III Qrt]	T1 Median [I Qrt – III Qrt]	P Value
Arm Curl test right	18.50 (15.00 - 24.00)	22.00 (18.25 - 28.50)	0.001
Arm Curl test left	18.00 (15.0 - 26.0)	22.00 (18.0 - 30.0)	0.009
Sit to stand	9.00 (4.50 - 12.00)	10.00 (6.00 - 12.25)	0.039
Sit and reach right	-16.00 (-29.0 - -8.0)	-14.00 (-20.0 - -2.0)	0.011
Sit and reach left	-19.00 (-30.0 - -7.0)	-13.00 (-19.0 - 0.0)	0.006
Time Up&Go	13.65 (11.29 - 28.13)	13.11 (9.49 - 20.29)	0.015
6 Minute Walking test	205.60 (118.05 - 395.85)	214.50 (133.45 - 415.60)	0.001

Discussion
This preliminary study shows that a four-month APA program improves autonomous walking ability, lower limb muscular endurance, aerobic endurance, functional mobility, and walking distance in SwMS, with no deterioration in clinical parameters. Although no significant changes were observed in spatio-temporal gait parameters during the intervention, APA proves effective in maintaining motor function. Further analyses in the coming months will clarify the long-term effects.

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Analysis and comparison of kinematic and dynamic changes in subjects with hemiparesis and spastic hypertonia after transition from solid AFO to AFO-Botter

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Introduction

In pediatric and young adult patients who have developed hemiparesis with spastic hypertonia of congenital or acquired origin, Ankle-Foot Orthoses (AFOs) are fundamental for restoring functional independence. AFOs can have diverse characteristics and address various functional deficits (e.g., equinus foot due to weakness/spastic hypertonia), ankle/foot instability, and knee flexion-extension. Recent advancements in orthotic design aim to provide not only corrective tools but also personalized, dynamic devices that contribute to optimizing patient movement. The AFO-Botter dynamic orthosis, made of carbon fiber, leverages its inherent flexibility and lightness. This design optimizes biomechanical control of the foot, ankle, and knee, thereby improving the push-off phase of gait [1, 2, 3].

Methods

This preliminary study aims to evaluate and compare the kinematic and dynamic gait parameters in patients with hemiparesis and spastic hypertonia of the triceps surae, at the time of transition from a solid AFO to the AFO-Botter dynamic orthosis.

Results

In this preliminary phase, we present data collected from two patients already enrolled in the study, both of whom underwent Instrumented Gait Analysis (IGA) under two conditions: initially with conventional ankle-foot orthoses (AFOs), and subsequently with AFO-Botter orthoses.

Discussion

The main data from the kinematic, electromyographic and dynamic analysis comparing the two conditions will be reported.

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Visual clustering for video inclusion in automated General Movement Assessment: evaluation of dataset robustness

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Introduction

General Movement Assessment (GMA) is a validated, non-invasive approach for early identification of neurodevelopmental disorders [1]. Its broader application is limited by the need for certified evaluators, subjectivity, and time-consuming procedures [2]. To address these limitations, various automated, video-based solutions have been proposed [3]. State-of-the-art pose estimation tools based on convolutional neural networks (e.g., OpenPose, AlphaPose, DeepLabCut) require a robust training-set to extract accurate trajectories. This work introduces a protocol designed to determine, prior to network inference, whether a newly recorded video needs manual annotation or can be processed using the existing model to optimize dataset expansion and reduce annotation workload.

Methods

GM videos (GoPro Hero 9, 240 fps, 1920x1080p) of 116 very preterm infants were recorded at 40 weeks and 3 months of corrected age. A subset of 15-50 frames per video (selection via k-means) was manually annotated using a 14-point scheme and used to train a DeepLabCut network. To characterize the training-set (Figure 1), all annotated frames underwent white balance correction, blue channel suppression, and color normalization. Infants were segmented with DeepLabV3 (pre-trained on COCO dataset), refined through GrabCut and morphological operations to remove background artifacts. From the resulting masks, Histogram of Oriented Gradient (HOG) features were extracted and clustered into 32 groups using k-means, as in DeepLabCut pipeline. The same procedure was applied to 31 newly acquired videos. Frame-wise HOG features were compared to those of the clusters: a video was considered covered by the training-set if more than 70% of its frames fell within cluster bounds. To assess protocol performance, each new video was also analyzed using the trained DeepLabcut model: videos in which over 30% frames contained reference points with confidence level below 95% were considered to require manual annotation. Agreement between the two methods was evaluated.

Results

Trajectories extracted from training-set videos showed an average of 29.5% missing frames (median = 27.9%, IQR = 18.9%). Among 31 new videos, the clustering-based protocol identified 13 as requiring manual annotation, DeepLabCut results flagged 17 videos (accuracy = 38.7%). The protocol achieved a precision of 38.1% and a recall of 57.1% in detecting videos needing inclusion.

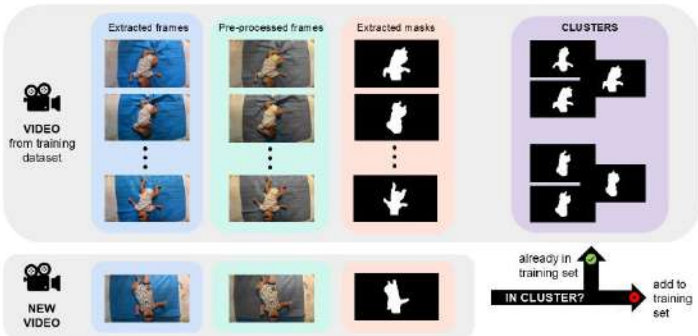

Figure 1 - Dataset characterization pipeline.

Discussion

The limited agreement with DeepLabCut outcomes indicates that clustering based solely on pose features does not sufficiently capture the visual variability influencing network performance. To optimize dataset update strategies and manual annotations efforts, future approaches must incorporate additional visual features and establish objective, data-driven thresholds.

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Dual-task challenge in COPD patients: how cognitive load amplifies hidden postural deficits

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Introduction

Chronic respiratory diseases, particularly Chronic Obstructive Pulmonary Disease (COPD), are associated with reduced locomotor efficiency and a significant increase in fall incidence. Although pulmonary rehabilitation addresses muscle deconditioning, residual motor deficits—particularly under cognitive loading—remain poorly characterized. This study used the inertial Stand-and-Walk (SAW) protocol with three wireless Inertial Measurement Units (IMUs) to assess stance, straight-line gait, and turning performance in hospitalized COPD patients, quantifying the additional burden imposed by a cognitive Dual Task (DT).

Methods

Twenty-two hospitalized COPD or chronic respiratory failure patients (73 ± 8 years; 86% male) performed three single-task (ST) trials (30 s quiet stance followed by a 7 m walk-turn-walk) and one DT trial involving serial-7 subtraction. Spatiotemporal gait parameters were recorded using Mobility Lab software (APDM Inc, Portland, OR, USA). Dual-task cost (DTC) was calculated for ten participants who completed both ST and DT trials, defined as $\%\Delta = (DT - ST)/ST \times 100$.

Results

COPD patients exhibited conservative gait strategies during ST conditions: Mean stride length was 0.98 ± 0.16 m (13% below normative lower limit of 1.13 m), and gait speed was 0.81 ± 0.18 $m \cdot s^{-1}$ (23% below the established community ambulation threshold of 1.05 $m \cdot s^{-1}$).[1]. Double-support phase accounted for 25.7 ± 4.1% of gait cycle duration, exceeding the normative upper limit (22.8%), and mean turning duration was 2.78 ± 0.47 s versus a normative upper reference of 2.50 s. Introducing cognitive condition, gait impairment worsened significantly: median DTC revealed a 22% decrease in gait speed (IQR −28% to −15%), a 13% increase in double-support duration (IQR +9% to +18%), and heterogeneous turn-duration changes centered at +2%, ranging from −20% to +30% (Figure 1). These findings underscore that limited postural reserve is exacerbated under cognitive load.

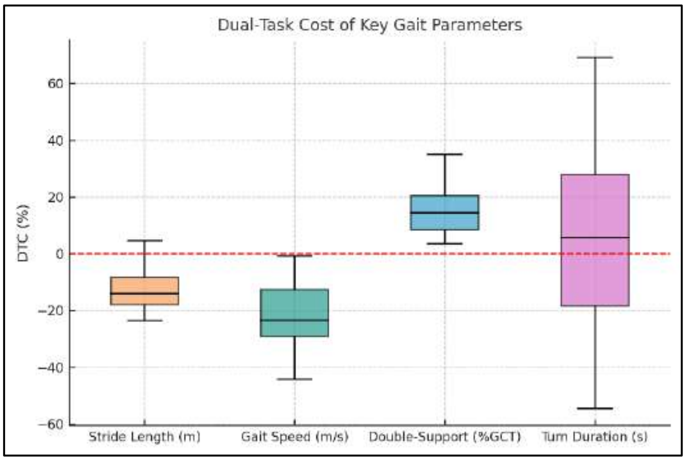

Figure 1. Dual-task cost (%) of stride length, gait speed, double-support and turn duration.

Discussion

These preliminary findings indicate that hospitalized COPD patients demonstrate stability-oriented gait patterns, which deteriorate significantly under cognitive load. The considerable reduction in gait speed and prolonged double-support under DT conditions highlight diminished dynamic balance reserves, emphasizing increased fall risk when cognitive resources are challenged. The heterogeneous turning response, a validated fall-risk indicator [2,3], further emphasizes the importance of assessing curved-path locomotion. Collectively, the investigated inertial parameters and their associated DTC represent a concise, objective measure set suitable for targeted dual-task intervention and prospective fall-risk stratification in larger COPD populations. These results advocate the integration of cognitive dual-task paradigms into pulmonary rehabilitation programs.

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Predicting ground reaction forces from kinematics data: evaluating the impact of marker-based vs markerless data prediction

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Introduction

In recent decades, motion analysis has become increasingly popular in sports, offering valuable insights for both performance enhancement and injury prevention [1]. However, it is very rarely adopted in controlled environments, due to limitations associated with reproducibility of on the field conditions [2]. When considering kinematics parameters markerless (ML) or IMU systems are currently preferred, however they don't provide information about the kinetics (i.e., ground reaction forces and joint torques) which showed to be fundamental in application such as injury prevention. Regarding ground reaction forces (GRFs), instrumented insoles have been introduced, though they are often limited to measuring only the vertical component. In this scenario the possibility to predict GRFs leveraging ML algorithms applied to kinematics variables has been recently explored. [2]. The aim of this study is to test the reliability of deriving GRFs considering marker-based (MB) or ML inverse kinematic (IK) variables within the OpenSim (OS) environment.

Methods

Ten healthy individuals' gait analysis sessions (age: 22.7±2.5 years; BMI: 21.2±2.6 kg/m²) were collected at the BiomovLab (University of Padova, Italy) using an 8-camera optoelectronic system (120 Hz, Vicon) synchronized with two force plates (960 Hz, AMTI) and two GoPro Hero v7 (60 fps, 1080p). The IORGait protocol was employed. Pose2Sim [3] ML workflow was applied to compute the 3D body pose and estimate the IK in the OS environment. MB data was imported in OS through MOtoNMS for the IK estimations. For both solutions, GRFs were then predicted using OpenGRF (https://simtk.org/projects/opengrf/). Outcomes were compared between predictions (i.e., MB, ML) and with respect to measured GRFs, using 1-D SPM [4]; RMS and the Coefficient of Multiple Correlation (CMC) were computed to assess accuracy and agreement between predicted and measured ones.

Results

As shown in **Figure 1,** MB GRF estimates were found in better agreement with experimentally measured ones, displaying lower RMS and higher CMC especially for the antero-posterior and the vertical GRF components. In general, ML underestimated the GRFs, showing a different pattern especially during the load acceptance phase and in the final part of the swing.

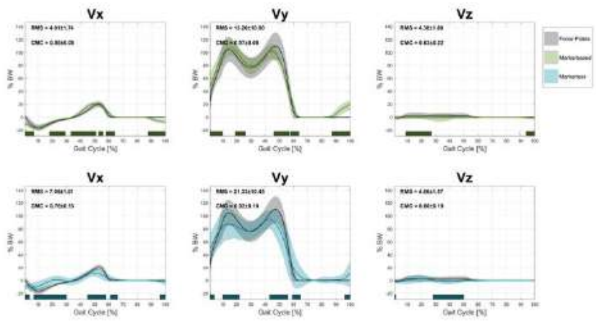

Figure 1. Comparison of GRF estimation [%BW] from MB (green) an ML kinematics (blue) with measured force plates' data (grey)($p<0.05$)

Discussion

This study highlights the great potential of a physically based GRF estimator, while pointing out its current main limitations. Reliability issues seem to arise mainly when usingML data as input. However, when considering sport applications ML solutions are preferable. Future development would be investigating other both GRF prediction and ML algorithms.

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Evaluating AI-driven markerless motion capture reliability for remote quantitative assessment of Parkinson's disease

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Introduction

Although marker-based (MB) gait analysis still represents the gold standard, it has not been fully integrated in the clinical pathway, due to several constraints such as costs associated with both the instrumentation and the expertise required by the operators, long processing time not always compatible with pathological populations such as Parkinson's Disease (PD), the need of dedicated sophisticated laboratories where it is not possible to represent the gestures' variability typical of daily living conditions [1]. To address these issues, markerless (ML) approaches have been introduced, allowing the application of motion capture in any environment, enabling continuous remote assessment of individuals (i.e., tele-rehabilitation). Among the available ML technologies, AI-driven solutions represent the most innovative and frequently adopted approach. In this regard, caution is necessary when applying them to pathological subjects, given the limited representation of impaired human motion in their training datasets. The aim of this study is to assess the reliability of different AI-driven ML techniques applied on different single or multi camera setups simulating possible home-based scenarios.

Methods

Ten PD individuals (Age: 73.50±6.64 years, BMI: 25.39±1.73 kg/m²) were recruited from Fresco Parkinson Foundation Center, Villa Margherita upon signing informed consent (ClinicalTrials.gov NCT04778852). Data collection involved simultaneous recordings of gait trials through an optoelectronic system (Vicon, 120 Hz) and two GoProHero® v7 cameras (60 Hz, 1080p) positioned sagittally and frontally. The IORGait protocol served as the gold standard for the comparison. Considering both single and multi-camera approaches, several joint kinematics and space-temporal parameters computation solutions were considered based on three frameworks: MediaPipe [2], AlphaPose and Pose2Sim [3]. **Figure 1** reports the data processing pipeline. A simplified kinematic model was adopted for Marker-based joint kinematics estimation to match the ML one. For statistical analysis RMS, Coefficient of Multiple Correlation (CMC) and SPM [4] t-test were applied.

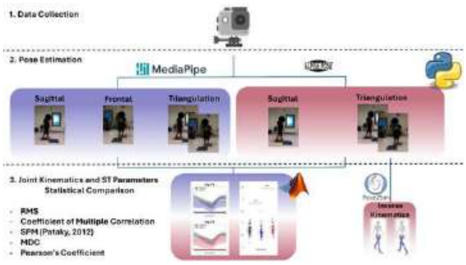

Figure 1. Framework of data processing from camera setup to ML pose estimators.

Results

Single- and multi-camera solutions showed similar CMC (0.53-0.92) and RMS values (6.94 -12.91 deg) for MediaPipe and AlphaPose. Knee flexion-extension reported the best CMC (>0.91) among sagittal kinematics, while hip kinematics showed poor reliability (CMC<0.56, RMS>10.76 deg). Pose2Sim results aligned with these findings.

Discussion

Results suggest that AI-driven ML represents a promising solution for out of the lab applications, however its reliability still remains a challenge, especially when dealing with pathological subjects.

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Dual-task cost reveals hidden gait instability in patients with severe mental illness: a pilot study

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Introduction

Severe mental illness—particularly schizophrenia spectrum—exhibits pronounced executive-motor interference that compromises gait control [1] and elevates fall risk [2]. Despite this clinical relevance, quantitative dual-task (DT) gait studies in psychiatric in-patient settings remain limited to small exploratory cohorts [3]. We therefore applied a three-sensor Stand-and-Walk (SAW) protocol with inertial-measurement units (IMUs) to characterise baseline gait and the impact of a cognitive DT in patients admitted for psychiatric rehabilitation.

Methods

Ten adults (53 ± 12 y; 70 % male) with schizoaffective disorders performed three single-task (ST) trials—30 s quiet stance followed by a 7 m walk-turn-walk—and one cognitive DT trial, consisting of serial-7 subtraction, while wearing three Opal IMUs (APDM Inc, Portland, OR, USA), positioned on L5 and the dorsum of each foot. Raw signals were processed in Mobility Lab software. ST spatiotemporal metrics were averaged across the three trials. Dual-task cost (DTC) was computed for paired ST–DT trials as %Δ = (DT – ST)/ST × 100. ST–DT differences were analysed with two-tailed Wilcoxon signed-rank tests (α = 0.05).

Results

Baseline ST gait deviated from reference limits: stride length 1.03 ± 0.23 m (norm 1.13–1.47 m; $Z = -2.52$, $p = 0.012$) and gait speed 0.90 ± 0.26 m s^{-1}, 14 % below the 1.05 m s^{-1} community-ambulation threshold [4] ($Z = -2.31$, $p = 0.021$). Double-support occupied 24.7 ± 6.4 % of the gait cycle (norm < 22.8 %; $Z = 2.56$, $p = 0.010$), while turn duration reached 2.60 ± 0.72 s (norm < 2.50 s; $Z = 1.87$, $p = 0.061$). The cognitive DT exacerbated these deficits: median DTC for gait speed was –18 % (IQR –11 % to –25 %, $Z = -2.70$, $p = 0.007$), stride length –13 % ($Z = -2.46$, $p = 0.014$), and double-support +14 % ($Z = 2.52$, $p = 0.012$). Turn-duration DTC showed wide dispersion (median + 12 %, IQR –8 % to + 31 %; $Z = 0.78$, $p = 0.43$), as illustrated in Figure 1.

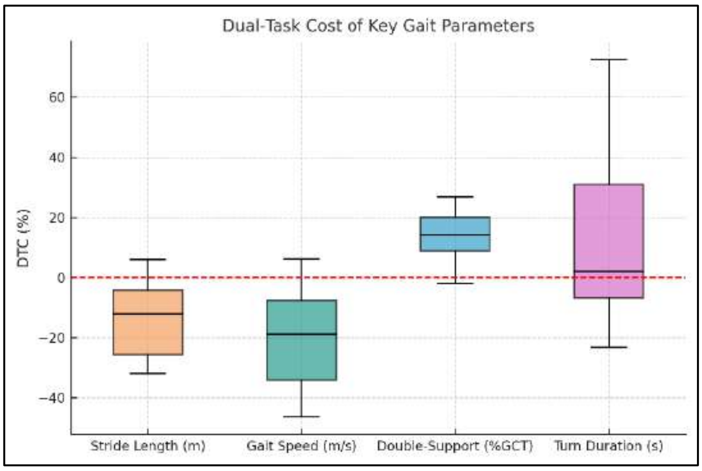

Figure 1. Dual-task cost (%) of stride length, gait speed, double-support and turn duration.

Discussion

Patients already walked near the energy-inefficient "guarded" region of the speed–stability curve and adopted compensatory prolongation of double support. The additional 18% velocity loss and 14% double-support prolongation under DT suggest rapid exhaustion of residual dynamic-balance reserves when attention is diverted. Similar DT penalties predict prospectively recorded falls in psychiatric cohorts [2] and corroborate evidence of executive-motor interference [3]. A minimal IMU-derived outcome set comprising DTC of gait speed, stride length, double-support and turn duration exposes concealed balance deficits and provides a reproducible metric for DT-oriented training, risk stratification and treatment monitoring.

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Sensor-based assessment of gait and balance in aging and neurological disorders: exploring biomarkers through progressively complex tasks

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Introduction

Clinical assessment of balance and gait in controlled and standardized settings often involves simple measurement protocols (such as walking along a 10-meter straight path). While these methods capture important gait characteristics, they may not effectively detect motor impairments in real-world environments, as they do not adequately challenge the individuals [1]. Sensor-based assessments of gait patterns through progressively complex motor tasks may give deepest and more comprehensive information about the functional status of those under exam [2]. This study aims to explore the feasibility of using wearable technology to identify suitable biomarkers of instability through a series of tasks ranging from simple, controlled movements to complex, real-world scenarios.

Methods

Seventeen Healthy Elderly (HE), 16 with a diagnosis of Parkinson's disease(PD), (Hoen and Yahr 2), and 15 chronic Stroke patients (ST), (Fugl-Meyer_LowerExtremity 22) were asked to perform 3 motor tasks in different conditions: 1) linear walking: standard clinical evaluation (10-meter walking test, 10MWT), linear walk on a led floor surrounded by a mountain landscape (LMW), and on a mat with no elastic resistance (MatW); 2) curvilinear walking: standard clinical evaluation (Figure-of-eight walking test, Fo8WT), curvilinear walk with the mountain landscape (CMW), and a dual-task grocery shopping (DT); 3) timed up and go test (TUG): standard clinical TUG, and mimicking kitchen activities (RTUG). A set of spatio-temporal parameters was extracted from 16 Inertial Measurement Units (Captiks srl, Italy, 100Hz) through Motion Analyzer validated algorithms [3].

Results

Coloured dots in Figure1 highlight those participants with atypical gait performance (outliers) who experienced a fall within two months from the assessment. Outliers are more evident in walking cadence, stance/swing ratio (both linear and curvilinear conditions), and TUG duration. In contrast, parameters like gait speed, step length, TUG sit-to-stand/stand-to-sit trunk flexion show more scattered data with no clear trends. Interestingly, data scattering increases with task complexity, especially in curvilinear and real-world scenarios, consistently with the general decline in gait performance across groups.

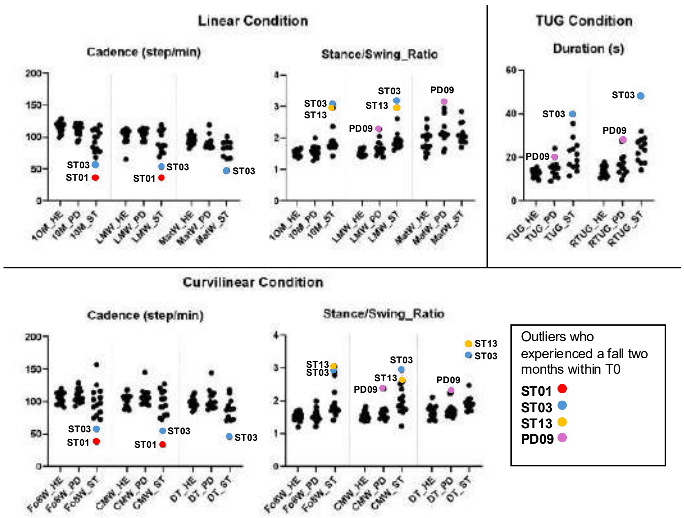

Figure 1. Scatter plots show individual variability and outliers in cadence and stance/swing ratio (both linear and curvilinear condition) and in TUG duration, across groups (HE, PD, ST).

Discussion

Preliminary results suggest that the joint use of real-life scenarios with increased task complexity and selected IMU-based biomarkers could provide useful insights about gait performance anomalies, giving the opportunity to alert care providers about potential fall risk in neurologic patients. Further research is needed to determine if this framework could effectively promote a reliable identification fallers from non-fallers.

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An exploratory study of factors influencing non-immersive virtual reality telerehabilitation in individuals with Parkinson's disease

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Introduction

Telerehabilitation (TR) is a branch of the telemedicine field, encompassing a broad range of services, including assessment, monitoring, and intervention, which can be provided remotely to patients and their caregivers [1]. This rehabilitation approach is widely considered among patients affected by neurological disorders, such as Parkinson's disease (PD), in which motor symptoms (e.g., resting tremors, rigidity, and bradykinesia) can significantly limit daily activities [1]. Advanced TR systems such as the VRRS HomeKit (Khymeia, Padua, Italy) not only support structured at-home therapy but also generate performance data that can inform real-time treatment adjustments, reducing the need for frequent in-person visits and improving cost-effectiveness [2]. However, interpreting the clinical relevance of these data remains a key challenge. This exploratory study analyses data from a pilot cohort of 10 patients with idiopathic PD who completed a 20-session upper limb TR program using the VRRS HomeKit. Clinical outcomes were measured using standardised scales, including the Unified Parkinson's Disease Rating Scale (UPDRS) and the Fugl-Meyer Assessment (FMA). The study aims to identify the most relevant digital markers from the system's reports and assess clinical changes both before and after the intervention.

Methods

Ten right-handed patients (5 males and 5 females, with a mean age of 53 ± 9,37) affected by idiopathic PD (with a Hoen and Yahr - HY mean of 2) attended the IRCCS Neurolesi Centre Bonino-Pulejo of Messina (Italy) from 2022 to 2023 and were enrolled in this exploratory study. Motor TR sessions lasted about 1 hour/day, 5 days/week, for 4-6 weeks. In particular, patients underwent TR sessions for upper limb motor recovery tailored to their specific functional needs and performance levels. All PD patients were evaluated by a neurologist and a physiotherapist, before (T0) and after (T1) the TR sessions, by using standardised and validated clinical scales, such as the UPDRS section III and the FMA for the upper limb. The TR sessions were delivered using the VRRS HomeKit, and upper limb exercises primarily focused on catching and reaching, performed with both left and right hands in various directions (e.g., top-down, left-right and vice versa, forward-backwards, and combined directions).

Results

Due to non-normal data distribution, nonparametric methods were used to analyse correlations between clinical measures and VRRS HomeKit parameters in two upper-limb tasks: reaching and catching. Spearman's correlations revealed strong negative associations between score and omission errors in both tasks ($r = -1$ and $r = -0.95$, respectively). In reaching, more repetitions were linked to shorter durations ($r = -0.89$) and higher scores ($r = 0.34$), while longer durations correlated with lower scores ($r = -0.43$). In catching, correct items positively correlated with score ($r = 0.73$), while the level variable showed no direct link to performance. The HY stage correlated with age and performance metrics in reaching, but mainly with level in catching, showing task-specific patterns of clinical association. Furthermore, significant improvements were observed between T0 and T1 in FMA scores for both the right and left upper limbs ($p = 0.008$; $p = 0.013$), as well as in upper limb coordination tasks ($p = 0.005$; $p = 0.009$).

Discussion

TR devices, such as VRRS HomeKit, can offer a promising solution by supporting both therapeutic exercises and movement evaluation in patients with PD. Findings showed that reaching scores were closely linked to movement efficiency and error rate, while catching scores depended mainly on task completion, regardless of difficulty level. Disease severity (HY scale) was associated with slower and less frequent movements, especially in reaching tasks. Furthermore, significant improvements were observed post-intervention in FMA scores for both upper limbs, including overall motor function and coordination, suggesting the positive effects of TR in enhancing global upper limb functions in PD.

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Exploring Complex Network Analysis for Human Activity Recognition from Inertial Data

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Introduction

Human activity recognition (HAR) employs artificial intelligence methods for remotely monitoring human behavior to identify possible dangerous situations, assist patients' activities of daily living (ADLs) at home and provide real-time feedback. This study explores an approach that lays the basis for the use of Complex Network Analysis (CNA) as a core classification method in the context of HAR recognition. The relationships between data, acquired from wearable inertial sensors, are represented as a complex network, exploiting the fact that such sensors, distributed over the human body, naturally define a network structure [1]. Hence, this approach intends to employ the intrinsic structure of sensor data as a complex network, with the aim of discriminating among different motor patterns, thus offering new perspectives in the field of HAR and proposing an alternative to traditional artificial intelligence models.

Methods

Data were collected from ten healthy subjects (34.9 ± 11.5 years old) with four Opal™ wearable inertial sensors placed on the left (LP) and right pelvises (RP), right wrist (RW), and sternum (S), while performing four ADLs, which have been defined in collaboration with the clinical staff of IRCCS Maugeri: Walking, Turning, Sit-to-stand, and Lying-down [2]. The activities differ in specific biomechanical features and involve the main body segments in various ways. The IMU data, properly pre-processed (segmentation and min-max normalization), have been used to compute correlation matrices based on Pearson's coefficient (ρ) between the Euclidean norms of the accelerometer, gyroscope, and magnetometer signals. The relevant correlations ($|\rho| > 0.7$) have been used to construct a connected network representing the kinematic relationships between the IMU components. In doing so, specific motor structures were identified for the recognition of each activity.

Results

The results of CNA conducted on the acquired IMU signals are shown in Figure 1. The relationships among IMU components are represented as graphs, where nodes correspond to the accelerometer, gyroscope, and magnetometer at each body location, and edges depict kinematic connections.

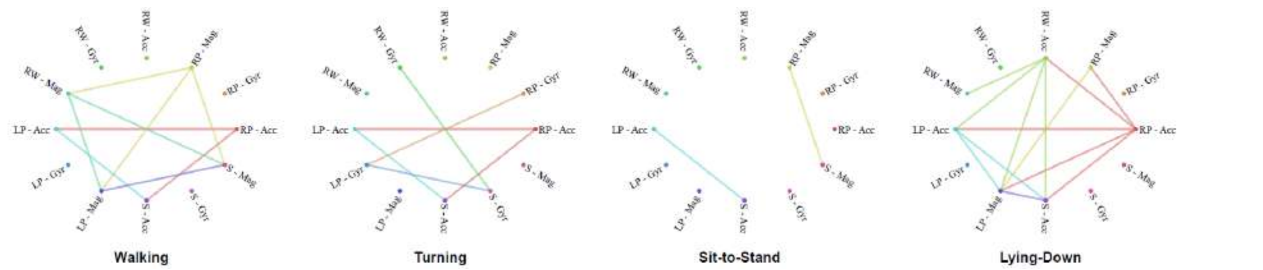

Figure 1. Complex networks illustrating IMU components relations with $|\rho| > 0.7$.

Discussion

As regards *Walking*, the magnetometer components are all correlated each other, whereas the RW-Acc is correlated with no other edges, thus meaning that the wrist conveys a relevant information for recognizing activities. Secondly, relevant correlations can be noticed among LP-Acc, RP-Acc, and S-Acc. As for *Turning*, the above-mentioned correlation triangle can be observed among LP-Acc, RP-Acc, and S-Acc as well, since the turning activity is executed while walking. Nonetheless, the magnetometer exhibits no correlation with other components, thus proving their discriminativeness. On the other hand, correlations among gyroscope components only for this motor action, which may be due to coordinated movements of the human joints while turning. As for *Sit-to-Stand*, only the LP-Acc is correlated with the S-Acc and the S-Mag with the RP-Mag; as for *Lying-down*, all acceleration components are correlated among them and with LP-Mag.

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Predicting fall risk using clinical and kinematic features from the Timed-Up-and-Go Test

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Introduction

Falls are a major cause of disability, loss of autonomy and mortality in the elderly population. More than 30% of individuals ≥65 years fall at least once a year, with the incidence progressively increasing with age [2, 3]. Gait instability is a well-established risk factor for falls, therefore, most screening programs include an assessment of gait and balance to identify individuals at risk. The Timed-Up-and-Go test (TUG) is a standardized functional test adopted extensively in clinical and research settings, used to assess global mobility, postural control, and dynamic balance. It is an useful tool for estimating fall risk in elderly individuals. The aim of this study is to evaluate whether a machine learning model, trained on the kinematic parameters acquired during the TUG test, can improve the prediction of fall risk in the elderly. Features also include information from the Morse scale, which clinically classifies the risk of falling. Therefore, in this work, we combine the clinical input from the Morse scale with the kinematic parameters collected in order to predict the risk class defined by the scale, thus integrating the clinical and motor aspects into a single predictive approach.

Methods

A total of 41 patients (mean age: 67.2 ± 10.1 years) were enrolled at the IRCCS Maugeri of Bari. The subjects presented different neurological and orthopedic conditions, including hemiparesis, femur fracture, intramedullary lesion, arteriovenous malformations, Parkinson's disease, hip prosthesis and knee prosthesis. Each participant performed the TUG test, in which the subject is asked to get up from a chair, walk 3 metres, turn around, walk back and sit down again. The evaluation was conducted both at the beginning and at the conclusion of the rehabilitation treatment. During the execution of the test, the G-WALK sensor placed on the lumbar region was used, which allowed the acquisition of kinematic parameters of movement [1]. Each patient was assigned a score according to Morse's fall risk scale, simplified into two classes (low vs. medium/high) due to the imbalance in the data. For the prediction of the risk class, three machine learning models were tested, i.e. XGBoost, neural network and logistic regression. The dataset was divided into 70% training, 20% validation and 10% testing.

Results

The best classification metrics, obtained from logistic regression, are shown in Table 1.

Table 1. Classification performances on the validation and test set.

	Accuracy	**Precision**	**Recall**	**F1-Score**
Validation	100%	100%	100%	100%
Test	96%	92%	100%	96%

Discussion

Despite the limited sample size, the results on the test set are promising and highlight the clinical relevance of predicting outcomes using only data recorded before the start of rehabilitation treatment. Furthermore, it would be interesting to evaluate the correlation between the duration of the TUG test and the outcome of the MORSE scale. The integration of kinematic parameters and qualitative data from the clinical scales could be particularly useful for predicting the outcome of the rehabilitation program and evaluating an intervention modality that is patient-specific.

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Machine Learning-Based Prediction of Clinical Improvement in Cardiac Rehabilitation: The Role of the Multidimensional Prognostic Index

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Introduction

Cardiac rehabilitation is a multidisciplinary intervention aimed at clinical stabilization, secondary prevention, disability reduction, and quality-of-life improvement. In these patients an early, personalized rehabilitation program improves functional status compared to usual care. The Comprehensive Geriatric Assessment (CGA) supports diagnosis and treatment planning; in particular, the Multidimensional Prognostic Index (MPI) stratifies frailty, rehospitalization and one year risk of death. The MPI is validated in acute and chronic conditions and predicts mortality post-discharge. At this phase, telemedicine plays a crucial role by enabling remote monitoring and follow-up, which allow physicians to assess patient status and lead treatment plans without in-person visits. The aim of this study is to predict 3-month clinical improvement using machine learning models based on baseline clinical and functional data. [1]

Methods

This study started in April 2024 at the Cardiology Unit of ICS Maugeri, IRCCS Bari, after receiving ethical approval and informed consent. Participants aged 65 or older were admitted to intensive cardiac rehabilitation following an acute cardiovascular event, such as acute coronary syndrome, heart failure, cardiac surgery, or recent percutaneous coronary intervention without acute coronary syndrome. Individuals who are unable to cooperate or have a limited life expectancy (≥50% mortality at 1 year) are excluded. The MPI is assessed within 72 hours of admission, at discharge, and again at the 3-month follow-up using the TELE-MPI. Risk is categorized into three classes: low (MPI 1: 0.00–0.33), moderate (MPI 2: 0.34–0.66), and high (MPI 3: 0.67–1.00) [2]. A first analysis was performed on a cohort of 79 patients using a Random Forest algorithm implemented in MATLAB R2022b.

Results

An accuracy of approximately 82% was achieved on the test set. Figure 1 shows the ROC curve.

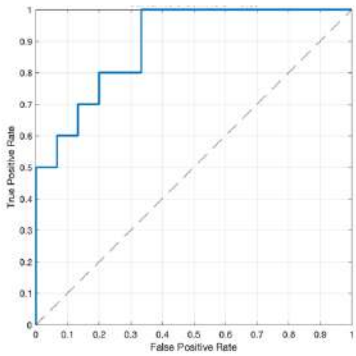

Figure 1. ROC curve for the test set showing an AUC of 0.89.

Discussion

Analysis of admission data, including functional, nutritional, cognitive, and comorbidity assessment; enabled prediction of clinical improvement, defined as a reduction in MPI risk class. This predictive ability is helpful when TELE-MPI data are missing or incomplete, offering an alternative way to assess frailty early and identify patients who may benefit from rehabilitation.

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Towards automated facial mimicry assessment using RGB-D data and a commercial tracking software: preliminary results on healthy and parkinsonian subjects

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Introduction

Hypomimia is an early and disabling symptom of Parkinson's disease (PD) consisting of the reduction of spontaneous facial movements. Currently, clinical assessment of hypomimia is subjective and based on qualitative scales. Stereophotogrammetry and surface electromyography (EMG) are considered gold standards, but require expensive equipment, trained personnel, and may interfere with the patient's natural expressivity. Markerless methods (ML) offer a non-invasive alternative. Although several deep learning-based facial landmark detection algorithms have been proposed, their clinical validation is still debated. This study proposed and preliminary validated a low-cost ML protocol to extract quantitative parameters of facial muscle activity, in healthy subjects and individuals with PD.

Methods

Healthy subjects (young (YH): 25.5 ± 3.7 y.o., n=17; elderly (EH) 69.7 ± 4.2 y.o.; n=13), and 9 PD patients (69.7 ± 8.7. y.o) were recruited. ML acquisitions were performed using an RGB-D Azure Kinect camera (1280×720-pixel, fs = 30 Hz) while EMG signal was recorded using a D360 amplifier (Digitimer Ltd, fs = 5 kHz). Each subject was recorded at rest, during maximum voluntary contraction (MVC) of the depressor anguli oris muscle (DAO) and while expressing sadness. MediaPipe Face Mesh [1] was employed to identify 2D facial landmarks of DAO muscle (Figure 1a), and their relative depth coordinates were extracted from the depth image. For validation, DAO length variation (absolute difference between its length at rest and during MVC) from ML protocol was compared with manual measures. The root mean square (RMS) values of the EMG signal during MVC were also assessed. For the dynamic analysis of sadness, DAO length variation and corresponding contraction velocity were calculated. The Wilcoxon–Mann–Whitney test was used to identify statistically significant differences between YH - EH subjects and between EH - PD subjects during MVC and while expressing sadness.

Results

The absolute difference between automatic and manual measurements of DAO length variation averaged across all subjects (n = 39) was 1.5 mm (28%), with no significant difference observed (p = 0.12). Comparison between YH, EH and PD subjects during MVC and sadness are shown in Figure 1b and 1c, respectively.

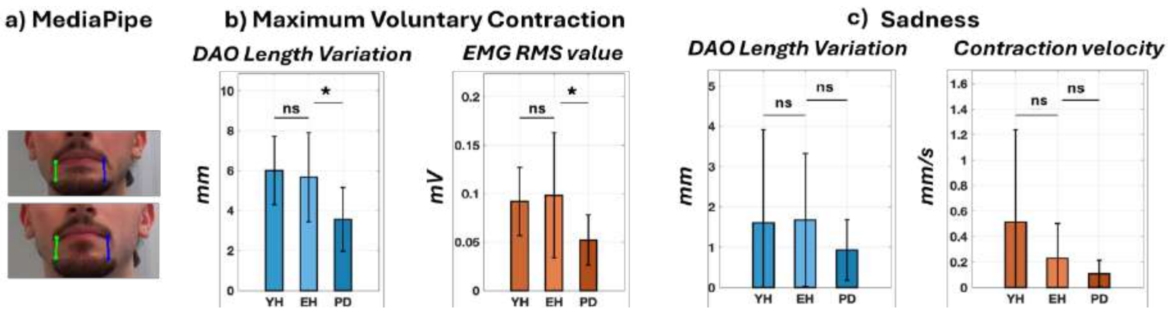

Figure 1. a) Identification of 2D landmarks of DAO; b) DAO length variation and EMG-RMS values in YH, EH, and PD subjects during MVC c) DAO length variation and contraction velocity in YH, EH and PD subjects during facial expression of sadness. *: $p < 0.05$; ns: $p > 0.05$.

Discussion

The variation in DAO length estimated using the ML protocol did not significantly differ from manual measurements, confirming the method's validity. As expected, during MVC (Figure 1b), no significant differences in DAO length variation and EMG RMS values were found between YH and EH subjects. In contrast, PD patients exhibited a significant reduction in muscle contraction compared to EH, as indicated by lower EMG RMS values and a reduced length variation. During the expression of sadness (Figure 1c), we failed to detect any significant difference between groups. This is likely due to inter-subject variability in expressing sadness and a limited range of motion comparable to measurement error. Overall, these findings support the proposed ML method as a valid tool for assessing facial hypomimia in PD.

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Does sports experience influence motor-cognitive interference in everyday locomotion? An integrated fNIRS-IMUs approach

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Introduction

Motor-cognitive interference (MCi)—the competition for shared neural resources during the concurrent performance of motor and cognitive tasks—is closely influenced by an individual's physical activity [1]. A sports background can result from open-skill (OS) sports, demanding rapid adaptation to unpredictable environments, or from closed-skill (CS) sports that involve more predictable, self-paced movements [2]. These different motor experiences may lead to the development of distinct motor-cognitive strategies that extend beyond the sports settings [3], potentially impacting everyday activity. Thus, this study aims to examine how experience in OS/CS sports influences MCi, assessing whether long-term involvement in these sport types results in different motor-cognitive adaptations.

Methods

Seven CS (25 ± 3.2 years, 2 females) and 8 OS athletes (23.5 ± 3.3 years, 3 females), each with over five years of continuous practice in their sport, walked for 10 meters and turned left/right based on arrows displayed via LED display. Turns were either planned or spontaneous, representing predictable and unpredictable direction changes, and triggered by proximity sensors (WittySEM, Microgate, Italy). Prefrontal cortex activation was measured through changes in blood oxygenated (O_2Hb) and deoxygenated (HHb) hemoglobin using a 24-channel functional near- infrared spectroscopy system (Artinis, The Netherlands, 50 Hz). Gait quality was assessed using four synchronized inertial measurement units (Opal APDM, USA, 128 Hz). A 2x2 mixed model (SPSS v29, IBM Corp) was used for statistical analysis.

Results

As in Figure 1, CS athletes showed higher O_2Hb and lower HHb concentrations in planned turning, In terms of motor performance, CS showed decreased walking speed, gait stability, symmetry, and smoothness, especially during planned tasks when compared to OS.

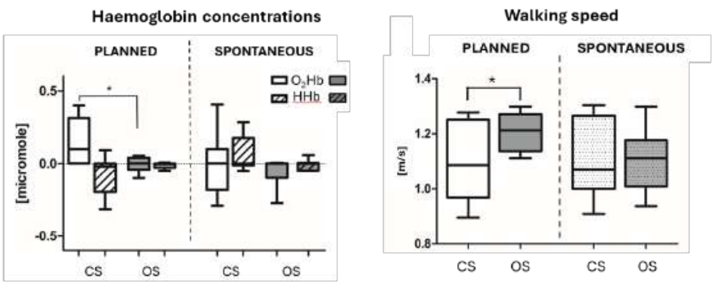

Figure 1. Median and interquartile ΔO_2Hb and HHb (left panel) and walking speed (right panel) values during planned and spontaneous turning in closed (CS)- and open-skill (OS) sports (* = $p< 0.05$).

Discussion

This preliminary study suggests that OS sports, with their dynamic and unpredictable nature, promote more efficient motor-cognitive strategies. In contrast, CS athletes rely on routine movements, leading to higher cognitive demands even in planned conditions. Despite the performance cost of unpredictability, OS athletes maintain better walking speed, highlighting the benefits of their training background. These findings emphasize the role of sports type in MCi and the potential of OS training to enhance dual-task performance.

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Surface EMG analysis of cervical muscle activation in chronic whiplash-associated disorder

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Introduction

Chronic Whiplash Associated Disorder (CWAD) is a condition characterized by persistent disability lasting at least three months following an acceleration-deceleration injury to the neck [1]. Despite CWAD is linked to motor control deficits and maladaptive cervical muscle recruitment, the neuromuscular behavior of cervical muscles during stabilization tasks remains insufficiently understood. This study aims to compare the surface electromyographic (sEMG) responses of the sternocleidomastoid (SCM) and cervical spine erector (CSE) muscles, key components in neck stabilization, during external perturbations induced by shoulder flexion movements (via activation of the anterior deltoid muscles, ADM) in individuals with CWAD and healthy controls.

MethodsThis study included 52 participants with CWAD and 52 healthy controls. Participants performed four bilateral shoulder flexions to 90°, namely two with slow and two with fast reactions, triggered by alternating visual and auditory stimuli, according to the protocol developed by Falla et al. [2]. The sEMG signals were automatically segmented to isolate the regions of interest (ROIs) corresponding to each movement (slow and fast) using the sEMG of the ADM, and then applied to sEMG of both SCM and CSE muscles. For each ROI, two time-domain features: time to peak (TP) and zero crossings (ZC) and two frequency-domain features: mean frequency (FM) and skewness (SKEW), were extracted. To compare these features between healthy and pathological groups, the non-parametric Mann-Whitney test was carried out considering a confidence interval equal to 95% (statistical significance set at p-value < 0.05).

Results

Table 1 summarizes the results of the statistical analysis. For each subject, all the features extracted from sEMG of both SCM and CSE muscles, were averaged between the first and the second slow trial and the first and the second fast trial.

Table 1. Mann-Whitney test results between healthy and Whiplash Associated Disorder groups during the neck stabilization test.

Features	Muscle	Task	Control (median)	CWAD (median)	p-value	Features	Muscle	Task	Control (median)	CWAD (median)	p-value
TP	SCM	Slow	1.43	1.90	< .001	FM	SCM	Slow	97.63	107.52	0.042
		Fast	0.72	0.73	0.704			Fast	79.70	100.73	< .001
	CSE	Slow	1.27	1.63	0.025		CSE	Slow	78.80	90.71	0.093
		Fast	0.53	0.61	0.048			Fast	71.78	79.97	0.005
ZC	SCM	Slow	828.62	997.75	0.015	SKEW	SCM	Slow	5.76	5.12	0.025
		Fast	543.50	695.00	0.001			Fast	5.53	5.07	0.004
	CSE	Slow	705.50	813.12	0.027		CSE	Slow	5.72	5.43	0.136
		Fast	475.00	602.37	0.004			Fast	5.35	5.53	0.300

Discussion

The analysis showed that 12 out of 16 extracted features (75.0%) exhibited statistically significant differences between CWAD subjects and healthy controls. This result suggests that such features may serve as potential biomarkers for characterizing the CWAD condition. Notably, participants with CWAD exhibited higher values of ZC and FM compared to the control group. This pattern is indicative of altered neuromuscular control and the implementation of compensatory motor strategies likely triggered by pain or instability. Specifically, increased ZC and FM values reflect inefficient recruitment of motor units and greater neuromuscular effort during tasks requiring stabilization, thereby supporting the hypothesis of motor control dysfunction in individuals affected by CWAD [3].

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Sensor-based gait analysis reveals superior functional performance after femoral neck fractures compared to intertrochanteric fractures in post-acute rehabilitation

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Introduction

Hip fractures are a major public health concern among older adults. Femoral neck fractures (FNF) and intertrochanteric fractures (ITF) differ in terms of biomechanics, treatment approaches, and expected outcomes [1]. FNF are typically treated with hemiarthroplasty, while ITF are commonly managed with internal fixation by osteosynthesis. Compared to FNF, ITF patients show higher mortality, more pronounced gait impairments, and lower odds of regaining independent mobility [2]. Nevertheless, current evidence regarding the prognostic value of fracture type on functional recovery remains inconclusive. In Italy, rehabilitation protocols are generally the same for both types of fractures, despite their biomechanical and clinical differences [3]. This study aimed to assess whether gait performance differs between ITF and FNF patients at the end of post-acute inpatient rehabilitation, using metrics derived from the instrumented Timed Up and Go (iTUG) test.

Methods

A retrospective analysis was conducted on 169 older adults (>70 years) with low-energy hip fractures: 77 with FNF treated by hemiarthroplasty, and 92 with ITF treated by internal fixation. Gait was assessed using the iTUG test, which provides reliable spatiotemporal and kinematic parameters. Group comparisons were performed using the Wilcoxon rank-sum test for independent samples. Cohen's *d* was used to estimate effect size (ES) magnitude. Variables with large ES (≥0.5) were selected for machine learning classification models (Naive Bayes, Logistic Regression, Random Forest, and KNN).

Results

There were no significant differences in age or sex between groups. Length of stay was significantly longer in patients with ITF compared to those with FNF (32 vs. 29 days, $p<0.001$). Figure 1 displays the best 15 iTUG gait variables able to discriminate between the two groups, ordered by absolute ES. Harmonic Ratios (medio-lateral and antero-posterior), range of medio-lateral angular velocity, and step duration emerged as the most discriminative features, consistently favoring the FNF group. Although patients with ITF showed a significantly longer total duration ($p<0.01$), its ES was only moderate compared to other iTUG-derived metrics. The Naive Bayes model achieved 76% classification accuracy in distinguishing fracture type based on gait parameters.

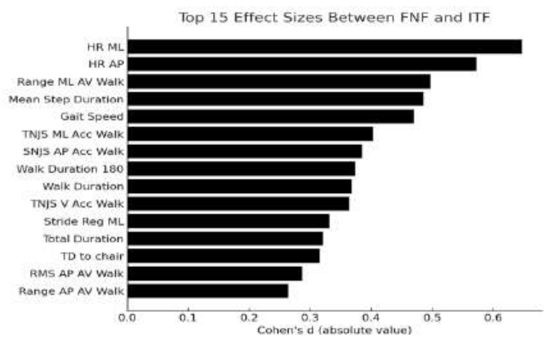

Figure 1. The best 15 iTUG gait parameters differentiating FNF and ITF, by ES. Higher values indicate greater between-group differences, consistently favoring superior gait symmetry, regularity, and speed in the FNF group. Acc, acceleration; AP, antero-posterior; AV, angular velocity; HR, Harmonic Ratio; ML, medio-lateral; RMS, root mean square; Reg, regularity; SNJS, speed-normalized jerk score; TD, total duration; TNJS, time-normalized jerk score; V, velocity.

Discussion

Despite a shorter rehabilitation stay, patients with FNF undergoing hemiarthroplasty exhibited more symmetric, faster, and stable gait patterns than those treated with internal fixation for ITF. These differences likely reflect greater biomechanical stability and more efficient recovery in the FNF group. These findings emphasize the clinical relevance of fracture type and support the use of sensor-based gait assessment for tailoring rehabilitation strategies in post-acute care.

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Evaluation of a prototypical telerehabilitation system using wearable sensors: the REHACT case study

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Introduction

Telerehabilitation can complement traditional therapy by enhancing motor rehabilitation, treatment adherence, and enabling remote monitoring [1,2]. The REHACT project developed a prototype system based on wearable sensors to support home-based rehabilitation. This study evaluated the system's usability and assessed whether sensor-based motor characterization aligns with functional evaluation.

Methods

One participant (female; age: 68; height: 1.67m; mass: 62kg; with low back pain, type2 diabetes and asthma), under informed consent, completed a telerehabilitation protocol (1-hour biweekly 6-week sessions) using the validated REHACT system [3], which integrates inertial sensors and a smartphone application. Motor abilities were assessed using the parameters validated in [3], and compared with the functional evaluation conducted by a clinical kinesiologist. This assessment was conducted before and after the protocol by visually evaluating how the patient performed the exercises. Additionally, the ease of use of the system was assessed using a visual 1 to 10 scale (7-10 to be considered as highly usable).

Results

The outcomes of the kinesiological evaluation and the analysis of the parameters collected during the various exercise sessions are presented in Table 1. The participant reported positive comfort (7/10), indicating ease of use and general acceptance of the technology.

Table 1. Patient's improvements. REP: Number of repetitions. TIME: Repetitions time. MI: Movement Intensity. MIV: Movement Intensity Variability. RAV: Range of Angular Velocity. LDLJ: Log dimensionless jerk. DTW: Dynamic time warping. ROM: Range of Motion.

Movement parameters	*Improvement Detected By*
REP	Sensors and kinesiologist
TIME	Only sensors
MI	Only sensors
MIV	Not observed
RAV	Not observed
LDLJ	Sensors and kinesiologist
ROM	Sensors and kinesiologist
DTW	Only sensors

Discussion

The REHACT prototype demonstrated good usability for clinical practice. All qualitative kinesiologist's evaluation for movement parameters were aligned with sensor outputs (Table 1). Conversely, while improvements in some temporal, intensity and quality metrics (TIME, MI, DTW) were only detectable through sensor-based analysis. While this single-case study inherent limitations, the results showcase the complementary value of sensor-based metrics in detecting motor improvements not captured by traditional clinical assessment. The findings support further investment in REHACT's potential as a low-cost solution for clinical evaluation and home-based motor rehabilitation. Larger samples studies are necessary to reinforce these preliminary findings.

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A low-cost IMU for remote respiratory assessment: normative metrics and user usability

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Introduction

Monitoring respiratory function is essential in rehabilitation, particularly for older adults and individuals with respiratory diseases in a telerehabilitation context [1]. As telerehabilitation expands, there is a growing need for low-cost technologies to improve accessibility. Inertial measurement units (IMUs) offer a promising solution for tracking chest wall movements during breathing [3,4]. However, standardized characterization of respiratory exercises remains limited. This study aims to address this gap by providing normative values using a low-cost IMU designed for accessible respiratory monitoring.

Methods

Eleven older adults (9 females and 2 males; age = 72.6 ± 5.0 years; height = 1.66 ± 0.09 m; mass = 68 ± 10 kg) performed four types of respiratory exercises. A single low-cost 9-axis IMU [4] was placed on the lower rib to record chest wall motion. Data from the Z-axis (antero-posterior) accelerometer signal were filtered and normalized. A custom algorithm segmented the respiratory cycles by detecting peaks and valleys in the signal and extracted key respiratory parameters [5] to characterize breathing patterns during the exercises. User comfort was assessed using a visual analog scale (VAS).

Results

Participants reported a high value of comfort in different exercises (VAS 8.7±1.3). The prototypical IMU successfully detected respiratory cycles across all exercise conditions. Specific values for the selected parameters across exercises are reported in Table 1.

Table 1. Normative values (mean ± standard deviation). Respiration exercises: RE1 supine, RE2 sitting with back support, RE3 sitting without back support, RE4 standing. Resp: number of breaths; TimeRR, TimeInsp, TimeExp (s): respiratory cycle, inspiration, and expiration times; PeakInsp and PeakExp (g): normalized peak acceleration during inspiration and expiration; TVolume, TVar (a.u.): normalized tidal volume and tidal volume variability.

Exercise	*Resp.*	*TimeRR*	*TimeInsp*	*TimeExp*	*PeakInsp*	*PeakExp*	*TVolume*	*TVar*
RE1	8±0	4.2±1.8	2.6±1.2	1.6±0.6	0.8±0.1	0.1±0.1	0.7±0.1	0±0
RE2	7.7±0.5	3.1±1.3	1.7±0.7	1.4±0.7	0.8±0.1	0.2±0.1	0.6±0.3	0.2±0.4
RE3	8±0	2.8±1	1.6±0.7	1.3±0.5	0.8±0.1	0.2±0.1	0.6±0.3	0±0
RE4	8±0	4.3±1.3	2.5±1	1.6±0.6	0.8±0.1	0.2±0.2	0.6±0.2	0±0

Discussion

This study established normative values for respiratory parameters using a low-cost IMU across four common exercise positions. These quantitative metrics, based on reliable respiratory cycle detection across all conditions, are essential for standardized remote monitoring protocols. Temporal parameters varied with posture: supine and standing positions exhibiting longer respiratory cycles compared to seated positions, likely reflecting due to physiological differences between postures, possibly related to gravitational effects and variations in diaphragm activation. Peak inspiratory acceleration remained consistent across positions (0.8±0.1g), demonstrating the IMU's stability for amplitude-based measurements, while the variability of expiratory peak (0.1-0.2g), could reflect differences in passive respiratory mechanics. Also, minimal tidal volume variability confirmed breathing patterns repeatability, essential for longitudinal monitoring applications. High user comfort ratings support the system's usability for extended home-based use. These findings, combined with potential enhancement through smart textile integration (belts or shirts), highlight the technology's potential as an accessible and low-cost solution for remote respiratory monitoring into home-based telerehabilitation frameworks.

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Assessing the efficacy of home-based telerehabilitation in chronic low back pain patients.

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Introduction

Non-specific chronic low back pain (LBP) significantly affects quality of life and healthcare costs. Its multifactorial nature complicates treatment prediction, highlighting the need for objective, personalized monitoring [1,2]. This study aims to evaluate the effectiveness of a telerehabilitation protocol by analyzing both clinical outcomes and functional assessments obtained through wearable sensors.

Methods

Twenty-one volunteers with chronic LBP (16F; age 60 ± 10.7 y; 1.7 ± 0,1 m; 65,7 ± 9,0 kg) performed a six-week telerehabilitation protocol delivered via the HEFORA telerehabilitation platform (Geoslab, Spain). Pre-post assessment included clinical outcomes, assessed using standardized scales for disability, pain, functionality, and fear of movement [3,4]; functional performance, measured using parameters extracted by prototypical IMUs as in and by portable EMG during Timed Up and Go, Sit-to-Stand and three exercises not included in the telerehabilitation treatment ("Bird Dog", "Cat Camel", "Mobility in 4-points"). Pre-post data were compared using t-test or Wilcoxon test if data were normally distributed or not (tested using a Shapiro-Wilks normality test).

Results

Of the 21 patients recruited, 6 participants dropped out of the study. In Table 1, the results after the telerehabilitation protocol are shown.

Table 1. Pre-post evaluation summary statistical results. For clinical scales, statistically significant differences ($p < 0.05$) are marked by an asterisk (*). Functional results count sensor-derived parameters (IMU and EMG) significantly different ($p < 0.05$) for each functional test and exercise.

Assessment		*p-values*	
clinical	Disability Scale [3]	*0.018	
	Pain Scale [4]	0.087	
	Clinical Scale [5]	*0.0001	
	Clinical scale [6]	0.10	
functional		*IMUs parameters*	*EMG parameters*
	TUG	*4 of 33* has p-value< 0.05	*7 of 17* have p-value< 0.05
	STS	1 of 17 has p-value< 0.05	11 of 17 have p-value< 0.05
	"Bird Dog"	3 of 18 has p-value< 0.05	7 of 17 have p-value< 0.05
	"Cat Camel"	1 of 18 has p-value< 0.05	8 of 17 have p-value< 0.05
	"Mobility in 4-points"	7 of 18 has p-value< 0.05	8 of 17 have p-value< 0.05

Discussion

The telerehabilitation protocol showed a positive effect on disability and functionality (Table 1). Although pain and kinesiophobia scores did not significantly improve, these outcomes may require longer interventions to manifest measurable changes. Sensor-based assessments further support clinical findings: most significant improvements were detected in EMG parameters across both functional tests and exercises, suggesting improved neuromuscular activation. In contrast, IMU-derived metrics showed changes in quantity and intensity paramaters, indicating that the protocol may primarily affect muscle recruitment rather than gross movement patterns. Overall, results support the use of a telerehabilitation approach to provide clinical and neuromuscular improvements in LBP patients.

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Directional Motor Control Improvements Following Sport-Based Rehabilitation in Spinal Cord Injury Individuals During Reaching Tasks

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Introduction

Upper limb motor recovery is a key goal in neurorehabilitation, particularly in individuals with coordination impairments like spinal cord injury (SCI). Sport-based rehabilitation is increasingly used to promote functional recovery, yet its effects on motor control are understudied [1]. This study aims to investigate how such an intervention changes upper limb kinematics during a reach and grasp task in subjects with SCI. We hypothesize that movement variability in SCI patients would decrease after the sports, while temporal consistency would increase.

Methods

Ten participants with SCI (6 male and 4 female; age: 42.90 (±13.53) years; height: 1.73 (±0.08) m; weight: 79.90 (±12.79) kg; BMI: 26.76 (±4.39) kg/m2; time since the injury: 16.44 (±14.08) years) performed three reach-and-grasp movements before and after a three-months sport-based rehabilitation program. The program included archery, bowls, swimming, tennis, fencing, and athletics, and was specifically designed for the participants. An optoelectronic system recorded kinematic data from wrist joints in the three spatial dimensions, as shown in Figure 1a. Coefficient of Variation (CV_{joint}) [2] and Coefficient of Multiple Correlation (CMC) [3] evaluated variability and temporal repeatability. A Wilcoxon signed-rank test was performed, with statistical significance set at $p = 0.05$.

Results

Post rehabilitation, CMC significantly increased across all directions, as shown in Figure 1b. Currently, wrist CV_{joint} significantly decreased in all directions (Figure 1c).

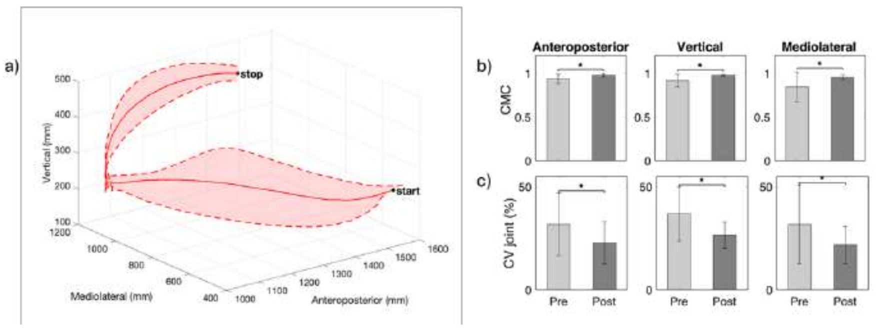

Figure 1. Kinematic analysis of wrist movement during reach and grasp. a) Mean trajectory ± standard deviation across trials; b) CMC in the three directions; c) CV_{joint} of the wrist in the three directions.

Discussion

Improvements in CMC across all directions suggest enhanced neuromuscular coordination, reflected in increased movement stability and consistency. These findings suggest a more stable and repeatable motor execution pattern, consistent with a reorganization of motor strategy after sport-based rehabilitation. The reduced wrist joint variability in all directions further supports this interpretation, suggesting a global refinement in motor control. Together, these results point to a comprehensive reorganization of motor strategies following sport-based rehabilitation, leading to more controlled and repeatable joint behavior, likely driven by improved sensorimotor integration and motor planning.

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SkelMamba: a markerless motion capture approach for automated diagnosis of neurological disorders based on RGB videos during walking

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Introduction

Gait analysis is valuable for diagnosis and monitoring neurological disorders such as Parkinson's disease, ataxia, and hereditary spastic hemiparesis. Traditional gait assessments rely on marker-based motion capture systems, which are expensive, time-consuming, and intrusive for patients. Recent computer vision advances enable markerless, non-invasive gait analysis from standard videos [1], promising in clinical settings where cost, time, and patient comfort are critical. In this work, we propose a novel framework for the automatic diagnosis of neurological disorders using 2D skeleton data extracted from RGB videos of patients walking in a clinical setting.

Methods

We collected a new clinical dataset of 396 video sequences from 40 walking subjects divided into four diagnostic categories: primary degenerative cerebellar ataxia (n=11), hereditary spastic paraparesis (n=12), idiopathic Parkinson’s disease (n=7), and healthy controls (n=10). We extracted 17 2D-keypoints per frame using a pre-trained HRNet model via the MMPose Toolbox [2] (Figure 1a). Our classification model, SkelMamba [3], based on a state-space model (SSM) that processes temporal sequences of skeletal joint coordinates to capture dynamic gait patterns over time, explicitly models temporal dependencies between frames, making it well-suited for analyzing subtle movement anomalies associated with neurological disorders. The model was trained and tested using three input configurations: joints only (Mj), joints and bones (Mjb), and joints, bones, and motion features (Mjbm). Baseline models were evaluated for comparison under identical conditions.

Results

SkelMamba reached an accuracy of 99.35% on M_j and M_{jb}, and 99.64% on M_{jbm}. Figure 1b shows detailed results across all input modalities, including a comparison with baseline models.

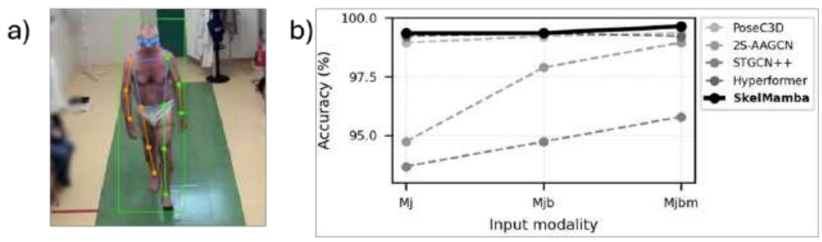

Figure 1. a) Example of the skeleton extracted from a single frame; b) Classification accuracy (%) of different models across three different modalities.

Discussion

Our method shows strong potential for real-world clinical applications, offering a non-invasive and fully automated solution for diagnosis of neurological disorders. These results consistently outperformed the baseline models (Figure 1b). The proposed approach demonstrated high sensitivity in detecting subtle gait alterations across all disorder types. While the sample size is modest, it is balanced across relevant clinical categories, and results are consistent and robust, suggesting good generalizability. Ongoing efforts aim to expand the dataset and validate the model in broader clinical settings.

Aknowledgments

This work is partially supported by the "Planning an assistive interactive and cooperative robot to aid balance and gait in elderly and individuals with cerebellar ataxia and Parkinson’s disease” project - CUP G25F21003390007 - Finanziato dall'Unione Europea – Next-GenerationEU

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Instrumental-based biomechanical risk assessment by using markerless and wearable approaches: a biomechanical comparison

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Introduction

Wearable sensor networks (IMUs, sensorized insoles, sEMG) enable real-time biomechanical risk assessment during manual material handling [1], but face limitations like cost and user compliance. Markerless motion capture systems offer a non-intrusive alternative for estimating kinematic variables essential for risk assessment, such as those used in the Revised NIOSH Lifting Equation (RNLE) [2]. This study compares markerless systems with wearable sensors in estimating these variables, aiming to simplify workplace risk assessment while preserving natural movement.

Methods

Ten subjects performed five repetitions of a lifting task under three different risk conditions defined by the RNLE (L=1, 2, 3). Kinematic data were synchronously acquired by XSens Awinda IMUs and eight infrared cameras BTS SMART-DX Evo 2 System, by extracting joint keypoints using CapturyStudio software. Variables (H, V, D, A) and multipliers (HM, VM, DM, AM) from the RNLE were estimated. Statistical analyses were performed using MATLAB R2023b. After assessing the normality through the Kolmogorov–Smirnov test, either a t-test or a Wilcoxon signed-rank test was applied. For each parameter and each risk condition, three comparisons were conducted: between the two conditions (paired), and between each condition and a theoretical reference value (one-sample). Bonferroni correction set significance at $\alpha=0.0014$ for 36 tests.

Results

As for the multipliers, significant differences between methods and references were found in most cases, except for no significant difference between methods in HM and VM at LI=1 (Figure 1). Differences with reference values were consistently significant, especially for the Y component.

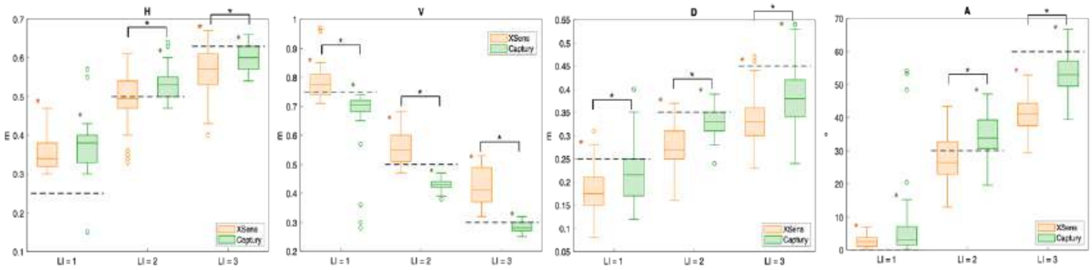

Figure 1. Box-whisker plots estimated variables for each risk condition. For each plot, the horizontal line indicates the theoretical reference values; asterisks highlight statistically significant differences (black for the comparison between the two methods, green and orange respectively for the comparison between the reference values and XSens and Captury.

Discussion

These results indicate that agreement between measurement methods varies depending on the risk condition and variable analyzed. The absence of significant differences between methods at lower risk levels (LI=1) suggests better consistency, while higher risk conditions show greater divergence. Consistent significant deviations from reference values point to systematic biases that warrant further investigation.

Aknowledgments

This work is partially supported by the "Planning an assistive interactive and cooperative robot to aid balance and gait in elderly and individuals with cerebellar ataxia and Parkinson’s disease” project - CUP G25F21003390007 - Finanziato dall'Unione Europea – Next-GenerationEU.

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A novel instrumented approach for multi-signal assessment of spasticity in multiple sclerosis: a pilot, single-session intervention study

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Introduction

Spastic hypertonia due to multiple sclerosis (MS) is a velocity-dependent movement disorder with heterogeneous presentation (e.g., hypertonia, pain, spasms, and fatigue) [1]. Its assessment represents a challenge to clinicians and researchers. In this context, developing wearable solutions for spasticity quantification seems a worthy endeavor [2]. The aim of the present pilot study was to develop and assess the clinical validity of a wearable multi-signal system for objective quantification of the joint resistance to passive motion (RPM) in spasticity due to MS.

Methods

Twenty-two participants with MS (median EDSS: 4.5, IQR=4, 5.75) with mild to moderate spasticity (median MAS: 1+) of the ankle plantarflexors participated in a single-session intervention study testing both the more- (MA) and the less-affected (LA) sides, as labelled by MAS score. Participants were imparted a passive, fast stretch mobilization (at least 400°/s) from full plantarflexion to maximal dorsiflexion by means of a manual maneuver by wearing 1) foot-mounted multi-sensor system Smart Assessment of Spasticity (SAS), consisting of two magneto and inertial measurement units (MIMU), and a force sensor [3] (Figure 1A) and 2) bipolar surface electromyography (sEMG) to evaluate involuntary neuromuscular activation in the triceps surae. All assessments were performed bilaterally by the same trained physiotherapist before and after a 20-minute, slow (5°/s), passive mobilization of the ankle joint, chosen as a paradigmatic intervention that is well-known to induce a decrease in hypertonia. Outcome measures consisted in area under curve of rectified EMG (AUC-EMG, Figure 1B) and of angle-*vs*-time curve (AUC-angle, Figure 1C), and maximal angular deceleration (Figure 1D).

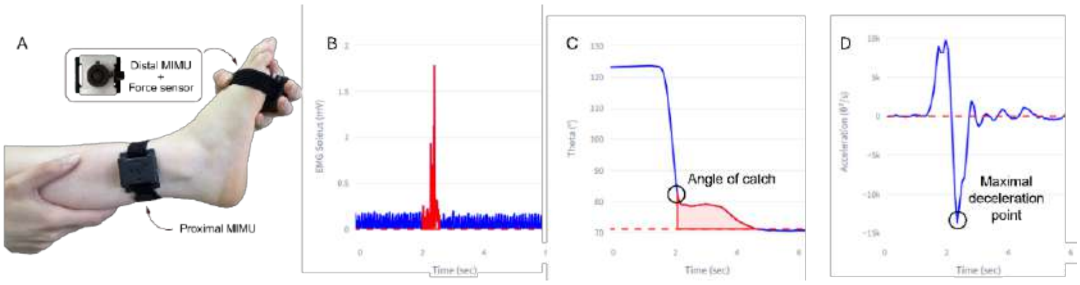

Figure 1. A) Experimental setup using SAS wearable system; B) AUC-EMG, C) AUC-angle, D) maximal angular deceleration, also corresponding to angle of catch.

Results

Ankle ROM was comparable between MA and LA sides, but during the fast stretch the AUC-EMG was larger in MA (0.16±0.03) than LA side (0.09±0.02; p=0.028) and decreased after the intervention only in MA soleus by 18.6% (p=0.01). AUC of the angle-*vs*-time curve depicting the RPM to manual maneuver was similar between sides at baseline (p=0.60) and decreased after the intervention only in MA (-24.8%; p=0.03). Maximal angular deceleration during fast stretch was similar between sides at baseline (p=0.21) and was found reduced following the intervention both in MA (-9.3%; p=0.02) and LA (-10.2%; p=0.05).

Discussion

The main finding of this pilot trial is the detection of hypertonia bilaterally, with different patterns of presentation in the MA and LA sides. In particular, the former displayed higher neuromuscular activation. Following the intervention, reductions in AUC-EMG only in MA confirm the predominance of a neural component of hypertonia in this side, while RPM changes seem to be mostly attributable to soft tissue stiffness in LA. While preliminary in nature, the present data highlights the need to test MS-spasticity bilaterally, so that treatments tightly tailored to the components exhibited individually are planned and administered.

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Using artificial intelligence for classifying healthy and pathological subjects based on postural parameters: preliminary results

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Introduction

The technological revolution in Artificial Intelligence (AI) is redefining care pathways. As a technological revolution, AI has redefined and optimized care pathways, enhancing their overall effectiveness. Within the domain of rehabilitation, Machine Learning (ML) models can assist medical professionals in identifying posture abnormalities associated with specific pathologies [1]. Stabilometric measurements reflect postural variability and can reveal underlying postural disorders and/or balance impairments [2]. The objective of this study was to compare and select the most effective ML model in identifying the nature of stabilometric measures, regarding their correlation with healthy subjects or patients with paraparesis.

Methods

We recruited eight subjects, four healthy subjects and four with lower limb paraparesis. Each subject underwent two 30s stabilometric recordings with the platform "P-Walk" (BTS Bioengineering Srl, Italy). The following parameters were selected from the set of those extracted: the position of the centre of pressure along the transverse axis and the sagittal axis, the respective standard deviations, the sway path, its mean displacement velocity, the length as a function of surface area, and the sway area of the 95% confidence ellipse of the COP. Then, we developed, using Python (version 3.13), an algorithm that compared the classification performance of supervised learning of the following models: Random Forest (RF), Support Vector Machines – radial kernel, polynomial kernel and linear kernel (SVM – R, SVM – P and SVM – L, respectively), XGBoost (XGB) and Naïve Bayes (NB). Accuracy and Kappa statistic were the indices chosen for the evaluation of the capabilities of the models to discriminate between healthy subjects and patients.

Results

Table 1 shows that the model trained using XGB and SVM-P algorithm achieved the best discriminative performance, both in terms of accuracy and Kappa statistics, whilst the worst discriminative performance was achieved by the RF algorithm.

Table 1. Discriminative performance of the models used.

Model	Accuracy	Kapp
RF	0.62	0.25
SVM – R	0.75	0.50
SVM – P	0.75	0.50
SVM - L	0.69	0.38
XGB	**0.81**	**0.62**
NB	0.69	0.38

Discussion

The analysis demonstrated that the XGB model outperformed. These findings are motivated by XGB characteristics. However, it is important to note that performance differences among the models are often minor and may depend on the dataset's specific characteristics and the details of the implementation. The limited dataset size imposed constraints on the performance of the alternative models. In conclusion, future studies should involve a larger number of subjects and incorporate a broader range of classes, possibly including additional pathologies that influence posture—such as Parkinson's disease and cerebellar ataxia. This approach would strengthen the study's robustness in both engineering and clinical domains, ultimately contributing to the development of a tool capable of accurately classifying pathological cases based on postural parameters.

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A pilot implementation of the Sensory Organization Test using the CAREN system

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Introduction

The Sensory Organization Test (SOT) is a standard tool for assessing static stance stability in clinical settings. The sagittal oscillations of the body center of mass (COM) are estimated from the displacements of the center of pressure on 2D force plates during 20s runs. Vision can be abolished (Romberg test) and/or vision and ankle proprioception can be made uninformative by "tuning" the platform or/and the visual surround with the subject oscillations [1]. Equilibrium scores (ESs, from 0=fall or stepping to 100=full stability) for each condition and their combination (CES) are computed. "Sensory analysis" gives the ratio between ES scores in optimal and neutralized sensory input: absence of vision (SOM), of ankle proprioception (VIS), of both (VEST), and the capacity to suppress the "preference" for visual information when misleading (PREF). This study presents the development and validation of a novel implementation of the SOT within the Computer Assisted Rehabilitation Environment (CAREN) (Fig. 1A), a multisensory, immersive system used for clinical gait and posture analysis. The goal is to enhance balance assessment and extend the range of CAREN-based diagnostic applications.

Methods

A custom software module (CAREN-SOT) was developed to implement the six SOT conditions (Fig. 1B) [2] using CAREN's six-degree-of-freedom motion platform, dual force plates, a 3D motion capture system, and an immersive visual scene projected onto a 180-degree curved screen. We validated our CAREN-SOT implementation in eight healthy subjects (4 males aged 23–40 years). The COM sway was estimated using synchronous force plate signals (Force input), and optoelectronic motion-capture signals (Marker input) [3]. A generalized linear mixed model was used to assess differences between modalities, while latency and platform responsiveness were monitored to ensure protocol reliability.

Results

The CAREN-SOT protocol was successfully executed with both input modalities. No statistically significant differences emerged between force plate and motion capture estimates across SOT conditions and Sensory Analysis. Comparison with NeuroCom™ normative data (Fig. 1C) [4] indicated comparable ES and Sensory Analysis values, with minor differences likely attributable to the different mechanical and sensory environments and the limited sample size.

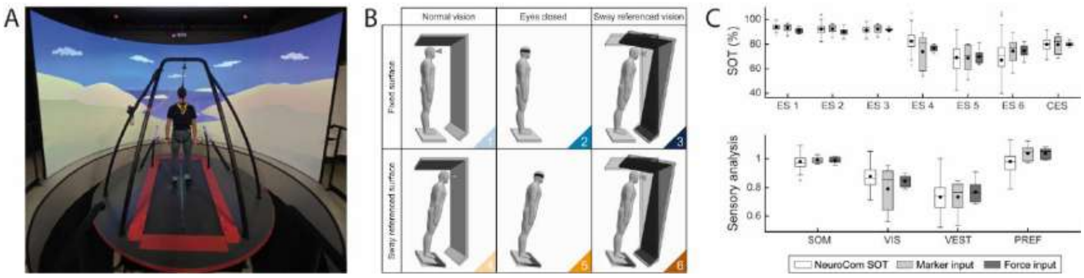

Figure 1. A) Experimental setup. B) SOT conditions (1–6). Conditions 1–3 (blue gradient) fixed surface; conditions 4–6 (orange gradient) sway-referenced platform. C) Comparison of ES and Sensory Analysis values across SOT conditions (see Introduction for labels).

Discussion

The CAREN-based SOT offers a promising and flexible alternative for clinical assessment of postural control, potentially increasing diagnostic specificity in balance disorders. The method is suitable for integration in neurorehabilitation protocols and may support tailored treatment planning. Future studies will focus on clinical populations, expanding normative datasets, and investigating mediolateral sway patterns.

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Unsupervised identification of children with Fragile X syndrome among typically developing peers

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Introduction

Fragile X Syndrome (FXS) is a rare genetic disorder caused by CGG triplet repeat expansion in the *FMR1* gene, leading to reduced or absent Fragile X Mental Retardation Protein [1]. Individuals with over 200 define a full mutation (FXSFull). Somatic mosaicism (FXSMos) can modulate FXS phenotypes [2]. As a leading genetic cause of intellectual disability and autism spectrum disorder (ASD), FXS is often associated with orthopaedic features such as flat feet, joint laxity, hypotonia, and abnormal gait. Gait analysis (GA) enables objective assessment of musculoskeletal alterations and can be used as a support for planning physical therapy interventions [3]. When comparing FXSFull with FXSMos and healthy control subjects (CS) through standard statistical analysis, significant differences were observed [3] on both lower limb joint kinematics and surface electromyographic (sEMG) activity, thus demonstrating the presence of a characteristic gait pattern in FSX individuals. The aim of this study is to verify the possibility to classify children with FXS from CS by leveraging unsupervised machine learning (ML) techniques.

Methods

Forty-one children with FXS (mean age:10.04 ± 3.55 years; BMI:18.02 ± 6.66, 30 presenting FXSFull and 11 FXSMos) and four-teen age-and BMI-matched CS were enrolled. Gait data were recorded using four synchronized GoPro Hero 7 cameras (60 fps) and a Cometa sEMG system (2000 Hz), capturing muscle activity bilaterally from the Tibialis Anterior (TA), Gastrocnemius Lateralis (GL), Rectus Femoris (RF) and Biceps Femoris (BF). Extracted features included spatiotemporal (ST) metrics, joint kinematics, and EMG-derived parameters [3,4], including features obtained through Dynamic Time Warping algorithm. Multiple clustering algorithms were applied to both the full and reduced feature sets, and clusters were characterized using sEMG activation heatmaps and signal envelopes.

Results

In Figure 1 the clustering solution obtained through hierarchical clustering (linkage Ward, Hamming distance) with stride length, velocity, step width, double support time, stride time, and first and second muscle activation duration as input variables is reported. The model separated CS (cluster C2) from FXS group (clusters C1 and C3). The heatmap of the activation of the TA which shows a different sEMG activity pattern in C1 and C3 with respect to C2.

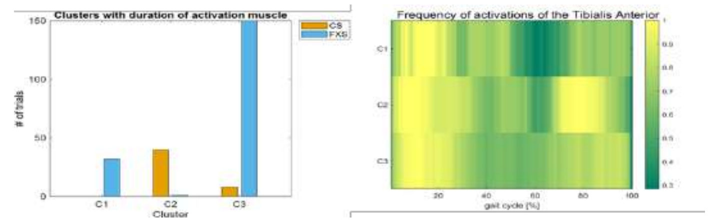

Figure 1. Cluster analysis with the number of trials for each phenotype (CS group in yellow; FXS group in light blue) on the left side; heatmap of the activation of the TA on the right side.

Discussion

The cluster analysis presented in this study demonstrates that gait features, such as ST parameters and muscle activity, can effectively distinguish children with FXS from CS. Further analysis will consider including joint angle range of motion in the sagittal plane and the introduction of supervised ML methods.

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Step length and step width estimation using an IMU-based wearable device with embedded dual wide-field-of-view cameras: a preliminary study

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Introduction

Spatio-temporal parameters such as step length (SL) and step width (SW) provide critical indicators of gait stability. Even though wearable inertial measurement units (IMUs) allow for low-cost, reliable gait analysis including numerous spatio-temporal parameters, the estimation of both SL and SW using IMUs remains challenging [1]. Latest advances in wearable motion sensors for gaming applications have led to the development of IMU-based wearable trackers, recently applied to gait analysis purposes [2]. Among these, the Vive Ultimate Tracker (HTC, Taiwan) features embedded dual wide-field-of-view cameras for self-contained 3D tracking within a spatially mapped environment. This study aims at assessing the accuracy of Vive Ultimate Tracker focusing on its performance in measuring SL and SW during gait.

Methods

Two healthy young male subjects performed five non-consecutive walking trials at three different speeds: slow (~0.7 m/s), self-selected (~1 m/s), and fast (~1.3 m/s), along a 5-meter linear path. Participants wore a Vive Ultimate Tracker equipped with four retro-reflective markers on each foot. A 14-camera Vicon system was used as a gold standard for SL and SW. The sampling frequency was set at 50 Hz. For both systems, foot linear trajectories were aligned to the direction of progression estimated via Principal Component Analysis. Heel strikes (HS) and toe-offs (TO) were detected using foot angular velocity [3]. SL and SW were defined as the anteroposterior and mediolateral distances between consecutive HS events, respectively.

Results

Table 1 reports the mean and standard deviation of SL and SW as measured from the optoelectronic system (MV_m) and trackers (MV_t), along with the relevant mean absolute error (MAE) and the root mean square error (RMSE).

Table 1.

		Slow	**Comfortable**	**Fast**
Step Length	MV_m ± SD [m]	0.599 ± 0.047	0.698 ± 0.04	0.835 ± 0.059
	MV_t ± SD [m]	0.600 ± 0.047	0.700 ± 0.04	0.833 ± 0.059
	MAE [m]	0.013	0.016	0.02
	RMSE [m]	0.016	0.019	0.027
Step Width	MV_m ± SD [m]	0.062 ± 0.032	0.058 ± 0.042	0.049 ± 0.029
	MV_t ± SD [m]	0.064 ± 0.034	0.059 ± 0.044	0.051 ± 0.033
	MAE [m]	0.007	0.009	0.012
	RMSE [m]	0.009	0.011	0.014

Discussion

This preliminary study shows that the VIVE Ultimate Trackers can accurately estimate both SL and SW of walking, with mean absolute errors below 20 mm and 13 mm, respectively. The technology implemented in the VIVE Ultimate Trackers represents therefore a promising improvement for indoor gait analysis with respect to the traditional wearable IMUs when a low-cost, portable solution is preferred. However, the traditional IMUs remain the technology of choice when spatial mapping of the surrounding environment is not feasible, such as in most outdoors environments.

Acknowledgements

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A step toward early prevention in diabetic foot: clustering of gait analysis data from a 15 years follow up study

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Introduction

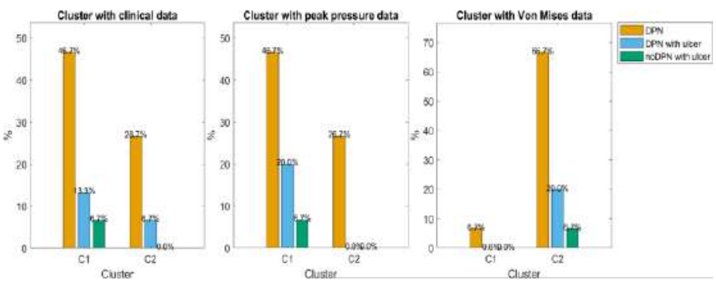
Diabetic foot (DF) is one of the worst complications of diabetes, with peripheral neuropathy (DPN), vasculopathy, and foot deformities representing the major risk factors, [1]. DF can lead to foot ulcers and consequent amputations. Even though the development of DF ulcers is multifactorial, consensus has been reached on the key role played by repetitive overloading and limited joint mobility in its development. The aim of this study is to demonstrate the possibility of identifying diabetes subjects at risk of foot ulcers based on gait analysis and internal stresses (i.e., Von Mises stresses computed through finite element analysis) data between 5 and 15 years in advance.

Methods

Eighty subjects were enrolled from 2009 to 2013 and prospectively followed up for 15 years with the following characteristics: Years of disease: NoDPN 15.9±10.65, DPN 23.4± 14.5; BMI: NoDPN 26.8±3, DPN 25.2±2.8, CS 24.5±2.44; age:NoDPN 61.9±9.08, DPN 61.3±8.4, CS 61.2±4.3. Participants underwent foot inspection for skin lesions, deformities, infections, ulcerations and amputations. Screening for DF risk was carried out according to IDF recommendations. Gait analysis data were collected using stereophotogrammetric system (BTS) synchronized with 2 Bertec force plates, a 16-channel surface electromyographic (sEMG) system (POCKETEMG, BTS), 2 plantar pressure plates (Imagortesi, Piacenza). sEMG was recorded bilaterally from key lower limb muscles involved in gait as in [2]. Sensor placement followed Blumenstein guidelines [3]. Whole body joint and foot subsegment kinematics and ground reaction forces were determined as in [4], as well as peak pressure. Von Mises internal stresses were obtained for bones and soft tissues through a quasi-static Finite Element Foot Model [5]. Cluster analysis (i.e., k-means and hierarchical) was performed on subsamples of subjects (n°37, n°15) with Orange Canvas (v.3.37) by considering different combinations of variables including: clinical assessment (i.e., presence of neuropathy, vasculopathy…), joint kinematics, ground reaction forces, peak pressure, Von Mises stresses.

Results

Meaningful clusters were obtained by considering plantar pressure or Von Mises stresses through Hierarchical clustering (linkage Ward and Hamming distance): all subjects who developed foot ulcers in the following 10 years were included in the same cluster. Differently when considering only clinical data, ulcerated subjects were distributed over clusters with larger presence of DF complications.



Discussion

Preliminary results demonstrate the potential of improving DF prevention by leveraging biomechanical data to identify DF subjects at risk for foot ulcers. Future development will include complete the analysis over the whole dataset and available variables.

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Correlations between EEG connectivity and motor performance: a comprehensive strategy for early detection of Alzheimer's disease

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Introduction
Alzheimer's disease (AD) is a major global challenge among neurodegenerative disorders. Recently, motor performance has gained attention as a relevant clinical indicator, not only in advanced stages of dementia but also in early phases. Alterations in gait, balance, and motor coordination have been consistently associated with cognitive impairment and are being explored as early markers of pathological aging. In this context, electroencephalography (EEG) is a valuable, non-invasive, and cost-effective tool for investigating brain activity [1]. Combining EEG with motor assessments helps to better understand the neurophysiological mechanisms involved in the progression of AD [2].

Methods
The present study includes 208 participants, grouped into healthy controls, individuals with mild cognitive impairment (MCI) and AD patients, matched by age, sex and education level according to established clinical criteria. EEG signals were acquired under resting-state conditions with eyes closed for several minutes. Motor function was evaluated through a battery of standardized assessments designed to measure multiple aspects of physical performance, including tests of gait speed, strength, and balance. This multidimensional approach allows for a complete profile of motor abilities. To provide a detailed profile of neural communication patterns, functional connectivity was investigated through the computation of Total Coherence (TotCoh), a measure of the overall synchrony and coherence of EEG activity, quantifying the degree of coordination among all brain regions. TotCoh can offer valuable information regarding functional synchronization and was calculated separately within each EEG frequency band. This approach allowed the investigation of how alterations in global brain communication relate to motor function across different stages of cognitive impairment [3]. Pearson correlation analyses were used to explore the relationship between TotCoh values and motor performance scores.

Results
Significant positive correlations emerged between TotCoh and motor parameters, particularly in strength-related assessments. Specifically, higher values were positively associated with better performance in both the Handgrip Strength Test and the Quadriceps strength evaluation, suggesting that greater inter-regional brain connectivity supports the maintenance of muscular strength in both upper and lower limbs. Positive associations were also observed in the Two Meters Walk Test, suggesting that higher coherence is linked to faster gait speed.

Discussion
Overall, the findings highlight a complex but consistent relationship between motor impairments and altered brain connectivity in aging and dementia. The presence of significant EEG–motor correlations supports the notion that combined neurophysiological and motor biomarkers could be valuable for early detection of AD-related changes. These results underscore the importance of integrating multimodal approaches to improve our understanding of neurodegenerative processes and to develop more sensitive tools for diagnosis and monitoring.

Acknowledgements
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A preliminary evaluation of the performance of a hand-held tablet-mounted RGB-D camera in assessing infant movements

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Introduction

Markerless video analysis is increasingly being used to complement clinical visual assessment of infant movement; however, limb occlusions remain a major limitation [1]. To enhance the visibility of limbs of interest, it can be convenient to move the camera to change the best view in response to the infant's motion. This study evaluates the feasibility of using a hand-held tablet-mounted RGB-D camera through the preliminary comparison of two commercial 2D tracking software integrated with a custom algorithm for 3D coordinate estimation, enabling to compensate for motion-related artifacts.

Methods

A hand-held tablet-mounted RGB-D camera (IntelRealSense D435, fs = 30 fps) was used for two video recordings of a doll, one with right and left arms straight (RS and LS) and one with right arm bent (RB), starting from a frontal view (0.5 m distance) and then moving the camera to the right/left of the operator, nearer (-0.2 m), further (+0.5 m), above (+0.3 m up), and below (–0.3 m down). MediaPipe (MP) and Sapiens (SA) [2] were used for the 2D tracking of the following Points of Interest (PoIs): left and right shoulders (S), elbows (E), and wrists (W). Then, 3D coordinates of PoIs were estimated as in [3] and referred to an infant reference system to account for camera motion. The variability of PoIs estimation was assessed in terms of standard deviation of the norm of the 3D PoI positions (Figure 1). The 3D upper arm (UA) and forearm (FA) lengths (S–E and E–W, respectively) were compared to manual measures (Figure 1).

Results

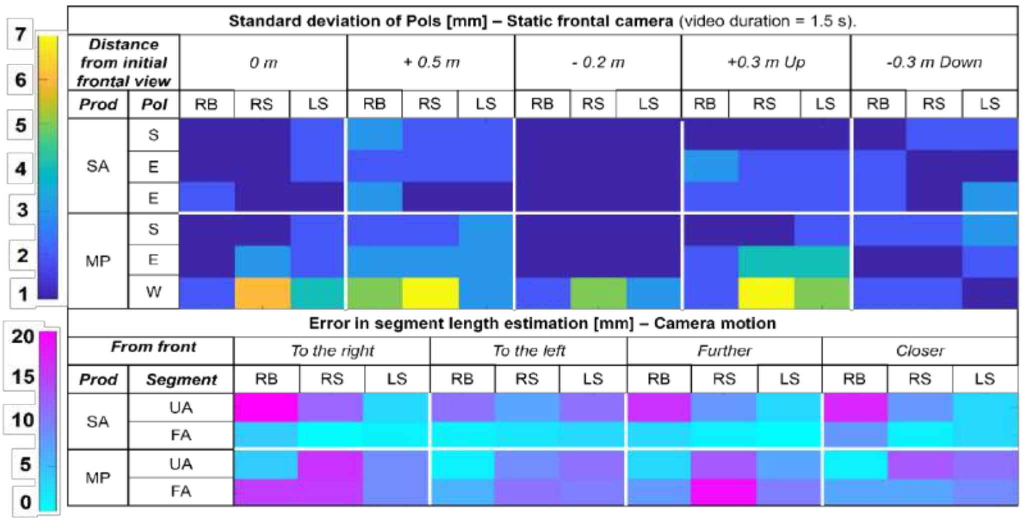

Figure 1. Summary of the performance of SA and MP. (1) Standard deviation of PoIs in mm (2) Error in segment length estimation in mm for UA and FA segments at each camera view.

Discussion

The standard deviation of the PoIs for both tracking software were comparable and below 7 mm. For both, as expected, the highest errors in segment length estimation occurred when the arm was occluded by body parts (e.g., right UA in the right-side view), confirming the need to adapt the camera view to maximize the limbs visibility. SA showed lower variability and smaller forearm errors compared to MP. Future infant studies will validate the use of a moving camera in clinical and home settings.

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Association between motor behavior and driving performance in adolescents

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Introduction

Driving is a multifaceted task requiring the integration of cognitive, perceptual, and motor processes. Among these, body movements, particularly of the head, have been shown to reflect underlying attentional and control mechanisms. Previous works have suggested that subtle changes in motor behavior can serve as markers of cognitive load and driving performance [1], [2], yet the relationship between these movements and driving performance in young drivers remains underexplored. This study aims to investigate how body movement relate to driving metrics in a sample of adolescents during a simulated driving task.

Methods

Fifteen neurotypical adolescents (13-19 years) completed the driving simulation using ADRIS 2.1 [3]. Driving performance metrics that include number of collisions, violations of traffic rules (wrong direction, speeding, ignored stop and ignored red lights), and speed (mean, std and max) were saved during the simulation along with input signals from pedals and steering wheel. Simultaneously body movements were recorded using a stereo camera. Head pose (pitch, yaw, roll) was extracted using the method by Cantarini et al. [4], while trunk motion in the sagittal plane was estimated using MediaPipe. Head and trunk signals were low pass filtered (Butterworth), and angular displacement and velocity were computed to quantify movement intensity and temporal dynamics. Their magnitude was assessed using root mean square values. For accelerator and brake signals, mean values and the percentage of time above activation threshold were extracted while steering behaviour was described using its standard deviation and angular velocity. Spearman's correlations were performed to investigate associations between movement variables and driving outcomes.

Results

Pitch angular velocity and displacement were negatively associated with wrong-direction violations (ρ= -0.54, p=0.04; ρ= -0.71, p=0.003), while yaw metrics were linked to collisions (angular velocity: ρ=-0.74, p=0.002; angular displacement: ρ= -0.66, p=0.008). Trunk displacement was negatively correlated with max speed (ρ= -0.69, p=0.03) and speed variability (ρ= -0.65, p=0.05). Trunk velocity also showed significant associations, being negatively correlated with both max speed (ρ= -0.72, p=0.02) and mean speed (ρ= -0.67, p=0.04). Mean accelerator pressure correlated with speeding infractions (ρ=0.91, p< .001), collisions (ρ=0.61, p=0.02), and total infractions (ρ=0.79, p< .001). Percentage of time above threshold was also correlated with collisions (ρ=0.58, p=0.02) and speeding (ρ=0.87, p< .001) for the accelerator while only with speeding violations (ρ=0.58, p=0.02) for the brake. Steering angular velocity correlated with mean (ρ=0.73, p=0.003), max (ρ=0.54, p=0.04), and standard deviation of speed (ρ= 0.65 p=0.01), while greater steering variability was associated with fewer collisions (ρ= -0.71, p=0.003).

Discussion

Findings suggest that reduced head and trunk movement is associated with poorer driving performance in adolescents. Specifically, lower pitch and yaw activity may reflect decreased visual scanning or attentional disengagement, impairing navigational accuracy, critical for avoiding wrong turns or collisions. Reduced trunk mobility in the sagittal plane, as reflected by lower movement amplitude and velocity, may point to diminished postural adaptability and motor responsiveness, which appeared crucial when managing acceleration and brake. The strong positive correlation between acceleration and driving infractions supports its role as a sensitive marker of behavioural impulsivity. Notably, while increased steering activity might intuitively be seen as erratic, our data suggest that greater steering variability, when not excessive, could reflect adaptive control strategies, allowing for corrections that reduce crash risk. These results support the hypothesis that bodily motion metrics can serve as non-invasive indicators of attention and behavioural state during driving. Future studies will extend this work to clinical populations, particularly those with attention deficit hyperactivity disorder (ADHD). This work was supported by the Italian Ministry of Research, NRRP – Fit4MedRob.

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Beyond the lab: walking and head-trunk motion parameters during real-world activities

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Introduction

Real-world walking involves active modulation of head and trunk motion to support visual exploration and situational awareness [1]. This calls for context-aware mobility analysis that captures locomotion variability in natural settings under the presence of visual and acoustic confounders and stimuli [2]. This study investigates how upper and lower body motion adapt during daily-life walking tasks with varying sensory and cognitive demands, with the goal of characterizing a motor baseline for healthy individuals.

Methods

8 young adults (60% females, 21-33 years) completed four straight walking trials in a lab setting and a 2.5-hour real-world session. Participants wore the INDIP multi-sensor system [3], including pressure insoles, distance sensors and 5 magneto-inertial measurement units (MIMUs) positioned on the head, chest, lower back, and feet (100 Hz), along with smart glasses for video recording (1920×1080 px, 30 fps) (Figure 1A). INDIP data were used to segment strides. Video data were used to annotate four real-world walking situations: road crossing, texting, phone calls, and visual search within a supermarket (Figure 1B). The relative yaw orientation of the head and trunk was estimated by a fusion algorithm [4], and yaw head-trunk relative range of motion (ROM) was calculated as the range of such relative orientation over a stride. Stride variability was computed as the standard deviation of stride duration. Both metrics were averaged per activity and subject. Real-world situations were compared with lab walking for all parameters. A one-way repeated measures ANOVA ($\alpha = 0.05$), followed by Holm's post-hoc test, was used to assess differences across activities. This study was part of the project NODES, MUR – M4C2 1.5 of PNRR funded by the European Union - NextGenerationEU (ECS00000036 – CUP E13B22000020001).

Results

Yaw head-trunk ROM during visual search exhibited significantly higher median (28.30°) and interquartile range (IQR, 27.28°) than the other activities ($p < 0.001$). Yaw ROM during *texting* and *phone calling* was also significantly smaller than during *road crossing* ($p < 0.001$). Stride variability was significantly higher ($p < 0.01$) during real-world visual *search* tasks (median: 0.19 s, IQR: 0.21 s) than all other conditions (Figure 1C).

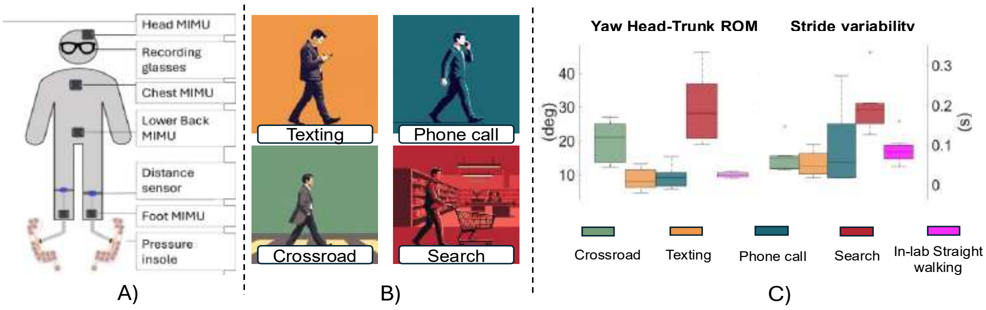

Figure 1. A) Experimental setup; B) Activities labeled from real-world video recordings; C) Boxplots of the extracted parameters across real-world walking activities and laboratory straight walking.

Discussion

The increased yaw ROM during visual search reflects the greater head scanning demands of this task compared to other activities. The higher variability in stride duration during real-world tasks, especially visual search, compared to laboratory walking suggests that natural environments impose greater motor control challenges. These results underscore the need to consider ecological contexts when assessing gait and upper body movement. Future studies should investigate whether these daily-life movement patterns are altered in populations with motor or cognitive impairments.

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Muscle activity during walking in water and overground: pilot test in multiple sclerosis

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Introduction

Multiple sclerosis (MS) often leads to muscle weakness and severe fatigue, impairing gait and reducing endurance [1]. Aquatic environments modify biomechanical demands through buoyancy and resistance, potentially facilitating safer, more efficient walking [2]. This pilot study compares muscle activation patterns and functional performance of people with MS (PwMS) and Unimpaired Subjects (UI) during the 6-Minute Walking Test (6MWT) performed overground and in water, to assess the feasibility of integrating aquatic gait exercises into MS rehabilitation [3].

Methods

Seven PwMS (age 58.7 ± 5.2 years, 2 W; Expanded Disability Status Scale (EDSS) 4.1 ± 1.7) and seven UI (age 26.4 ± 1.3 years, 4 W) completed two walking sessions: overground and in water. Each session included six 4-m walking trials at both normal and fast speeds, followed by the 6MWT performed within an 18 m perimeter. All analysis were performed on the 6MWT. Water walking trials were conducted at two immersion levels: approximately 90 cm for the 4-m tests and 110 cm for the 6MWT. Surface electromyography recorded eight lower-limb muscles bilaterally; each probe included an integrated tri-axial accelerometer used for step segmentation. EMG signals were band-pass filtered (40–450 Hz), rectified, low-pass filtered (4 Hz) and normalized to peak envelope per muscle. Also, distance traveled was recorded for the 6MWT. A two-way repeated-measures ANOVA (factors: group, condition) was applied to walking distance and normalized EMG values. EMG statistical analyses were performed using the SPM1D open-source MATLAB tool (spm1d.org).

Results

Both groups walked more slowly and covered shorter distances in water compared to overground. In the 6MWT, PwMS walked 354.6 ± 92.0 m overground and 189.0 ± 61.5 m in water, while UI walked 517.7 ± 88.6 m overground and 209.0 ± 40.4 m in water (mean ± SE). Statistical analysis showed a significant main effect of group ($p = 0.037$, $F(1,6)=7.16$), with UI walking farther overall, and of condition ($p = 0.009$, $F(1,6)=97.71$), confirming that walking distances were shorter in water. A significant interaction ($p = 0.022$, $F(1,6)=9.32$) indicated a greater performance drop in UI, suggesting a differential impact of the aquatic environment. EMG data showed that water walking reduced peak activation of key lower-limb muscles in both groups, especially the plantarflexors and knee flexors, along with delayed activation timing ($p = 0.008$, $F(1,6)=9.81$). While attenuation was less marked in PwMS, no significant group differences emerged, likely due to the small sample. Notably, PwMS showed a smoother and more prolonged muscle activation during stance, indicating steadier, more evenly distributed neuromuscular recruitment in water.

Discussion

Walking in water significantly reduces walking distance in the 6MWT in both groups but also narrows the gap between them. PwMS already walk with a cautious, stability-oriented gait on land; the buoyant and resistive properties of water impose relatively less additional challenge on them than on UI, effectively bringing their performance closer. In parallel, the resistance and hydrostatic pressure of water provide continuous sensory feedback and a controlled muscle load, resulting in smoother and prolonged activation of the lower-limb muscles, as evidenced by EMG recordings. These activation patterns suggest that aquatic gait training can optimize neuromuscular recruitment in PwMS, potentially improving balance confidence, reducing perceived exertion, and delaying the onset of fatigue during everyday walking. Furthermore, the supportive aquatic setting may encourage higher adherence to exercise programs by minimizing fear of falling. These findings support incorporating structured water-based therapy, combining endurance, strength, and proprioceptive drills, into MS rehabilitation protocols.

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Evaluating patient experience with 3D-printed personalized orthoses: comfort and satisfaction survey

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Introduction

The ankle foot orthoses (AFOs) are essential devices supporting the dorsi-flexion of the ankle in patients with walking disorders. In the context of the APTIS project, the development and adaptation of 3D printed AFOs to meet the requirements of single patient needs with foot drop has been undertaken [1]. However, in the development of a device for a patient, it is necessary to evaluate not only its quality and performance but also its potential acceptance. This involves assessing its comfort, usefulness in performing an action, and effectiveness in the context in which it is used. The aim of this study was to evaluate patient comfort and overall satisfaction with a customized orthosis produced using a tailored design process.

Methods

Fourteen subjects with drop foot were recruited to assess how well the orthosis meets their specific needs. Each of them was provided with a tailored orthosis designed and manufactured according to the methodologies defined in the APTIS project [1]. After use, the patients expressed their evaluations of the device by answering two questionnaires: the Comfort Rating Scale (CRS) and the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST). The CRS assesses the level of comfort in 6 domains (with scores ranging from 0 for high comfort to 20 for extremely low comfort), while the QUEST measures overall satisfaction in 8 items on a scale from 1 to 5.

Results

In Figure 1, the results of the CRS scale and the QUEST scale are reported. In the case of the CRS scale, it was found that all scores, except for sporadic outliers, reached an average value of less than 5. This demonstrated the quality of the orthosis in terms of wearability, with the perceived contact being the highest value (4.60). This indicated that a wearable system was in place, but that recommended interventions were necessary. In the case of the QUEST scale, all scores are contained within a range of 3 to 5, except for sporadic outliers. The lowest mean value recorded was for size, which was 3.73. Conversely, the highest mean value recorded was for weight and stability and safety, which was 4.40 and 4.00 respectively.

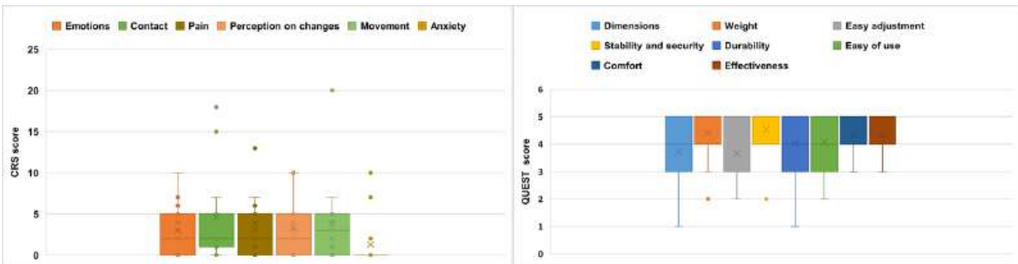

Figure 1. CRS scale results (left) and the QUEST scale (right).

Discussion

While previous studies [2] have already demonstrated the functional efficacy of these orthoses, this work further investigates their acceptance and wearability among users. High satisfaction scores in areas such as device stability, safety, and overall usability support the notion that addressing individual morphological and functional requirements is key to effective rehabilitation. Minor concerns, such as lower scores in ease of use and sizing, highlight areas where further refinements may yield even better outcomes. Overall, this study reinforces the importance of patient-centered design, demonstrating that personalization plays a crucial role in ensuring both functional success and user comfort.

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Effects of a physical therapy program on surface electromyographic activity of erector spinal muscles in sports patient with non-specific low back pain: a case report

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Introduction

Non-specific low back pain (NSLBP) is a common condition that can impair neuromuscular function and sports performance. Heavy lifting during training is a frequent trigger for NSLBP. This case report aimed to evaluate the impact of a physiotherapy intervention on pain levels, neuromuscular control assessed through surface electromyography (sEMG), and sports performance in a patient with NSLBP [1, 2].

Methods

A 30-year-old male athlete reported NSLBP following heavy lifting during sports training. The physiotherapy intervention included education, manual therapy, therapeutic exercises, and motor control training, progressing to the reintroduction of the previously painful movement.

Results

Patient-reported outcome measures (PROMs) demonstrated significant improvements, including a reduction in the Örebro Musculoskeletal Pain Questionnaire (OMPQ) score from 71 to 55, an increase in the SF-36 Physical Functioning (PF) score from 81 to 90, and an improvement in the Aberdeen Stairs score from 34.78% to 10.86%. Pain levels, as measured by the Numeric Pain Rating Scale (NPRS), decreased from 7/10 to 1/10. sEMG analysis revealed improved flexion relaxation ratio (FRR), indicating enhanced neuromuscular control, particularly in the eccentric activity of spinal erectors (Table 1).

Table 1. Flexion Relaxation Ratio (FRR) and Flexion Relaxation Phenomenon (FRP) as computed from sEMG data.

Time point	Index	ES L1-L2 left	ES L1-L2 right	ES L4-L5 left	ES L4-L5 right
12/09	FRP	3.48/18.98	4.71/9.19	2.90/25.34	3.91/21.05
	FRR	10.67	7.33	9.01	5.69
3/10	FRP	3.70/23.67	4.36/10.68	4.35/25.68	5.28/15.27
	FRR	10.38	7.95	10.63	6.55

Discussion

This case highlights the importance of tailored physiotherapy interventions for athletes with NSLBP, emphasizing the relevance of addressing neuromuscular deficits to restore sports performance and prevent recurrence. The integration of objective sEMG measures and PROMs provides valuable insights for sports physiotherapy practice.

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Formative research on video documentation in perinatal brachial plexus injury assessment: A clinical practice improvement study

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Introduction

While video movement analysis shows promise for identifying infants at risk for neuromotor impairment [1,2], current gold standard methods require precise setup and time-consuming processing that creates barriers to clinical implementation.[3] There is currently little attention given to paediatric clinicians' perceived practice improvement needs and how video movement analysis technologies might scale and adapt to day-to-day clinical environments. The purpose of this study was to conduct formative research on clinicians' perceived utility of video documentation in their practice. Perinatal brachial plexus injury (BPI), where timely diagnosis is of particular concern [4], was our chosen test domain.

Methods

We collected video of 14 infant assessments in the biweekly BPI clinic of a major US Children's hospital. A multidisciplinary team comprised of three clinicians, one each from occupational therapy, physical medicine and rehabilitation, and paediatric neurosurgery, participated in each infant assessment. Video was captured using a Surface Pro 4 tablet with standardized handheld positioning. The multidisciplinary BPI clinic team was debriefed (recorded and transcribed) on the same day as assessments were conducted. Videos were subsequently processed using the MediaPipe machine learning (ML) pipeline to obtain anatomical points of interest (PoI) and to overlay joint angle measures (Figure 1.) on each video frame to serve as an exemplar of possible computational approaches to increase the efficiency of video review. MMS used content analysis to identify key use cases, requirements, and barriers, which were then verified and elaborated by MT, BPI Clinic occupational therapist.

Figure 1. Shoulder angle overlay on infant with BPI

Results

The key driver for use of video in BPI assessment was the affordance it provided clinicians to review and drill down on the subtle quality of an infant's movement in contrast to the grosser measures documented in the prescribed quantitative scale. The main contexts for use of video were identified as preparing for an infant's subsequent visits and as an aid to clinical decision making, particularly relative to surgery. Clinicians saw value in automated reporting of relative frequency of BPI pathognomonic, ML-identified movements and postures. Barriers to incorporating video in BPI workflow included time to review, difficulty of video capture given infant unpredictability, the need to setup/troubleshoot equipment, and lack of accommodation of video in the patient electronic medical record.

Discussion

Video records represent the richest, most accessible repository of movement data in clinical practice - analogous to how MRI provides comprehensive structural information, but without, in the specific context of infants and BPI, requiring sedation or specialized facilities. Video documentation of clinical assessment further enables a full range of possibilities for use, from human review to computational analysis and reporting. Addressing workflow integration barriers represents the critical first step toward unlocking video's potential for computational enhancement in clinical practice. Fostering the routine use of video in clinical practice provides a foundation for building computational tools that authentically address clinicians' needs and are more likely to improve patient outcomes.

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Exploring neuromuscular control through EMG-informed modeling: a comparison of estimation methods for a 6DOF knee model

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Introduction

Anterior Cruciate Ligament injuries are common in high-intensity sports due to movements like drop landing (DL) and squat [1]. In this context, accurate musculoskeletal models (MSMs) are needed to simulate these challenging tasks with the final aim of estimating internal parameters as activations (MA) and muscle forces (MF) as well as ligament strains. In this regard, standard methods (i.e. Static Optimization (SO)) are commonly used, however, they may lack in taking into account the subject-specificity of neuromotor control when pathological or elite athletes are the object of the investigation. To overcome this limit electromyography (EMG)-informed approaches, such as Computed Muscle Control (CMC) [2] and Moco [3], could represent an interesting alternative as they showed to provide muscle excitations closer to the experimental surface EMG (sEMG) [4]. The aim of this study is to compare the impact of integrating sEMG signals in a 6-degree-of-freedom (DOF) knee MSMs [1] by leveraging Moco and CMC approaches.

Methods

Ten healthy subjects (mean age and BMI: 26.1 ± 1.5 years, 22.6 ± 2.0 kg/m^2) were acquired through six BTS cameras (60 Hz), synchronized with two Bertec force plates (960 Hz) and an 8-channel sEMG system (1000 Hz, Free EMG, BTS) during three bipodal DL and bipodal squat. Two sets of muscles were acquired placing sEMG sensors bilaterally: 1. Rectus Femoris, Biceps Femoris, Tibialis Anterior (TA) and Gastrocnemius Lateralis; 2. Vastus Lateralis, Semitendinosus, TA and Gastrocnemius Medialis. Thirty reflective markers were positioned following a modified IORGait protocol with clusters on pelvis, thigh and shank [5]. Data were processed in OpenSim (Inverse Kinematics, Inverse Dynamic, SO) using a 6DOF knee MSM [1] to generate input files for Moco EMG-informed analysis and constrain muscle excitations for the CMC. sEMG envelope peaks were calculated via bandpass filtering (10–450 Hz) with a fifth-order Butterworth filter. To assess the impact of integrating sEMG data into MSMs, the root mean square error (RMSE) and coefficient of multiple correlation α [6] between MA estimated through the different approaches and experimental sEMG were computed. Paired t-tests using SPM were conducted across all methods.

Results

Preliminary results considering 5 subjects performing a bipodal DL task are reported in Figure 1 and suggest that Moco estimates closely match the experimental sEMG (α > 0.98; RMSE < 0.02).

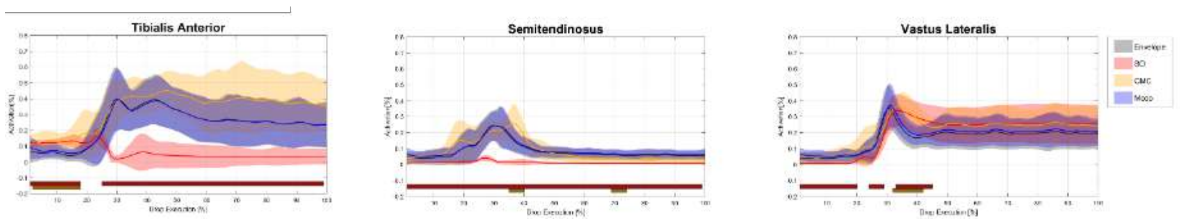

Figure 1. Comparison among experimental sEMG and SO, CMC, Moco MA estimates: mean ± std. *statistical significance ($p<0.05$)

Discussion

Given that MF cannot be experimentally measured, the state of the art reliability test relies on comparison between experimental sEMG and simulated ones [8]. Our results suggest that MF estimated through Moco EMG-informed should be preferred in the context of a 6DOF knee model.

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Towards clinical translation of EMG-informed models via synergy-based input reduction

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Introduction

Computational neuromusculoskeletal (NMS) modelling allows non-invasive estimation of muscle activity [1]. Electromyography (EMG)-informed approaches (i.e. Moco [2]), improve subject-specificity and the reliability of force predictions. However, their clinical adoption is limited by the complexity of EMG acquisition protocols, which in the case of EMG informed approaches, might require a considerable number of signals making the simulation computationally inefficient, and the acquisition session complex for the patients [3]. This study proposes a reduced EMG setup leveraging muscle synergy analysis to full muscle excitation from a minimal number of signals.

Methods

Twelve right gait trials were acquired from four healthy control subjects (mean age: 60 ± 2.16 years; mean BMI: 26.66 ± 4.13) using a motion capture system (BTS, 60 Hz), synchronized with 2 force plates (Bertec, 960 Hz) and a 15-channel surface EMG system (FreePocketEMG, 1000 Hz). The enhanced IOR-Gait protocol (i.e. with clusters [4]) was adopted for marker placement, and EMG signals recorded from 15 lower-limb muscles listed in Figure 1a. Data were processed in OpenSim to perform scaling, inverse kinematics, and inverse dynamics. Muscle activation and forces were then estimated using Moco EMG-informed, which incorporated the full set of experimental EMG signals. Four muscle synergies were extracted via Non-negative Matrix Factorization [1], and each synergy was mapped to a representative muscle per joint function group using Statistical Parametric Mapping and Coefficient of Multiple Correlation (CMC) [5]. Finally, the original NMS model was augmented with a synergy-based controller, and simulations were performed using a reduced EMG setup consisting of the four most representative muscles.

Results

Figure 1c shows CMC values for the four muscles best matching each synergy in one trial of a subject: Vastus Lateralis, Gastrocnemius Medialis, Semitendinosus, and Tibialis Anterior.

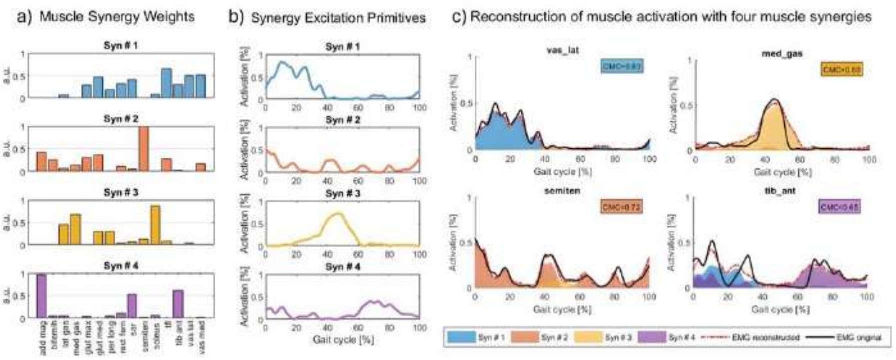

Figure 1. (a) Synergy weights; (b) Excitation primitives; (c) Experimental (black) and reconstructed (red) EMG signals for a representative subject. CMC values quantify reconstruction accuracy. Signals normalized in arbitrary units (a.u.) over a gait cycle.

Discussion

The implemented methodology allowed the analysis of the estimation of muscle forces during gait with four EMG signals. The variability in muscle recruitment across individuals confirms the subject-specific nature of synergies, emphasizing the need for personalized calibration. Preliminary results support the feasibility of synergy-based muscle excitation prediction, but further validation is needed on larger and pathological populations.

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Dystonia: usefulness of 3D gait analysis and dynamic surface electromyography in discriminating dystonic actions from compensatory mechanism

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Introduction
Dystonia is a movement disorder characterized by involuntary contractions of one or more muscles causing abnormal, often repetitive, movements, postures, or both [1]. Botulinum Neurotoxin (BoNT) represents an effective treatment option, but muscle selection for injection is particularly challenging. Some muscles may present hyperactivity as a compensatory mechanism to counteract dystonic movements. Correct identification of dystonic muscles is therefore critical for successful outcomes [2,3].

Methods
A 35-year-old Caucasian female with a painful dystonic foot posture in dorsiflexion and supination and a marked big toe extension during walking was evaluated by 3D gait analysis (GA) and dynamic surface electromyography (sEMG) of the lower limb [3]. Since results obtained confirmed the clinical evidence of Tibialis Anterior (TA) and Extensor Hallucis Longus (EHL) hyperactivation but also showed a not clinically detectable abnormal recruitment of Gastrocnemius Medialis (GAM), in the same evaluation session, sEMG was registered during the execution of some segmentary movements including foot eversion, the opposite foot posture to the dystonic one.

Results
GAM showed abnormal recruitment both during gait and during eversion, so it was suspected to be the real dystonic muscle, while TA and EHL hyperactivaction a compensatory mechanism. By a selective peripheral motor nerve block, GAM was temporarily switched off with an evident relief of patient’s dystonic posture (Fig. 1) that confirmed the suspicion.

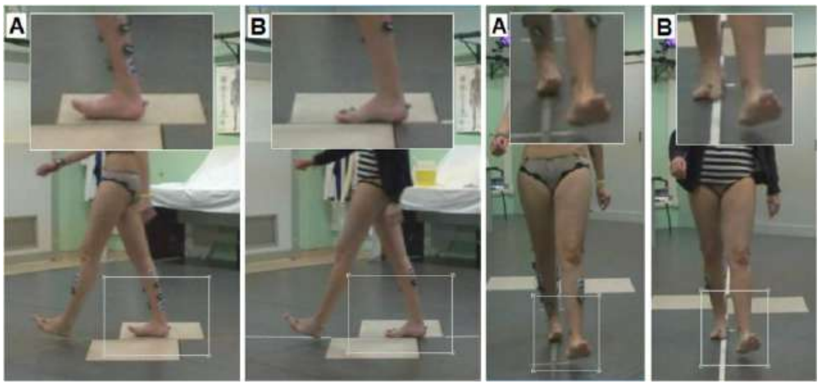

Fig.1 Sagittal and frontal view of the right foot posture at the end of MidStance. Comparison between pre(A) and post(B) motor nerve block for GAM branch.

Discussion
Based on the results, GA and dynamic sEMG during personalized motor tasks demonstrate in our clinical case to be a valid evaluation tool for discriminating hyperactive compensatory muscles, TA and EHL, clinically observable, from the dystonic muscle, GAM, whose contraction was covered. This is only a single case, but it could inspire a possible way to proceed in dystonic patients.

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Evaluation of the optimal number of steps to obtain reliable running gait variability in outdoor

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Introduction
Gait variability (GV) has become an increasingly important focus in sports science [1], offering valuable insights into the mechanisms of human locomotion, particularly in relation to bioenergetics and motor control. However, GV research in track and field settings, for improved ecological validity, remains limited and requires further exploration. Therefore, the primary aim of this study was to determine the optimal number of steps needed to obtain reliable parameters for quantifying GV in trained runners. A secondary aim was to describe the absolute reliability metrics of running parameters related to GV.

Methods
Ten trained runners (age 40.9±14.7 years, training experience 16.7±8.2 years) completed two 10-minute running trials at their previously assessed individual critical speed [2], following a 10-minute warm-up. Trials were conducted on separate days to assess measurement reliability. Each participant wore GPS devices (Garmin Forerunner Rc730-XT) while a sports scientist accompanied them on a bicycle equipped with a similar GPS unit. Heart rate was continuously recorded using Polar H-10 monitors and expressed as percentage of maximal heart rate (%HRmax; calculated as 220-age). RunScribe™ foot-pods (Scribe Lab Inc., 500 Hz sampling rate, 0.002s precision) were attached to both shoe laces to capture step data [3]. Kinematic and kinetic parameters included contact time (CT, ms), flight time (FT, ms), step length (SL, m), stride time (ST, s; calculated as sum of CT and FT for both legs), leg stiffness (kleg), and vertical stiffness (kvert). The phase coordination index (PCI) was computed for each trial from a minimum of 600 footsteps [4], with optimal step number determined when steady-state PCI condition (±2) was reached. Reliability was assessed using ICC, and repeated measures ANOVA with paired t-tests compared metrics between conditions ($P<0.05$).

Results
For each trial at the critical speed (14.45±1.39 km/h), we observed good reliability of the measurements (Table 1). The optimal number of steps for calculating PCI was reached at 246±11.74 (range: 235–270 steps). No significant differences were found when comparing PCI calculated with 246 steps (1.563±0.536%) and PCI calculated with 600 steps (Table 1) ($P=0.551$). Time for 246 steps (168±7s) was similar to heart rate steady state (175±11s; $P=0.051$).

Table 1. Kinematic/kinetic, PCI and HR and for both trials.

Variables	Test	Re-Test	ICC	*P*	F-Value
Stride Time (s)	0.685±0.027	0.679±0.021	0.778	0.375	0.873
Stride Length (m)	2.65±0.30	2.56±0.35	0.903	0.031	5.433
Contact time (ms)	256.08±22.66	263.05±23.05	0.956	0.001	14.179
Flight time (ms)	85.58±16.98	77.18±20.31	0.861	0.001	13.993
k-leg ($kN \cdot m^{-1}$)	7.81±1.68	7.63±1.33	0.904	0.395	0.758
k-vert ($kN \cdot m^{-1}$)	19.89±2.82	19.71±1.33	0.717	0.804	0.063
PCI (%)	1.548±0.529	1.442±0.392	0.936	0.153	2.438
HR (%HRmax)	89.27±7.91	92.58±4.99	0.982	0.854	0.036

Discussion
This study demonstrated good reliability (Table 1) for kinematic/kinetic parameters, PCI, and HR under ecological conditions at critical speed. Approximately 246 steps are required to reliably quantify PCI in outdoor settings. The observed gait patterns may reflect central nervous system strategies for optimizing motor function. Additionally, increased coherence between cardiovascular and muscular systems has been associated with higher stride rates during high-speed running, resulting in improved metabolic performance.

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Radar-based center of mass velocity estimation in typical and simulated pathological gait.

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Introduction

Millimeter-wave radars provide non-invasive, continuous means for gait analysis and show potential for monitoring pathological walking patterns [1]. Combined with deep learning, they may yield accurate, unobtrusive estimates of clinical parameters beyond standard spatiotemporal metrics [2], yet their precision in tracking body center of mass (BCoM) kinematics remains untested. This study therefore estimated BCoM 3D velocity from three synchronized radars during typical and simulated pathological gait, using an optoelectronic system as reference.

Methods

Sixty healthy adults (34 men, 26 women; height 1.71 ± 0.09 m; mass 68.1 ± 12.6 kg; age 31.1 ± 8.5 years) walked on a treadmill for one minute: at 2 km/h while simulating pathological gait patterns (PG) and at 4km/h while walking normally (NG). Three Infineon Sense2GoL V1.2 radars (2.5 kHz) recorded antero-posterior (AP), medio-lateral (ML) and cranio-caudal (CC) motion; synchronously an optoelectronic Vicon Vero system (200 Hz) tracked 18 markers to derive BCoM trajectories and to segment gait cycles. Optoelectronic data were resampled to match radar length. Data were split 70/15/15 into training, validation and test sets. Six BiLSTM networks (one per radar-walking type combination) were built with three blocks composed of a BiLSTM layer (32 hidden units) and a normalization layer. The three blocks were followed by a dropout layer (20% probability) and a fully connected layer. Performance was assessed with Root Mean Square Error (RMSE) and a linear-fit method [3] yielding waveform correlation (R^2), offset (a_0) and scaling factor (a_1).

Results

All networks achieved RMSE < 0.04 m/s, low a_0 and R^2 > 0.93. The amplitude scaling factor shows slightly lower performance. Figure 1 shows detailed results for each component and type of walking on the means of the test data subset over the entire gait cycle.

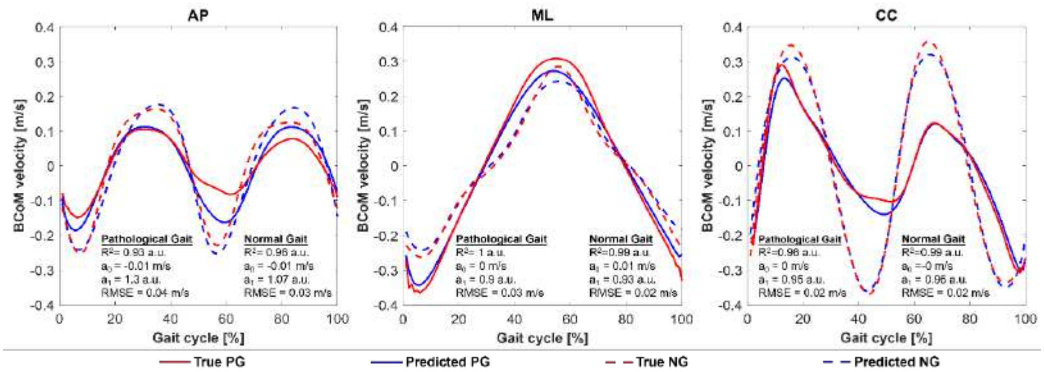

Figure 1. Mean of ground-truth (red) and predicted (blue) BCoM velocity during pathological gait (solid) and typical gait (dashed) of the test data subset.

Discussion

These findings demonstrate the feasibility of estimating 3-D BCoM velocity with millimeter-wave radar on a simulated pathological gait. Future research should validate the approach in clinical populations and explore alternative architectures or hyper-parameter tuning to improve peak-velocity estimation.

Acknowledgements

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Muscle co-contraction activity in altered visual perception of the hand: a case report on a stroke patient in virtual rehabilitation-guided reaching and grasping tasks

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Introduction

Visuomotor adaptation (VMA) is a form of motor learning that allows individuals to adjust movements in response to visual perturbations [1]. In post-stroke patients, this ability is often compromised due to motor and sensory deficits, such as abnormal co-contraction of agonist-antagonist muscles and altered body representation. Immersive virtual reality (VR) offers new opportunities to study and enhance neuroplasticity, with promising effects on motor dexterity and VMA [2]. However, no studies have examined how VMA is affected by VR-induced perturbations of internal body representation. This study investigates the effect of visually altering hand size on VMA, introducing a novel paradigm for post-stroke motor rehabilitation.

Methods

Surface electromyographic (sEMG) activity was recorded using the FREEEMG system (BTS Bioengineering) from eight upper limb muscles: adductor pollicis (AP), flexor and extensor carpi radialis (FC-EC), finger extensor (ED), biceps brachii (BB), triceps brachii (TB), anterior deltoid (DA), and upper trapezius (TS). Data were collected during reaching and grasping tasks performed in a virtual environment while visualizing the participant's own hand with either increased or reduced dimensions. The same tasks, executed in both a real environment and a virtual environment without hand size alterations, served as control conditions. EMG data were band-pass filtered between 20–450 Hz using a zero-phase, sixth-order Butterworth filter. Signals were rectified, and envelopes computed. An on–off detection algorithm [3] segmented EMG activity of agonist and antagonist muscles during repetitions. The co-contraction index (CCI) [4] was calculated for each muscle pair and repetition under real and virtual conditions. The pairs of muscles analyzed are shown in Figure 1. A nonparametric Wilcoxon rank-sum test compared CCI values between altered hand size and normal size conditions one for each muscle pair. Statistical significance was set at $p < 0.05$.

Results

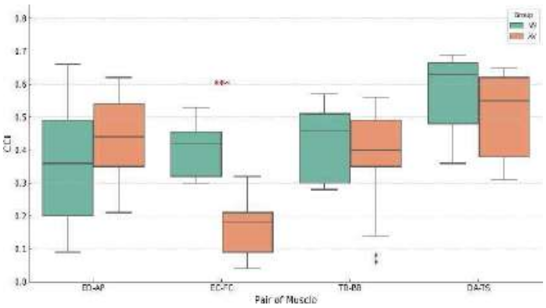

Figure 1. CCI comparisons for each pair of agonist antagonist muscles in NV and AV.

A strong statistical difference was found for the EC-FC pair ($p < 10^{-4}$), with median CCI values of 0.18 for modified size and 0.42 for normal size. Lower median CCI values in altered vs normal condition were also observed for the DA-TS (0.55 vs. 0.63) and TB-BB (0.40 vs. 0.46) pairs; however, these differences were not statistically significant. The ED-AP pair represents the only case in which the median CCI was higher in the altered hand size (0.44) than in normal size (0.36), though this difference also did not reach statistical significance ($p > 0.05$).

Discussion

The results suggest that altered visual perception of the hand during virtual rehabilitation may reduce muscle co-contraction, as indicated by a significant CCI decrease in the EC–FC pair under altered hand size conditions. Although TB–BB and DA–TS pairs did not show statistically significant differences, their median CCI values were also lower versus control conditions. This preliminary finding highlights the potential of modulating visual feedback to influence muscle engagement and promote more synergistic, efficient movements by reducing pathological co-activation. Further studies with larger stroke patient samples are needed to confirm these effects.

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Modelling real-world gait scenarios in knee OA with IMU-guided optimal control simulations

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Introduction

Falls pose a significant health risk in older adults with knee osteoarthritis (OA). In this context, the PowerAging project — part of DARE initiative — has two main aims: (1) To explore the relationships among mobility performance, muscle force, muscle power and motor control to identify early predictors of falls; (2) Develop and validate a workflow for predictive simulation of human movement using virtual inertial measurement unit (IMU) data, seeking to test hypothetical scenarios such as a decline in walking speed or in step length before they occur and explore the results of kinematics and dynamics. To this end, we are currently conducting a longitudinal clinical study on 50 adults with knee OA where we collect motion capture data from a gait assessment, isometric and isokinetic dynamometry data, and IMU data from a 5-day real-world assessment. In this contribution, we focus on the second aim of the project.

Methods

As a first case study, we scaled a generic musculoskeletal model to one participant, implemented with 11 contact spheres and a virtual IMU was added to the lower back to simulate acceleration signals. An initial optimal control simulation (OpenSim Moco [1]) is performed to track joint kinematics derived from inverse kinematics analysis and experimental ground reaction forces (GRF). A second simulation tracked virtual IMU-derived accelerations. Subsequently, IMU data recorded in the laboratory and during real-world activity were used to drive the simulations. To better represent the real-world a mean speed, derived from digital mobilise outcome [2], is used as endpoint constraint in further simulation. This workflow will be used in other subjects after data collection. The results analysis compares the output from optimal control simulations (e.g. knee kinematics, gastrocnemius lateralis activations, knee joint reaction forces) with those obtained through standard OpenSim analysis.

Results

In figure 1 knee joint kinematics show minor differences over 50% of gait cycle (R^2 = 0.993±0.07; RMSE = 2.034°±1.247°); instead gastrocnemius lateralis activations are higher in optimal control simulation than static optimization (R^2 = 0.486±0.115; RMSE = 0.093±0.022) and knee joint reaction forces follow a similar trend, though with different magnitude (R^2 = 0.737±0.058; RMSE = 515.816N±37.388N).

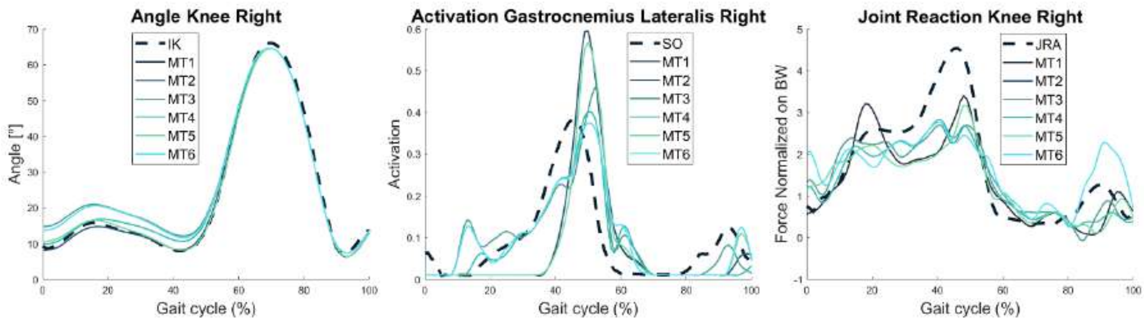

Figure 1. Comparison among inverse kinematics (IK), static optimization (SO), joint reaction analysis (JRA) with Moco tracking states & GRF (MT1); Moco track states, GRF & virtual IMU (MT2); Moco track states, GRF & real-lab IMU(MT3); Moco track states, GRF & real-world IMU(MT4); Moco track states, GRF & average speed (MT5); Moco track states, GRF, real-lab IMU & average speed (MT6).

Discussion

Although, this approach is still in the early stage, the results are encouraging. The discrepancies observed in the results may be due to simplifications in the model and contact representation. Optimal control simulations will provide a more physiological estimation of internal states and motor control patterns; moreover, integrating IMU data from real-world assessment will allow the exploration of hypothetical scenarios and support the design of preventive training strategies.

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Differences in shoulder neuromuscular activity and functional outcomes among breast cancer survivors and healthy controls

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Introduction

Advances in breast cancer treatment have significantly improved survival, with five-year rates reaching up to 90% in early-stage diagnoses [1]. Nonetheless, survivors frequently face both immediate and long-term complications, including pain, musculoskeletal dysfunction, lymphatic sequelae, and reduced quality of life. Altered scapular kinematics and neuromuscular activity - often linked with pain, surgery, or central sensitization - can contribute to persistent shoulder dysfunction. A comprehensive assessment of physical function, perceived disability, and structural damage may help identify distinct clinical profiles.

This study aimed to examine differences in physical function and shoulder neuromuscular integrity between breast cancer survivors and healthy women. We also explored within-group associations between perceived disability and neuromuscular function to identify potential neuromechanical patterns

Methods

A cross-sectional study included 36 consecutive women (61.8 ± 8.6 years) allocated into three groups: (A) long-term breast cancer survivors (n=16, ≥5 years post-surgery), (B) women in the acute post-surgery phase (n=10, ≤1-year post-surgery), and (C) healthy women controls (n=10).

Surface EMG (FREEEMG 1000, BTS Bioengineering) recorded anterior deltoid and upper trapezius activity during five repetitions of forward shoulder flexion (with 5-second rests).

Participants completed the following assessments: Quick-Dash, a self-reported measure of upper limb disability and symptoms; 6-Minute Walk Test (6MWT).

Arm flexion kinematics and gait during 6MWT were assessed using an inertial measurement unit (IMU, G-sensor–BTS Bioengineering). The Frost Co-Contraction Index (CCI) [2] was used to quantify upper trapezius compensation. Mean jerk (rate of change of acceleration) and forward/return velocity were calculated using EMG BTS Analyzer.

Results

Surgical type distribution was similar between groups (mastectomy with reconstruction: 40–45%), though Group A participants were older (F = 3.7; p = .03). Shoulder flexion range was significantly higher in controls (165 ± 10°) than in Groups A (151 ± 11°, p = .002) and B (151 ± 12°, p = .007) (F = 6.7;p=.003). Significant group differences were also found in 6MWT (F = 9.3; p = .005) and CCI (F = 9.3; p = .005). Group B showed reduced 6MWT performance (473.1 ± 64.1 m) compared to Group A (556.2 ± 30.5 m, p = .008) and C (562.2 ± 42 m, p = .002). Group B also exhibited higher CCI (operated: 0.59 ± 0.16; non-operated: 0.53 ± 0.21) than Group A (0.36 ± 0.15 / 0.35 ± 0.12; p = .006) and C (0.34 ±0.08;p=.003). Regression analyses revealed that CCI (operated side) negatively correlated with 6MWT (p = .0168), jerk (p = .01), and forward velocity (p = .0006), but positively with return velocity jerk (p = .02). QuickDASH scores did not differ significantly between groups, though they were influenced by age (F=10, p=.006). In Group A, higher CCI values were moderately associated with greater disability (QuickDASH) (R = 0.43; p = .09).

Discussion

In recently operated patients, co-contraction levels exceeded normative values (CCI = 0.33) [4], correlating with altered neuromuscular control (jerk, velocity) and reduced aerobic capacity. In older long-term survivors, CCI was also moderately associated with higher perceived arm disability, although not directly with shoulder pain—suggesting that upper trapezius overactivation may act as compensatory during early recovery.

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Decoding time-frequency properties of muscle synergies

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Introduction

Muscle synergies, typically extracted via non-negative matrix factorization (NMF) of electromyographic (EMG) signals, are thought to reflect modular activation patterns. However, motor control relies on common synaptic inputs that drive motor unit firings across muscles [1]. Unveiling the shared spectral features among synergistic muscles may provide novel insights on neural coordination. This study introduces a method based on continuous wavelet transform (CWT) to characterize the time-frequency properties shared by muscles within the same synergy.

Methods

Eight healthy participants generated isometric upper-limb force toward 32 targets in the 3D space (four example targets are shown in Figure 1A). EMG was recorded from 17 upper-limb muscles and synergies were extracted from filtered and rectified signals (Figure 1B) [2]. Co-scalograms were computed using CWT on raw EMG data [3] for all muscle pairs. Within each synergy, time-frequency coupling was estimated by summing co-scalograms, weighted by the product of the contribution of each muscle (Figure 1C). The resulting maps were projected back to the time domain via inverse CWT in two bands: alpha (5–15 Hz, related to force modulation) and low-beta (15–25 Hz, linked to cortical input). For each band, we calculated the percentage of time samples in which the signal exceeded a threshold, defined as the 95th percentile of surrogate-based distributions (via phase-randomized EMG). A linear mixed-effects model tested the association with synergy coefficients.

Results

A significant association was found between above-threshold activity and synergy coefficients in both alpha and low-beta bands ($p < 0.001$, Figure 1D).

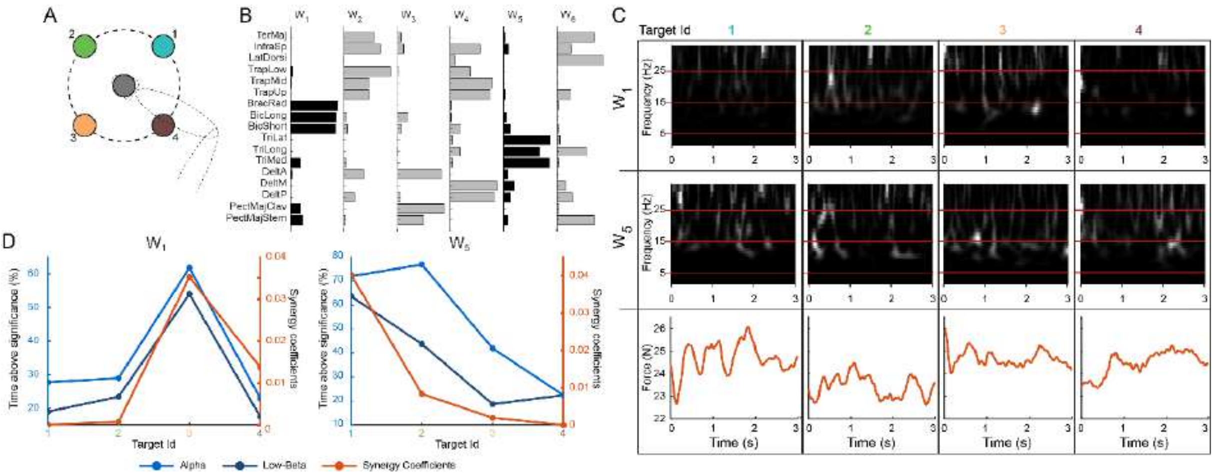

Figure 1. Overview of the analysis procedure. A. Four sample targets. B. Muscle synergies extracted from EMG collected from one participant; W_1 and W_5 (in black) used as examples. C. Co-scalograms for W_1 (upper panels) and W_5 (middle panels) across targets 1–4, and corresponding force norm (lower panels). D. Percentage of time above threshold for W_1 and W_5, and their synergy coefficients.

Discussion

This study shows that the proposed CWT-based method captures the activation of synergy coefficients while also providing additional spectral information that standard NMF-based approaches cannot reveal. As such, the method may offer new insights into the neural control strategies underlying muscle coordination in healthy individuals and may be extended to detect alterations in neurological populations.

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From markers to joint angles: a deep learning model for estimating gait kinematics

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Introduction

Human gait analysis is essential in clinical and rehabilitation contexts, offering insights into neurological disorders that affect movement. In standard practice, this analysis is performed using optical motion capture systems with reflective markers to extract key biomechanical variables [1]. Tools like OpenSim are commonly used to process motion capture data and compute kinematic and dynamic quantities through inverse kinematics and dynamics simulations [2]. Despite being a powerful and freely available tool, OpenSim's workflow is often complex, time-consuming, and requires expert supervision, which can limit its practicality in everyday clinical environments [1]. To address this, we propose a neural network model that directly estimates kinematic variables from marker trajectories, simplifying the analysis pipeline by reducing the need for complex simulations.

Methods

We designed and evaluated a deep learning model for estimating joint kinematics directly from 3D motion capture data. We selected a fully connected neural network with 2 layers and 256 neurons each. The input data consisted of 3D marker trajectories from the Carnegie Mellon University motion capture database [3], specifically focusing on the lower limb markers. Ground truth joint angles including knee flexion, hip flexion and adduction, and ankle dorsiflexion were extracted using OpenSim and used to train and evaluate the neural network. Our neural network architecture was designed to predict joint angles frame-by-frame from the 16 predefined lower-limb markers. The network was trained using supervised learning on a dataset consisting of 30 subjects (54 gait trials, 27482 frames), with Mean Absolute Error (MAE) as the loss function. After training, the model's performance was evaluated on an independent test set containing 3 subjects (9 gait trials, 2112 frames) to assess its generalization to unseen data. The performance metrics used for evaluation included the MAE, Root Mean Squared Error (RMSE), and correlation coefficients (Corr) between predicted and ground truth joint angles.

Results

The overall performance of the model on the test set was evaluated across all test sequences. For the complete test set, the MAE, RMSE, and Corr. were 5.02°, 6.40°, and 0.92, respectively. To provide a more detailed analysis, we present the performance metrics for each joint angle and each subject in the test set (Fig.1, left panel). Additionally, to offer a clearer visualization of the model's behavior, we show a representative example of the predicted and ground truth trajectories for selected joint angles from a single test trial of one subject (Fig.1, right panel).

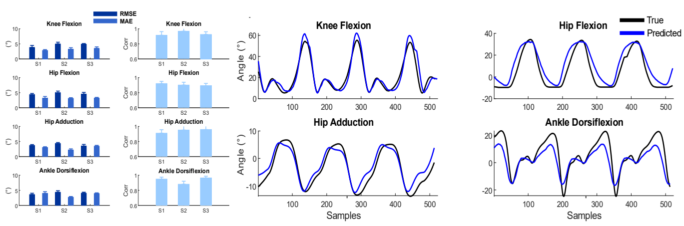

Figure 1. Left Panel: RMSE, MAE and Corr. for each joint angle (mean ± standard deviation).

Right Panel: Example of predicted (blue) and true (black) joint angles curves of a subject single test trial.

Discussion

The model demonstrated potential for predicting joint kinematics from marker trajectories. However, the accuracy remains low for reliable clinical assessment. This variability limits the model's practical use in clinical settings, where greater precision is essential. Nevertheless, the model can serve as a useful exploratory tool to provide initial insights and contribute to future improvements. To enhance robustness and clinical applicability, improvements in dataset size, and model architecture are needed. Future work will investigate markerless, video-based gait analysis to reduce dependency on markers and offer a more practical, non-intrusive solution for clinical and real-world use [4].

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A single wrist-mounted MIMU sensor for the automatic recognition of pill intake and drinking tasks among a set of ADL complex gestures

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Introduction

Adequate hydration and consistent medication intake are fundamental for maintaining health and independence in older adults. Wearable magneto inertial measurement units (MIMUs) offer a minimally intrusive solution for recognizing activities of daily living (ADL) in natural environments [1,2]. However, reducing device complexity and wearer burden by minimizing sensor count remains a key challenge [3]. This study evaluates a single wrist-worn MIMU paired with a bidirectional Long Short-Term Memory (BiLSTM) network to accurately detect drinking (DR) and pill-intaking (PI) gestures among fourteen common ADLs, paving the way for scalable remote monitoring applications.

Methods

Ten participants performed ten repetitions of each of 14 activities (including PI and DR), interleaved with rest periods. A single MIMU (MTw Xsens) on the dominant wrist recorded tri-axial acceleration (A), gyroscope (G) and magnetometer (M) signals. Two BiLSTM classification scenarios were evaluated:

1. **14-class:** simultaneous recognition of all ADL.
2. **3-class:** differentiation of PI, DR, and "other" (remaining 12 ADL).

For the first scenario, a total of 6 sensors combinations were investigated separately, i.e. accelerometer, gyroscope, and magnetometer readings alone, accelerometer and gyroscope (A+G), accelerometer and magnetometer (A+M), and gyroscope and magnetometer (G+M). For the second scenario, the three single sensor configurations, and the combination that gave the best result in the first scenario, were tested. Data were split into 70% for training and 30% for testing.

Results

High accuracies were achieved in both scenarios. The G+M combination yielded the best performance, with about 89% accuracy for the first classification scenario, and about 95% accuracy for the second one (Fig. 1). The accuracy resulted significantly higher ($p<0.02$) for G+M combination with respect to A and A+M for 14-class and with respect to A in 3-class scenario. Precision, recall, and F1-score followed the same trend, with G+M outperforming other combinations.

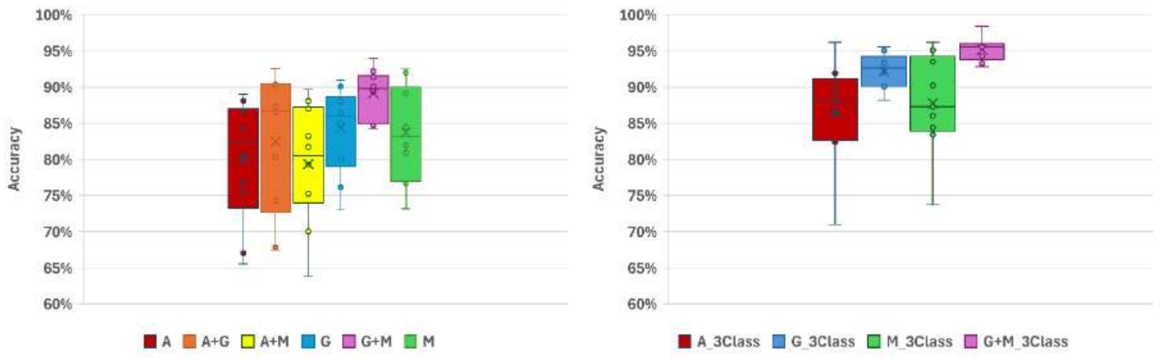

Figure 1. Box-plot diagrams for accuracy in different combinations of MIMU signals (A: Accelerometer; G: Gyroscope; M: Magnetometer) in both the scenarios considered (14-class and 3-class)

Discussion

The demonstrated capability of a single wrist-worn MIMU, leveraging gyroscope and magnetometer data, to distinguish drinking and pill intake with over 95% accuracy highlights significant progress toward low-burden remote monitoring platforms. By simplifying hardware requirements without compromising performance, this approach supports continuous, real-world tracking of critical health behaviours. Future work will explore real-time deployment and integration with telehealth systems to enhance elderly care and independence.

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3D Gait Analysis combined with wireless EEG for executive functions assessment during cognitive-motor task

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Introduction

Executive Functions (EFs) regulate goal-directed behavior and include working memory, inhibition, and cognitive flexibility [1,2,3]. The simultaneous performance of tasks relying on the same cognitive processes might lead to gait disturbances according to the attentional capacity theory, increasing risk of falls. The study explored the involvement of Working Memory and Inhibition during gait, improving EEG signal processing and identifying specific features for monitoring executive functions during walking.

Methods

31 healthy participants performed two cognitive tasks designed to engage inhibition (Go-NoGo) and working memory (N-Back). Data acquisition was performed using a 19-channel wireless EEG device with wet electrodes and a 3D Motion Analysis (Figure 1). Fifty-one EEG features (relative power across frequency bands), seven spatial-temporal and nine kinematic parameters were analyzed. Riemannian geometry-based methods were employed to enhance artifact removal of gait-related motion from EEG signals and to improve the generalizability of the EEG results across subjects. Repeated measure ANOVA with post hoc ($\alpha < 0.05$) were implemented to test multiple comparisons for gait parameters.

Results

EEG-based monitoring of EFs reveal alpha desynchronization at T5 and high beta desynchronization at F3, as reliable markers of working memory-related processes. Conversely, high beta desynchronization at Fp1 was found to indicate an enhanced engagement of inhibitory control mechanisms. Gait data analysis highlighted a predominant involvement of inhibition, whereas working memory engagement emerged only in response to higher cognitive demands. This involvement is evidenced by alterations in several spatial-temporal parameters, including step length, walking speed, cadence, and single support phase duration.

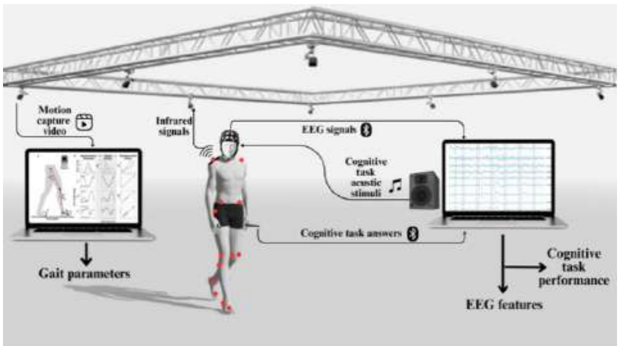

Figure 1. Dual-task walking acquisition using wireless EEG and a 3D optoelectronic system.

Discussion

The study underline that the EEG features, specifically relative powers in alpha T5, high beta F3, and high beta Fp1, were identified as potential biomarkers for working memory and inhibition during gait.

Evidence of Gait Analysis reveal a stronger interaction between motor activity and inhibitory control, with working memory demands impacting motor functions only at higher cognitive loads.

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Reducing calibration burden for sensor-to-segment alignment in IMU-based motion analysis

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Introduction

The definition of joint coordinate systems and clinically relevant rotations have standardized kinematic reporting, enabling objective evaluation of movement in clinical applications [1]. These protocols have been defined only for optoelectronic systems, representing the gold standard. However, this instrumentation is expensive and constricted to laboratory. Inertial measurement units (IMUs) offer a low-cost, portable alternative, but they require anatomical calibration due to misalignment between sensor axes and anatomical frames to obtain clinically meaningful results [2,3]. Calibration procedures based on active movements has been shown to accurately reproduce sagittal plane lower limb joint angles during gait [4]. Despite this, it remains unclear whether a reduced number of repetitions yields accurate joint angle estimates. This study explores the accuracy of a shortened calibration procedure for IMU-based lower limb joints kinematics estimation.

Methods

Six healthy subjects (34.5±10.6 years) were recruited for the study. Each subject was equipped with 15 retroreflective markers and four IMUs, as in [4]. Two different sets of movement were performed: calibration and validation sets. Calibration set includes standing and trunk, hip, knee and ankle flexion/extension (FE). In particular, the standing trial defined the segment longitudinal axis, supposed to be aligned to the gravity. The FE tasks identified the optimal axis of rotation, through a least-square minimization, and corresponding to the medial/lateral axis. The third axis was derived via cross product. The calibration procedure was then validated on clinically relevant tasks, i.e. gait and Time Up and Go (TUG). For gait, calibration using all the repetitions (10) was directly compared with a reduced number of repetitions (3). For TUG, three repetitions were directly used. Performances were evaluated by the RMSE between joint angles obtained from optoelectronic system and IMU-based procedure.

Results

Obtained results revealed that a shorter calibration session provides values of RMSE similar to those reported in other studies where longer sessions are considered, for the hip and knee joints. Indeed, average values of RMSE are about (1.7±0.4 deg) and (2.3±0.8 deg) for hip and knee, respectively, whereas higher values are reported for the ankle joint (Table 1). In this case, lower limb joint angles in the sagittal plane were considered, since these are mainly considered for a clinical evaluation due to their large range of motion.

Table 1. RMSE values (deg) of hip, knee and ankle joints computed considering ten repetitions for calibration and tested on gait trials (Gait10), and considering three repetitions for calibration and tested on both gait trials (Gait3) and TUG.

	Gait10	Gait3	TUG
Hip	1.7±0.4	1.8±0.4	3.8±0.8
Knee	2.1±0.7	2.3±0.8	3.1±2.0
Ankle	2.4±0.5	7.0±1.2	7.0±1.7

Discussion

The possibility to estimate accurate joint kinematics from IMUs, while substantially reducing the duration required for the calibration, carries significant clinical value. Indeed, reducing calibration time prevent risk of muscular fatigue or discomfort, particularly important when dealing with elderly or individuals with compromised musculoskeletal function. In this work, it has been demonstrated that a shorter calibration session yields joint angle estimates whose error remain clinically acceptable, especially for hip and knee joints. These findings pave the way for more accessible gait analysis systems, making them promising for rehabilitative and remote monitoring applications.

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Kinematic analysis of trunk static posture and dynamic mobility in patients with Parkinson's Disease with and without Pisa syndrome

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Introduction

Pisa Syndrome (PS) may represent a postural complication of Parkinson's Disease (PD). It is characterized by a lateral trunk flexion in upright standing position of at least 10°, alleviated by repositioning, mobilization, or supine position [1]. Kinematic motion analysis is a reliable and sensitive method for assessing both static posture and dynamic trunk mobility in all spatial directions (anterior flexion, extension, lateral flexion). This study aimed to perform a kinematic analysis of trunk static posture and dynamic mobility in patients with PD, with and without PS, as well as in healthy subjects (HC).

Methods

This is a cross-sectional study. All participants underwent a trunk kinematic analysis performed with a 6-camera optoelectronic system (ELITE, BTS Engineering, Milan, Italy). Seven reflective markers were placed on specific trunk landmarks to calculate the *C7-Sacrum* segment inclination according to a previously published protocol [2]. Synchronized acquisition and data processing were performed using analyzer software (BTS, Milan, Italy). The kinematic assessment included a static upright recording and evaluation of trunk range of motions (ROMs) during four dynamic tasks: forward flexion, lateral flexion toward the right and left sides, and trunk extension.

Results

We enrolled 130 patients diagnosed with PD, divided in two subgroups: 48 with PS (PD-Pisa) (73.2±5.0 years; 31 males) and 82 without PS (pwPD) (70.8±7.6 years, 59 males). We included 40 HC matched for age and gender (71.4±5.9, 23 males).

During static upright standing, PD-Pisa showed greater lateral trunk inclination (16.4 ± 8.0°) compared to both pwPD (3.5 C 2.2°) and HC (1.5 ± 1.2°) ($p < 0.001$ for both), as well as a higher forward trunk inclination (26.3 ± 14.2°) compared to pwPD (11.7 ± 8.8°) and HC (5.5 ± 3.9°) ($p < 0.001$ for both). The lateral trunk inclination did not differ between pwPD and HC (p=0.064), while the forward trunk inclination was higher in pwPD compared to HC (p=0.005). Regarding dynamic tasks, PD-Pisa were characterized by lower ROMs of the lateral trunk flexion contralateral to the side of static inclination (17.1±8.1°) and of trunk extension (13.9±5.9°) when compared to HC (23.6±13.9°; 21.9±8.6°) (p=0.006; p<0.001). The ROMs of right and left lateral trunk bending and trunk extension did not differ between PD-Pisa and pwPD (p>0.050 for all comparisons), while the ROM of the forward trunk flexion was higher in PD-Pisa (47.7±27.5°) compared to pwPD (19.7±15.8°) (p<0.001). For all the four dynamic tasks, trunk ROMs in pwPD were lower compared to HCs (p<0.050 for all comparisons).

Discussion

PD-Pisa group exhibited a complex trunk postural disorder, with a more pronounced camptocormia compared to pwPD subjects in addition to the well-known lateral trunk inclination. However, these static alterations were not associated with a more severe impairment of trunk mobility during dynamic tasks compared to PD subjects without PS. These findings suggest that the characteristic lateral misalignment of PS does not necessarily translate into a functional limitation of trunk dynamics.

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Instrumented test for the assessment of proprioception in post-stroke patients: preliminary validation data

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Introduction

Robotic upper limb rehabilitation has been shown to improve motor function and daily living activities in stroke survivors. However, large-scale randomized controlled trials [1,2] found no significant differences in motor outcomes, when compared to traditional therapies. Post-stroke cognitive and sensory impairments are common but often receive less attention than motor deficits. Multisensory stimulation offered through robotic systems may offer additional benefits. The SCORES trial (NCT06109324), funded by the Italian Ministry of Health (GR-2021-12374896), is investigating the effects of robotics on cognitive and somatosensory deficits in 126 post-stroke patients. Here, we present preliminary validation data for a quantitative proprioception assessment method developed in this study.

Methods

A novel quantitative proprioception assessment protocol was developed based on methodologies previously reported in the literature [3]. The protocol involves passive positioning of the paretic upper limb into nine standardized locations by a trained therapist, followed by active reproduction of each mirrored position by the patient using the contralateral (non-paretic) limb (Figure 1A). All movements are performed without visual feedback. Each position is repeated three times, in a randomized order. To ensure ease of implementation in clinical practice, data are collected using a standard smartphone camera. The recorded videos are analyzed using Kinovea, a free video analysis software, to extract the planar trajectories of markers placed on two plastic handles, to obtain the handles' planar positions on the tabletop. Based on these trajectories, several performance metrics are calculated in MATLAB, including the Systematic Shift [3], which quantifies the constant error between the passive and actively mirrored reproduced hand positions. The validity of this approach was preliminarily evaluated in a single subject by comparing the Kinovea-derived measurements with those obtained from a gold-standard optoelectronic motion capture system (BTS D500, Italy).

Results

Preliminary analysis demonstrated that the proposed method reliably reconstructed movement trajectories (Figure 1B) when compared to the gold standard, especially when the handles are in the center of the workspace, with higher errors in the peripheral movement. The Spatial Shift index derived from the Kinovea system and the optoelectronic reference showed no significant difference (Wilcoxon signed-rank test, $p = 0.820$). Agreement between the two systems in obtaining the metric was also supported by the Bland–Altman analysis (Figure 1C).

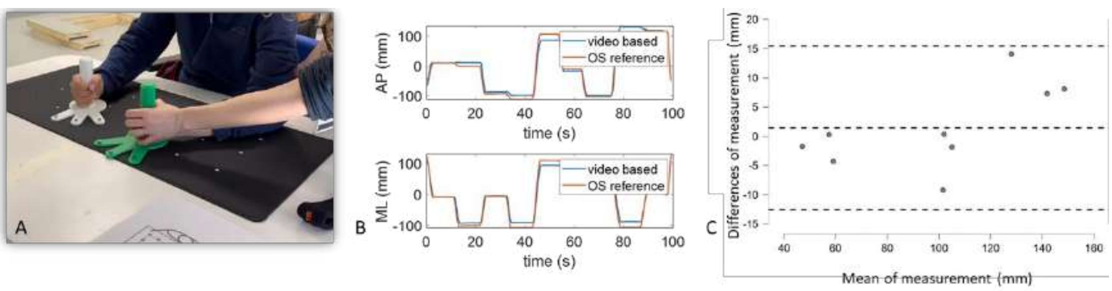

Figure 1. Set-up (A); comparison with the gold standard (B); Spatial Shift index Bland-Altman plot (C).

Discussion

Initial findings support the feasibility and validity of the proposed proprioceptive assessment tool. Further analysis of the larger patient cohort enrolled in the SCORES trial is planned to assess its reliability, sensitivity to change, and clinical applicability in post-stroke populations.

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Trunk acceleration-derived gait indexes and symmetry metrics describe the gait abnormalities of subjects with trunk lateral postural abnormalities in subjects with Parkinson's disease

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Introduction

Postural abnormalities affect around 20% of people with Parkinson's disease (pwPD) and may present as a lateral trunk flexion (≥5° to ≤10°) ($pwPD_{LF}$) or a Pisa syndrome (>10°) ($pwPD_{PISA}$) [1]. This study aims to evaluate whether symmetry indices [SI], ratios [SR] and angles [SA], and trunk acceleration-derived gait indexes (TADI) characterize gait abnormalities in pwPD with lateral trunk abnormalities.

Methods

A total of 106 pwPD were categorized into 3 postural classes according to the lateral deviation of the C7-sacrum segment in the frontal plane during upright stance [1]: 64 without postural abnormalities ($pwPD_{npa}$), 22 $pwPD_{LF}$, and 20 $pwPD_{PISA}$. Gait was assessed over a 30-meter walk using a lumbar-mounted mIMU. Fourty-two age and gait speed-matched healthy controls (HS) were included. SR, SI, SA [2], along with TADI in the three acceleration directions (harmonic ratios [HR], recurrence quantification metrics [RQAdet, RQArec]) were calculated. Differences between pwPD and HS were analyzed using ANOVA or Kruskal–Wallis, with Games–Howell or Dunn's post-hoc tests; pwPD subgroups comparisons used ANCOVA adjusted for clinical covariates with Games–Howell post-hoc comparisons. When required, 1000-permutation non-parametric inference was applied.

Results

Twenty-four gait features significantly differentiated at least one pwPD class from HS. After adjusting for covariates, HR_{AP} *(F= 30.523, p = 0.001),* HR_{V} *(F=14.791, p =0.001),* RQA_{detAP} *(F=5.083, p = 0.008)*, RQA_{detML} *(F=5.484, p=0.006)*, RQA_{detV} *(F=6.334, p=0.003)*, $SA_{pelvic\ obliquity}$ *(F=4.437, p=0.021)*, and $SR_{stridelength}$ *(F=5.791, p=0.004)* were associated with lateral trunk postural abnormalities. Post-hoc analysis results are reported in Figure 1.

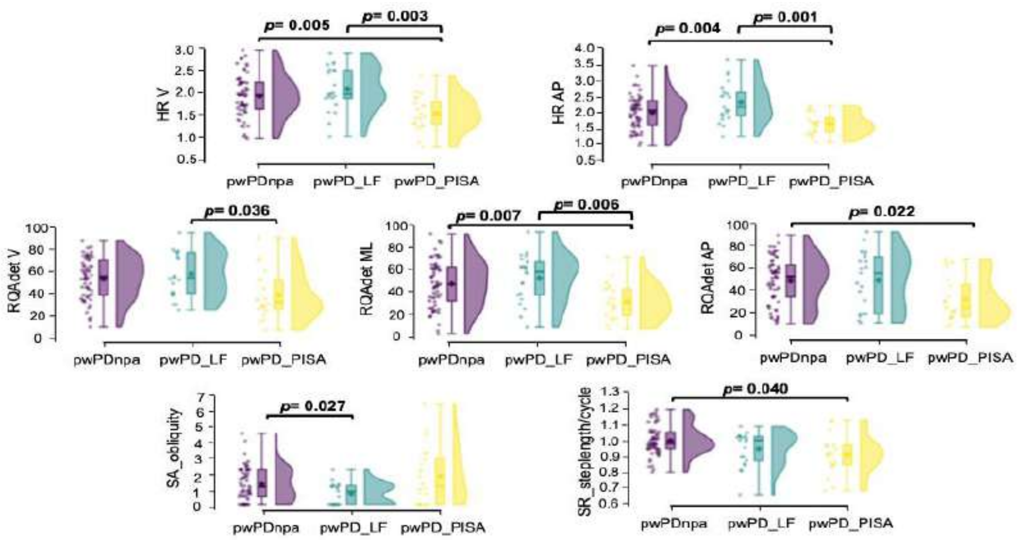

Figure 1 - Post-hoc results in pwPD subgroups

Discussion

HRs, RQAdet, stride length SR and pelvic obliquity SA reflect gait asymmetry in pwPD with lateral trunk postural abnormalities. Gait asymmetry is more prevalent in $pwPD_{PISA}$ than in $pwPD_{LF}$, suggesting dynamic trunk asymmetry with postural worsening. Class differences may be influenced by uneven sample sizes. Further research is needed to assess the responsiveness of these parameters.

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First rocker excursion and functional gait recovery in post-stroke patients: a 3D gait analysis retrospective study

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Introduction

The first rocker (heel rocker) is a key phase of the gait cycle that ensures smooth tibial progression through controlled plantarflexion [1]. In post-stroke patients, its impairment may contribute to reduced gait efficiency [2]. While recent evidence suggests that rearfoot initial contact is associated with better gait parameters than forefoot contact [3], no studies have yet quantified the magnitude of the first rocker or its relationship with functional outcomes over time.

Methods

This retrospective longitudinal study included 24 patients with ischemic or hemorrhagic stroke. 3D gait analysis was performed at three time points: during inpatient rehabilitation (T0), and after 6 (T1) and 12 (T2) months. All patients received a standardized neurocognitive rehabilitation program during hospitalization. Gait analysis was conducted using a six-camera infrared system (BTS SMART DX) and performed following the Davis protocol. First rocker excursion was calculated as the angular difference in ankle plantarflexion between initial contact and the minimum angle reached within the first 30% of the gait cycle, on the paretic side. Clinical assessments included the Functional Ambulation Category (FAC), Timed Up and Go (TUG), and 6-Minute Walk Test (6MWT). The statistical significance level was set at $p<0.05$. Spearman's correlation was used to assess associations between first rocker excursion, clinical tests and other 3D gait analysis outcomes.

Results

Cross-sectional analysis showed weak, non-significant correlations between first rocker and most clinical variables, with a moderate negative trend for TUG ($p=0.21$). Partial correlation analysis revealed a strong and statistically significant inverse association between first rocker excursion and TUG ($p=0.003$), indicating that greater rocker excursion is associated with better functional mobility.

In the longitudinal model, greater 6MWT performance was significantly associated with increased first rocker ($p=0.012$). In contrast, longer inpatient rehabilitation stay ($p=0.011$) and ischemic stroke etiology ($p=0.006$) were significantly associated with lower first rocker values. A positive trend over time ($p=0.094$) and higher values in male patients ($p=0.073$) were also observed, though not statistically significant.

Table 1. Longitudinal analysis between first rocker excursion and main clinical and gait variables.

Variable	Coefficient	Standard error	z-value	p-value
First rocker excursion	1.497	0.895	1.673	0.094
Sex (Male)	1.949	1.089	1.790	0.073
FAC	0.748	1.594	0.469	0.639
Timed Up and Go	0.253	0.239	1.058	0.290
6-Minute Walk Test	0.028	0.011	2.510	**0.012**
Cadence	-0.168	0.118	-1.419	0.156
Rehabilitation stay duration	-0.114	0.045	-2.536	**0.011**
Stroke type (Ischemic)	-3.001	1.102	-2.724	**0.006**

Discussion

This study aimed to fill the gap in current literature by quantifying first rocker excursion and examining its relationship with post-stroke recovery. Using 3D gait analysis, significant associations were found with TUG and 6MWT, showing that greater rocker excursion relates to better mobility. These findings support using first rocker excursion as a biomechanical marker to monitor and guide rehabilitation after stroke.

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Posture and virtual reality: effects of head mounted display and virtual environment on postural stability parameters in healthy subjects

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Introduction

Postural Control System continuously processes sensory inputs to generate motor responses stabilizing whole-body posture [1]. Among postural receptors, vision plays a dominant role in postural adaptations; in fact, different environmental conditions and visual target distances can affect postural stability parameters [2]. The lack of a standardized testing environment affects the reliability of many scientific and clinical results. Virtual reality (VR) could be a promising tool for standardizing clinical assessment [3]. The aim of this study is to analyze the effects of a standardized virtual room and the weight of the Head Mounted Display (HMD) influences stabilometric exam.

Methods

Fifty healthy young adults underwent postural analysis in upright standing under four conditions: (a) Open Eyes (OE), viewing a physical target at 0.70 m; (b) Closed Eyes (CE); (c) Open Eyes viewing a virtual target through a Head-Mounted Display (HMD) in Virtual Reality (HMD-OE); (d) Closed Eyes wearing HMD (HMD-CE) (Figure 1). Intra-subject variability of each parameter was evaluated by Coefficient of Variation (CV). Repeated measure ANOVA or non-parametric Friedman Test with post hoc ($\alpha < 0.05$) were used to test the effects of different conditions on postural control.

Results

The variability analysis showed that CoPsa and LSF had the highest variability (median CV: 30–50%), unlike CP-speed (median CV: 10-30 %). No significant differences emerged in the CVs of stabilometric parameters across the four conditions. Moreover, a significant increase of CoPsa and decrease of LSF were found both in CE vs OE condition and in CE vs HMD-OE ones; while, no significant differences were found both in OE vs HMD-OE, CE vs HMD-CE, OE vs HDM-CE and HMD-OE vs HMD-CE.

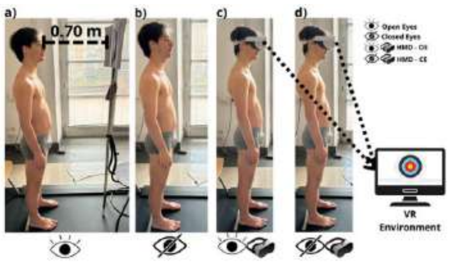

Figure 1. Healthy young adult in upright standing posture during postural assessment.

Discussion

The results of variability analysis show a low reliability of stabilometric parameters, regardless of the experimental condition; in particular, Copsa and LSF showed the highest CVs, while CPspeed exhibited the lowest. Regarding the effect of different conditions on the stabilometric exam, a visual impact was observed, with postural stability worsening in CE vs OE; moreover, the comparison between natural and virtual environments reveals that VR and HMD weight did not influence postural stability (OE vs HMD-OE; CE vs HMD-CE). Eventually, the significant differences, found for CE vs HMD-OE, associated with the other non-significant comparisons (HMD-OE vs HMD-CE and OE vs HMD-CE) seem to suggest an additional proprioceptive stimulation due to wearing HMD, reducing the subject’s sway.

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The impact of increased perceived fatigue on spatiotemporal and postural gait features in Parkinson's Disease: a preliminary analysis

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Introduction

Fatigue is a disabling symptom affecting ~50% [1] of people with Parkinson's disease (PwPD). Although several studies associate fatigue with other non-motor symptoms, few have investigated how increased perceived fatigue impacts spatiotemporal and kinematic gait features in PwPD. This cross-sectional study aimed to explore the effect of increased perceived fatigue on gait performance in this population.

Methods

Fifteen PwPD (age 70.9 ± 5.1 years; H&Y 2–3; 10 females) were recruited. Participants wore optical markers (LAMB protocol) and performed continuous overground walking in a gait lab with a motion tracking system (SMART-TD and P6000, BTS S.p.A., Milan, Italy) until reaching a perceived exertion of 17 (lower limbs or breath) on the Borg scale [2]. Spatiotemporal and kinematic gait parameters were recorded at baseline (T0), at regular intervals, and immediately post-task (T1). Median and interquartile ranges [Q1–Q3] were reported; T0–T1 changes were analysed using the Wilcoxon signed-rank test.

Results

Normalized gait speed (%BH/s) decreased from 83.9 [75.9–90.2] at T0 to 75.5 [73.3–91.1] at T1. Double support time (%Stride) increased from 27.6 [25.0–29.2] to 28.0 [26.4–30.4], and step width (%BH) from 6.7 [5.4–8.2] to 7.7 [6.1–8.9] (both $p \leq 0.05$) as reported in Figure 1 for each participants across time. The hip flexion (deg) at ipsilateral heel strike decreased from 33.8 [26.4–35.1] to 31.5 [25.7–38.2], while knee flexion (deg) during monopodalic stance increased from 22.8 [19.4–24.7] to 24.5 [20.9–26.2]. Finally, step length asymmetry (%Stride) increased from 1.5 [0.6–2.5] to 2.1 [0.8–2.6].

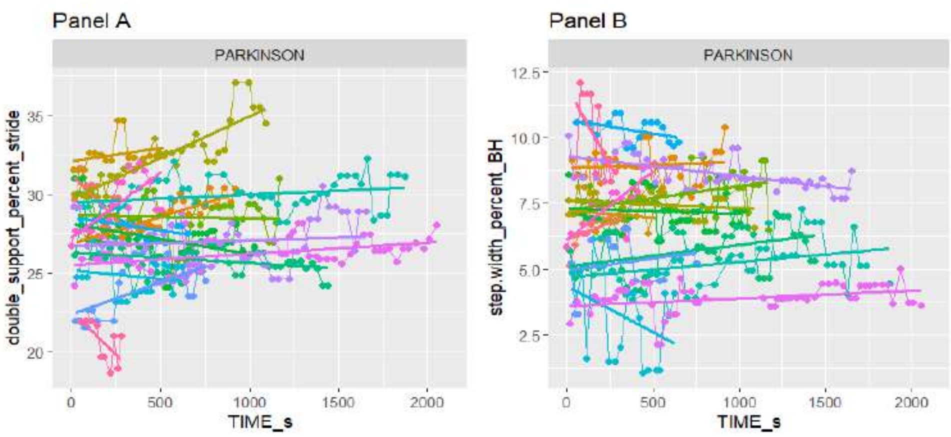

Figure 1. Rolling median plots for each participant showing (Panel A) Double Support Time (% of Stride) and (Panel B) Step Width (% of Body Height) over time during the walking trial.

Discussion

These findings suggest that increased perceived fatigue influences multiple gait aspects in PwPD. Specifically, it was associated with altered dynamic balance (e.g. increased double support time), changes in postural strategies (e.g. reduced hip flexion), and a potential decline in gait quality (e.g. increased step length asymmetry). Overall, the results highlight the multidimensional motor impact of fatigue and its relevance as a rehabilitation target.

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Gait analysis in individuals with multiple sclerosis: a pilot observational study

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Introduction

Multiple Sclerosis (MS) is a chronic inflammatory and neurodegenerative disease of the central nervous system, marked by significant clinical variability that impacts motor, cognitive, psychological, and social functions. Technological advancements are reshaping rehabilitation, enabling more precise and personalized assessments and treatments [1]. Among these, gait analysis is gaining increasing attention [2]. However, few studies have compared the gait of individuals with MS to age-matched healthy controls using objective gait analysis tools [3]. This study aims to analyze gait patterns in MS subjects in comparison with age-matched normative data from healthy individuals.

Methods

11 MS subjects (age: 47.09 ± 9.54 years, EDSS 1.5–6) with no relapses or steroid use in the previous three months, preserved visual and auditory function, and no botulinum toxin injections to the lower limbs in the last 12 weeks were recruited. 38 Healthy controls (aged 20–59, BMI 18.5–29.9) with no history of lower limb surgery or neurological/orthopedic disorders were included. Gait analysis was performed using an 8-camera optoelectronic system (VICON Vero 2.2, 120 fps) and two synchronized AMTI force plates (960 Hz). 2 analog cameras were aligned to the sagittal and coronal planes. The Plug-in Gait lower limb protocol was applied for gait analysis purposes. Each subject walked a 10-meter path 30 times; 5 trials with right or left foot strikes on the force plates were selected. The electromyographic (EMG) signal (Cometa, 2000 Hz) of 8 lower limb muscle groups was recorded bilaterally. Joint kinematics was computed in Nexus 1.8.5 while spatiotemporal parameters were derived using Polygon 3.5.2. Statistical analysis of gait curves was conducted using the SPM1D Matlab package (Pataky TC, 2019), applying a non-parametric Student's t-test ($\alpha = 0.05$).

Results

For comparison between healthy participants and individuals with MS, subjects were grouped into two age ranges: 20–39 and 40–59 years. Gait analysis showed statistically significant differences ($p < 0.05$), including reduced gait speed and stride length, as well as alterations in sagittal plane kinematics, particularly at the hip, knee, and ankle [**Figure 1**]. These changes in gait kinematics and kinetics were also reflected in altered EMG activity.

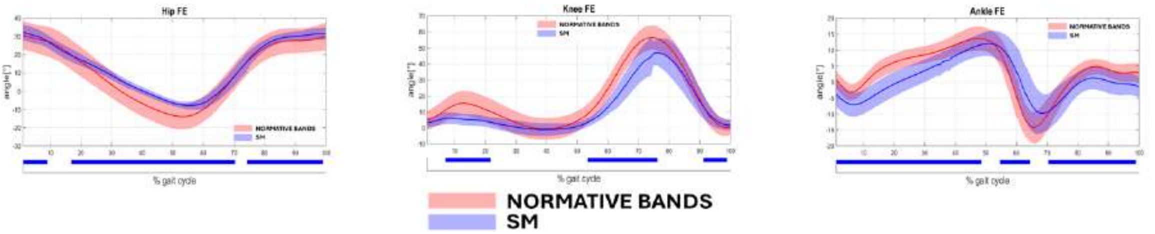

Figure 1. Comparison of sagittal plane kinematics between MS subjects (blue) and healthy controls (red) in the 40-59 age range ($p < 0.05$).

Discussion

These preliminary findings highlight altered motor strategies in individuals with MS compared to age-matched healthy controls, as confirmed by significant differences observed through gait analysis. Expanding the sample size may help to better characterize gait alterations and support the development of more effective, personalized therapeutic approaches.

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Minimum stiffness of dynamic AFOs for people with foot drop: A gait analysis study

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Introduction

Dynamic ankle foot orthoses (AFOs) are medical devices prescribed to individuals with mild foot drop (FD). This condition is characterized by weakness of the ankle dorsiflexor muscles, reduced foot clearance and increased risk of fall during gait. Recent advances in 3D technologies have enhanced the customization of such devices based on the individual's lower limb morphology [1]. However, standard guidelines on AFO mechanical properties are lacking. This study aimed at estimating the minimum AFO stiffness required to sustain the foot and footwear during the swing phase of gait in individuals with mild FD.

Methods

Ten individuals with unilateral FD (8M, 2F; age = 65±11 years) underwent gait analysis using a validated skin-marker based kinematic protocol [2]. Lower limb joint rotations data and markers trajectories were collected across five walking trials in shod condition (footwear mass = 0.164 kg). Foot mass and relevant inertial parameters were estimated from anthropometric data [3,4]. The maximum plantarflexion moment exerted at the ankle was calculated in static and in dynamic conditions by including the effect of the gravitational and inertial forces in gait (Fig. 1). The required minimum AFO stiffness (N*m/deg) can be calculated as the ratio between the maximum plantarflexion moment and the maximum acceptable plantarflexion angle in the swing phase. FEA and functional evaluation of AFOs with these mechanical properties, and made in fiberglass-reinforced polyamide, are undergoing.

Results

The estimated foot mass ranged 0.82 – 1.32 kg and 0.86 - 1.41 kg and the moments of inertia at the ankle joint ranged 0.010 – 0.016 kg*m² and 0.010 - 0.018 kg*m² respectively for the affected and non-affected foot. In static condition, the maximum ankle plantarflexion moment (N*m; median [25% 75%]) was 0.74 [0.46 0.91]. During the swing phase of gait, the maximum plantarflexion moment at the ankle joint was 1.66 [1.52 1.77] for the affected foot and 2.14 [1.46 2.58] for the non-affected foot (Fig. 1). By allowing a maximum 1 deg plantarflexion of the ankle, a median 1.66 N*m/deg AFO stiffness can be calculated.

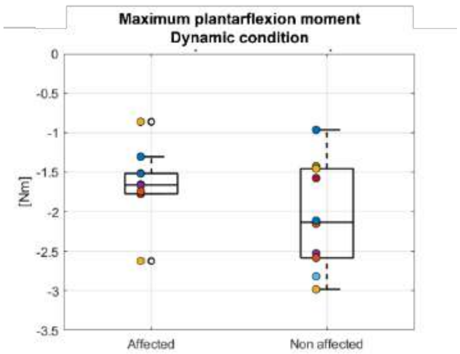

Figure 1: Maximum ankle plantarflexion moment across the ten FD patients in gait, in the affected (left) and non-affected (right) foot.

Discussion

In this study, we aimed at estimating the minimum AFO stiffness capable to support the foot and footwear in a population of FD people. The estimated ankle plantarflexion moment was about twice as large in gait with respect to the static condition. In addition, this was slightly larger in the non-affected foot due to the higher acceleration on this side. While the optimal stiffness of dynamic AFOs should consider the degree of ankle impairment, the type of footwear, and the physical demand, this study offers valuable quantitative data for the design of AFOs for people with mild FD and good residual mobility.

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Identifying neuromuscular indicators of return to sport readiness: a clustering analysis of EMG parameters in athletes with and without ACL reconstruction

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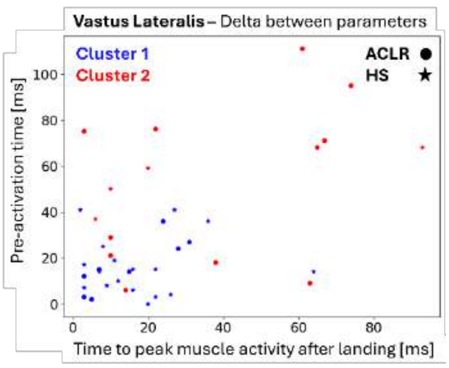
Introduction

Anterior cruciate ligament (ACL) injuries are among the most common and severe in sports, often leading to persistent joint instability and functional limitations [1,2]. Despite significant advances in surgical reconstruction and rehabilitation, there remains substantial ambiguity regarding the criteria for a safe Return to Sport (RTS) [3]. Understanding the complex interplay of biomechanical and neuromuscular factors is thus essential for establishing more reliable and individualized RTS protocols. Electromyography (EMG) plays a crucial role in this context, providing quantitative data on muscle activity during sport-specific tasks. However, the role of EMG-based parameters in identifying individuals ready to RTS or at risk of reinjury remains unclear. This study aims to contribute to this area by extracting muscle activity timing and amplitude data in both ACLR and healthy athletes, and analysing their informative value through unsupervised clustering.

Methods

Twenty-three athletes (median age 20, IQR 19-25, 22 male) with ACL reconstruction (ACLR) and 27 healthy athletes (median age 22, IQR 21-23, 19 male) (HS) were recruited. To evaluate neuromuscular performance, participants performed three drop fall trials per leg landing on a force platform (P6000, BTS) used to identify foot contact. EMG signals of Vastus Lateralis (VL), Vastus Medialis (VM), Semitendinosus (ST), and Biceps Femoris (BF) muscles were acquired bilaterally (FREEEMG, BTS), band-pass filtered (20–450 Hz) and rectified. Maximum voluntary contractions were registered and used to normalize the EMG signal amplitude of the drop fall. Parameters related to muscle activation onset times and normalized amplitudes were extracted and the difference (delta) between healthy and injured limb for ACLR and between dominant and non-dominant limb for HS was calculated for each parameter, assuming that small deltas were associated to greater inter-limb symmetry. Unsupervised clustering analysis was then applied to investigate potential differences in neuromuscular control. To this aim, the data related to the second trial were considered and all participants were clustered using K-means associated with a Silhouette Coefficient to extract the optimal number of clusters. The influence of each considered parameter was investigated through scatter plot visual inspection.



Results

K-means found two main clusters (red and blue in Figure 1), composed of 25 and 15 participants respectively. The distribution of ACLR and healthy participants was uniform among the two clusters. Among the considered parameters, the inter-limb symmetry of muscle pre-activation before landing and timing of peak muscle activity after landing were among the most impacting on clustering results (Figure 1).

Figure 1. Inter-limb delta for pre-activation time and timing to peak muscle activation after landing of the VL muscle.

Discussion

Unsupervised clustering of EMG-based parameters during a single-leg drop landing task suggests that inter-limb symmetry in muscle pre-activation before landing and time to peak muscle activity post-landing may serve as informative metrics for assessing readiness to RTS. In addition, clustering did not produce groups exclusively composed of either ACLR or healthy athletes. Instead, both clusters included a balanced mix of ACLR and healthy participants. This may suggest that increasing the sample size and conducting longitudinal studies could help establish specific thresholds to identify both athletes ready for RTS and healthy individuals potentially at risk of knee injury.

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Mapping the neuromuscular effect of Botulinum Toxin in spastic patients using High-Density surface EMG

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Introduction

The successful administration of Botulinum Toxin (BT) depends on the diffusion of its silencing effect rather than on its dispersion within the targeted tissue. Quantifying the distribution of muscle fibres responding to BT is therefore imperative if the muscle region under BT effect is to be assessed. To this end, here we investigate the potential of assessing the diffusion of the BT effect based on surface electromyograms detected from multiple skin location: the HD-sEMG.

Methods

Participants with unilateral lower limb spasticity were enrolled. Two 64-channel HD-sEMG grids were placed bilaterally on the medial gastrocnemius muscles. M-waves were elicited by supramaximally stimulating the posterior tibial nerve at three time points: baseline (T0), four weeks post-injection (T1) and 12 weeks post-injection (T2). Spatial maps of root mean square (RMS) amplitude were computed to quantify the local muscle response. These electrophysiological measurements were then compared with clinical scales (the Modified Ashworth Scale), patient-reported outcomes and ultrasound imaging.

Results

Figure 1 shows RMS maps at the first two evaluation points for a single subject. A notable T0–T1 reduction in RMS amplitude was observed on the spastic side, but not on the control side. This difference was significant only for 12-grouped electrodes.

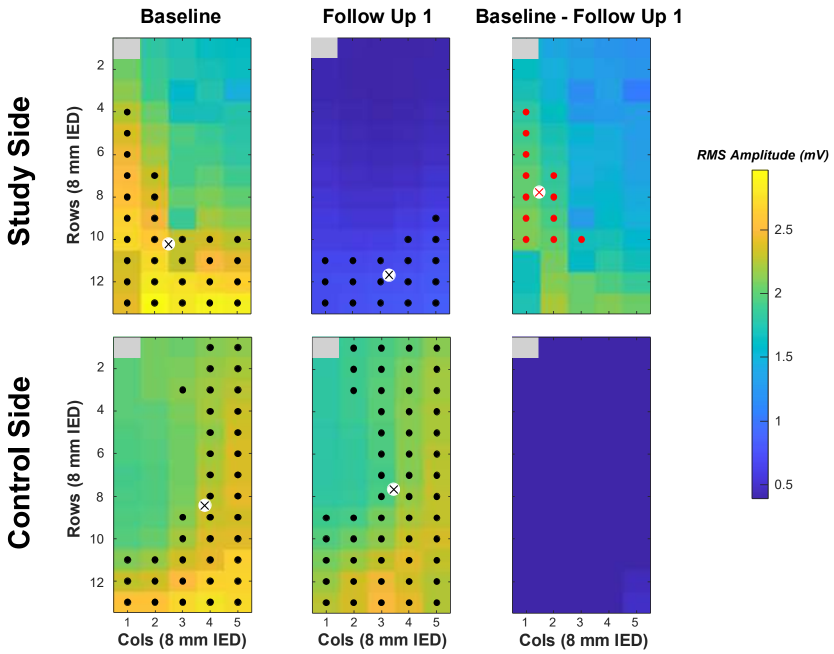

Figure 1. Spatial Distribution of RMS Amplitude for a single Subject.

Discussion

These findings suggest that HD-sEMG is sensitive to BoNT effects and can map its diffusion spatially. The reduction in amplitude in specific electrode regions corresponds with the expected distribution of BoNT's action. This supports the potential of the method for guiding and monitoring treatment.

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A novel approach for motor unit number estimation: integrating artificial intelligence and high-density electromyography

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Introduction

Motor Unit Number Estimation (MUNE) refers to a set of electrophysiological techniques used to quantify motor units within a muscle. These techniques are essential for diagnosing and monitoring neuromuscular disorders. However. traditional MUNE methods are limited by their reliance on single-channel recordings and their susceptibility to sampling bias and artefacts such as alternation. To overcome these limitations, we propose a new MUNE methodology that synergizes HD-sEMG with artificial intelligence (AI).

Methods

First, we generated a dataset of simulated HD-sEMG using a model of the medial gastrocnemius (MG) muscle that accurately reflects its anatomical and physiological properties [1]. This dataset reflects key biological and experimental sources of variability, including motor unit population size, subcutaneous fat thickness, and signal-to-noise ratio (SNR). Secondly, we designed a neural network (NN) architecture combining convolutional and recurrent layers to predict the number of active motor units from the simulated signals. Finally, we compared the performance of our method with that of two state-of-the-art MUNE methods: Incremental MUNE [2] and StairFit MUNE [3].

Results

Figure 1 shows MUNE results for three simulated subjects with varying numbers of motor units and stimulation steps. While Incremental MUNE markedly underestimates the ground truth and StairFit shows high variability, our proposed HDsEMG-AI method exhibits more accurate and consistent predictions across all conditions

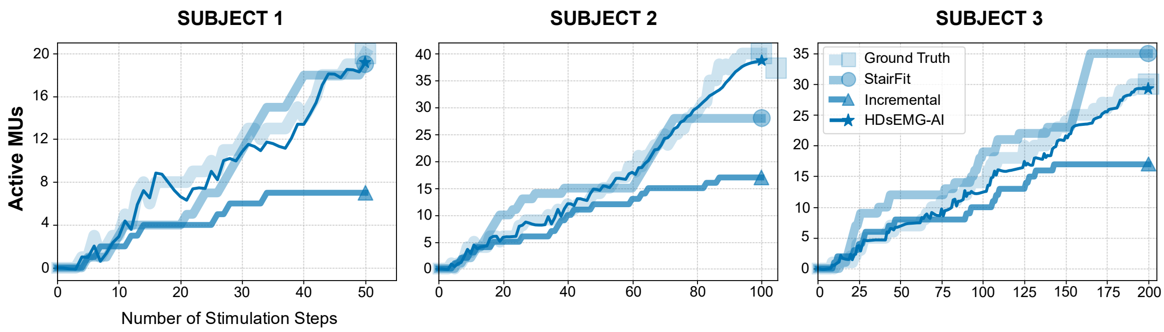

Figure 1. Comparison of MUNE Methods Across Three Simulated Subjects

Discussion

Our HDsEMG-AI approach outperforms existing MUNE methods, particularly under challenging conditions such as low SNR, small motor unit populations, and varying stimulation steps. Its robustness and accuracy across diverse simulated scenarios demonstrate its potential for reliable MUNE. Future work will focus on validating the method using experimental HD-sEMG recordings.

Acknowledgements: *BREAKingBONDS – funded by MUR under PRIN 2022 (D.D. 104, 02/02/2022)*

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Adaptive mixed reality squat training based on real-time physiological feedback

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Introduction

In recent years, Mixed Reality (MR) has emerged as a powerful tool for enhancing physical training by providing immersive, interactive, and adaptive environments. Unlike traditional training methods, which often lack personalization and real-time feedback, MR enables the integration of dynamic systems that can respond to individual user needs [1]. Heart Rate Variability (HRV) and Galvanic Skin Response (GSR) metrics can be used to dynamically adjust training difficulty based on the user's physical and cognitive state in MR environments, enabling real-time adaptation. This pilot study describes the implementation of an MR squat training scenario whose difficulty is adjusted in real-time based on physiological measurements recorded with wearable sensors.

Methods

ElectroCardioGraphic (ECG) and GSR data were recorded through a pair of wearable sensors (Shimmer Sensing, Ireland). The proposed system is implemented within an MR environment (HTC Vive XR Elite) and follows a structured two-phase protocol (**Figure 1)**. (1) **Calibration**: during a baseline light squat period, root mean square of successive differences (RMSSD) and standard deviation of NN intervals (SDNN) from HRV, skin conductance response (SCR) amplitude and SCR number of peaks from GSR were collected every 20 s. Personalized reference ranges of each metric were defined as mean ± 0.5 std [2]. (2) **Adaptive MR training**: participants engage in the MR squat training for 4 min. The training program comprises three difficulty levels ranging from easy (under-challenged) to difficult (over-challenged), achieved by manipulating height and frequency of the virtual obstacles. Every 20 s, an algorithm evaluates whether current metric values fall within the reference ranges established during the MR calibration and accordingly adjusts the level of difficulty.

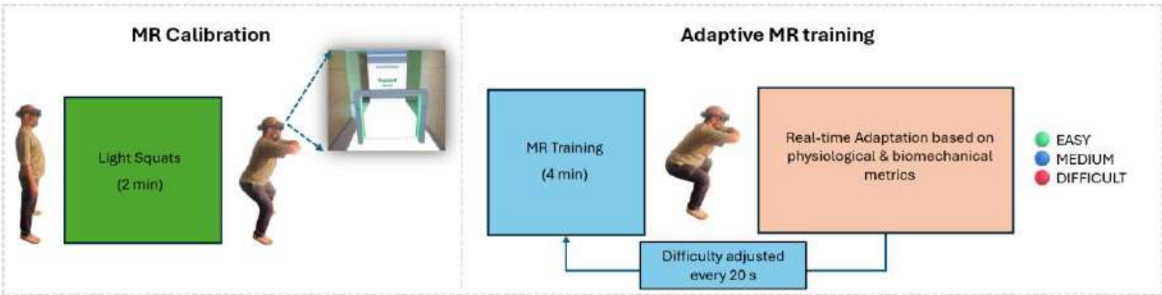

Figure 1.

Results

In this pilot study, 3 healthy participants (24,36 and 40 yo, 1 F) completed the protocol. Over the 4-min session, participants experienced different levels of difficulty, demonstrating the system's ability to personalize the training program. In total, an average of 4 adaptation events per participant were observed, with real-time adjustments triggering transitions between intensity levels.

Discussion

This pilot study suggests the feasibility of an adaptive MR squat training system, which dynamically adjusts difficulty based on real-time physiological measurements. The system's ability to maintain participants in an "appropriately challenged" zone could enhance training engagement and effectiveness while avoiding under or over-exertion. Further developments will integrate biomechanical and performance metrics, to adjust the difficulty also based on the subject's squat execution quality.

Acknowledgements

TrainAR - PRIN2022 PNRR - M4- C2 – I1.1, Next Generation EU, CUP J53D23013950001.

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Clinical use of instrumented six-minute-walking test: assessing the effects of drugs and supplements on walking performance in Parkinson's Disease patients

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Introduction

The six-minute walk test (6MWT) is a standard tool for assessing walking capacity in neurological disorders [1]. When combined with wearable inertial sensors, it enables detailed analysis of gait parameters [2], potentially revealing motor fluctuations and treatment effects not captured by conventional clinical scales. In Parkinson's disease (PD), where gait impairments are complex and variable, the instrumented 6MWT may offer valuable insights into the efficacy of pharmacological or nutritional interventions [2]. This study aims to assess the effects of Terazosin, which enhances cellular metabolism, and Lisosan-G, an antioxidant supplement, through minute-by-minute analysis of the instrumented 6MWT, to better understand continuous gait in PD.

Methods

A double-blind, placebo-controlled study is conducted to evaluate the effects of Terazosin and Lisosan-G on gait parameters in Parkinson's disease. Patients were divided according to the severity of the disease; during the 8-month trial, both placebo and the active ingredients of the two substances were administered randomly. 26 participants (10M 70,1 ± 10,8 years old) volunteer to study after completing a consent form. In each session patients underwent a clinical evaluation through UPDRS, PDQ-39, FOG and Tinetti scales [3]. Within each testing session, participants perform a 6MWT along a 30-meter corridor at most comfortable speed, while wearing a single inertial measurement unit (IMU, G-Walk, BTS Italy) positioned at lumbar level. A subset of 12 participants is then considered further analysis and pre-processing of raw IMU data using custom MATLAB scripts. Key gait parameters extracted for each trial include average cadence and average stride length. To analyze gait variability during the continuous walking test, the coefficient of variation (CV) is also calculated across different conditions. Between-group differences are subsequently analyzed using ANOVA. Post-hoc analysis is also performed considering the Bonferroni correction (α=0.017).

Results

The temporal parameters considered since now did not yet show any statistically significant changes following the intake of Terazosin and Lisosan compared to baseline. Interestingly, statistically significant differences in the coefficient of variation were found for both cadence and stride time during the Lisosan-G condition, suggesting a potential effect of this supplement in lowering temporal variation of the parameters during the 6MWT.

Condition	Cadence: M±SD (CV%)	Stride Time: M±SD (CV%)
Baseline	104.06 ± 18.01 (17.3%)	1.31 ± 0.48 (36.4%)
Lisosan	106.33 ± 14.68 (13.8%)*	1.26 ± 0.28 (22.1%)*
Terazosine	105.36 ± 19.22 (18.2%)	1.30 ± 0.42 (32.4%)

*The following values were statistically significant ($p < 0.017$)

Discussion

The present study confirms the interest of analysis continuous gait tasks in PD using wearable inertial sensors. The results, when extended to the overall available sample could confirm a role of Lisosan-G supplement in reducing gait variability in PD patients. Nonetheless, the inclusion of further biomechanical features, still under evaluation, could further strengthen the results, potentially pointing out average and, also, minute-by-minute differences between the conditions.

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Digital Mobility Biomarkers for Fall Risk Prediction: From Meta-Analysis to Clinical Implementation

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Introduction

Falls constitute the leading cause of years lived with disability globally [1]. Despite numerous studies investigating wearable sensor-based fall risk biomarkers, robust evidence for clinical application remains limited due to a lack of standardization and insufficient accuracy of current prediction tools. This work presents a comprehensive approach to identifying and validating digital mobility outcomes (DMOs) for fall risk prediction through systematic evidence synthesis and subsequent clinical implementation.

Methods

We conducted a systematic review and individual participant data meta-analysis (IPDMA) of studies investigating wearable sensor-based fall risk biomarkers in ≥20 community-dwelling older adults with prospective fall data (PROSPERO CRD42022367394). Digital mobility outcomes (DMOs) will be extracted through validated pipelines for physical activity, gait, balance, and transitions. Promising predictive DMOs from the IPDMA will inform ongoing prospective clinical studies, employing standardized protocols with inertial sensors at the wrist and lower back. Machine learning and logistic regression approaches will develop multivariable models with 12-month prospective fall follow-up.

Results

The systematic review identified 48 eligible datasets from 23 countries (21 - 32,619 participants) including healthy older adults and individuals with neurological conditions (Parkinson's disease, multiple sclerosis, stroke). Studies employed 1-10 wearable inertial sensors during laboratory-based functional tests, real-world monitoring, or combined protocols. A total of 592 DMOs were identified, with 27% emerging as significant predictors of prospective falls over 6 to 60 months.

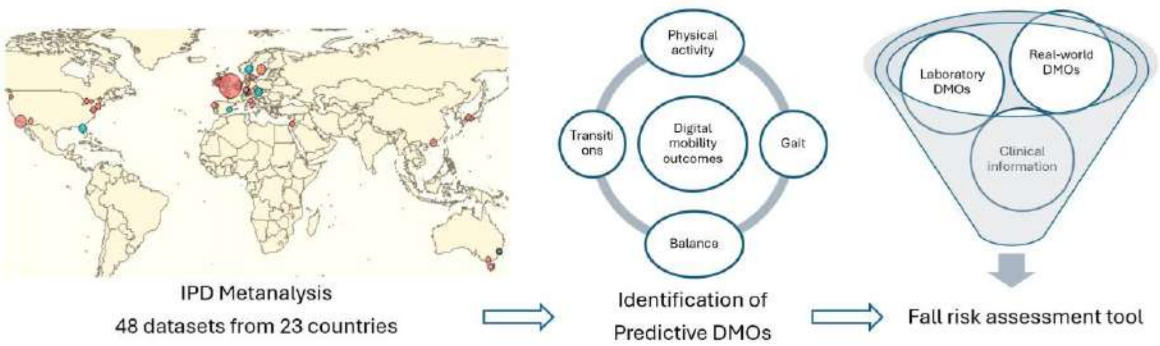

Figure 1. Structured approach for digital mobility outcomes for fall risk prediction

Discussion

This study leverages an IPDMA approach to compile wearable sensor-based fall risk research, enabling standardized feature extraction across diverse datasets. The variability in sensor placement, measurement protocols, and DMO extraction methods underscores the urgent need for harmonization. Findings from the ongoing IPDMA will drive prospective studies (e.g. DARE FALLSPREDICT), paving the way for a clinically viable fall prediction model that enhances precision and strengthens evidence-based prevention strategies for aging populations.

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Age-Related Changes in Real-World Turning and Postural Transfer Digital Mobility Outcomes

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Introduction

While gait parameters have been extensively studied as mobility biomarkers during aging, less attention has been given to turning and postural transfers (PT). These transitional movements are essential for daily functioning and may provide valuable insights into mobility decline [1]. Digital mobility outcomes (DMOs) derived from wearable sensors enable continuous monitoring of these features in real-world environments. This study investigated age-related changes in turning and PT characteristics and examined sex differences in these mobility features.

Methods

We analyzed data from 200 Italian community-dwelling older adults (79.5±6.7 years, 49% female) who wore a lower-back inertial sensor over a week. Previously described pipelines [2] identified turning and postural transfers (sit-to-stand, stand-to-sit), which were aggregated daily and averaged over a week. Age-related trends by sex were assessed using Generalized Additive Models, and sex differences tested with ANCOVA adjusted for age and BMI. P-values were corrected for multiple comparisons.

Results

Sit-to-stand and stand-to-sit transfers followed similar age-related trends and sex differences. Females performed more sit-to-stand transfers per day than males (100±45 vs. 73±44, p=0.002) and had shorter turning durations (2.70±0.34s vs. 2.91±0.47s, p=0.027), but longer PT durations (2.73±0.21s vs. 2.64±0.29s, p<0.001).The GAM analysis revealed that both turning, and PT features change with aging, with different patterns between males and females. Turn quantity and PT quantity both showed age-related decline, while turn and PT durations increased with advancing age.

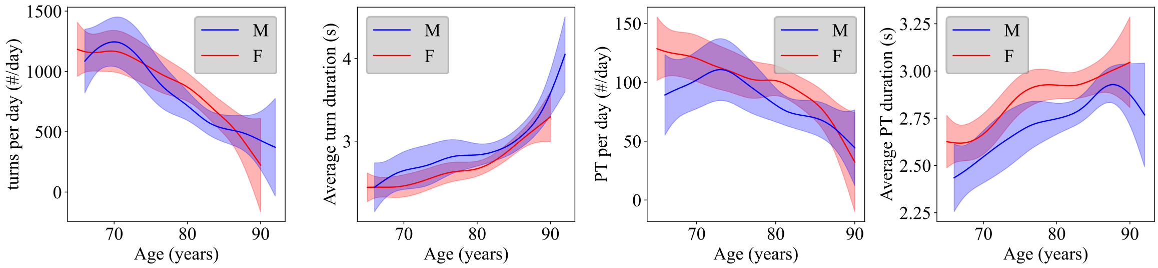

Figure 1. Sex-specific age-related changes in turning and PT (sit-to-stand)

Discussion

Our findings suggest that turning and postural transfers exhibit age-related changes like those observed in gait parameters, with sex-specific patterns. The increased duration and reduced frequency of transitional movements with aging are likely to reflect compensation strategies to maintain stability. Sex differences may be attributed to anatomical and physiological factors affecting movement biomechanics. These results highlight the importance of including turning and postural transfer assessment in mobility evaluation during aging. Future longitudinal studies should investigate whether changes in these features can predict mobility decline and fall risk.

Acknowledgement

This research was co-funded by the Italian Complementary National Plan PNC-I.1 "Research initiatives for innovative technologies and pathways in the health and welfare sector" D.D. 931 of 06/06/2022, "DARE - DigitAl lifelong pRevEntion" initiative, code PNC0000002, CUP: B53C22006450001.

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EMG-based visual biofeedback applied to upper limb motor tasks in virtual environment

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Introduction

It is well-known that, during elbow flexion-extension (F-E) exercises, the trapezius muscle ipsilateral to the limb used in the task is often over-activated in post-stroke individuals to compensate for poor control of the affected side lesion [1]. The manipulation of visual feedback during training has been extensively documented to improve motor learning of new skills, in both healthy and pathological populations under controlled conditions, particularly during upper-limb tasks [2, 3]. This pilot study, conducted in the framework of the VISIONARY project (Advanced VISual feedback for neurorehabilitatION systems based on virtuAl RealitY), aims to test the hypothesis that muscle over activation can also occur in unaffected people when performing elbow F-E exercise against elastic resistance. Additionally, the study seeks to preliminarily evaluate the use of EMG-based visual biofeedback to modulate muscular activity control during this training.

Methods

The experimental setup included a CalComp digitizer tablet to track hand movements on the horizontal plane, an elastic band (Fig. 1A), and a vertical screen to display visual stimuli and feedback (Fig. 1B). The hand position was represented on the screen by a blue cursor. Attached to this cursor, a light blue circle followed its movements, providing EMG-based biofeedback in case of intense trapezius contractions. Each participant was asked to perform F-E movements, moving the cursor and the attached circle back and forth inside a virtual curved pipe, whose radius was sized according to the participant's anthropometric parameters. The trapezius muscle activation above a participant-specific threshold caused the diameter of the circle to increase, up to matching the diameter of the pipe (Fig. 1C). At this point, the circle could "lock", causing the cursor to detach from it and requiring the participant to repeat the trial. The protocol consisted of three phases: (1) Baseline (30 repetitions without biofeedback); (2) Adaptation (60 repetitions with biofeedback); (3) Washout (same as Baseline).

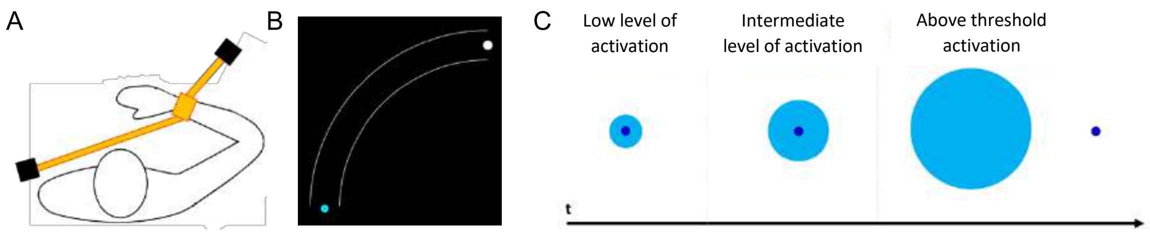

Fig. 1 – A: Experimental setup with the elastic band; B: Graphical elements of the visual stimuli; C: Sketch of the EMG-based visual feedback.

Results

Preliminary results from five unaffected participants revealed that the compensatory trapezius activation occurred in all participants during Adaptation, causing cursor detachment from the circle (number of detachments during E 4.28±1.25 and F 2.2±0.5, mean±std). Moreover, the EMG-based visual biofeedback was able to improve the control of trapezius activity, reducing over-activation in all participants, as indicated by less cursor detachment from early to late Adaptation (E 1.1±0.1, F 0.7±0.3).

Discussion

Future work will involve testing on a larger cohort and automating the activation threshold estimation. Funding: This work has been supported by the project "VISIONARY Advanced VISual feedback for neurorehabilitatION systems based on virtuAl RealitY" - funded by the MIUR Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN) Bando 2022 - grant 202275443W

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Identifying and assessing error contributions in inertial-based mediolateral foot motion tracking

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Introduction

Virtual Reality (VR) applications are increasingly adopted in motor rehabilitation. When improving gait is the goal, an accurate foot motion tracking is needed, to allow a natural interaction with the virtual environment. Inertial Measurement Units (IMUs) offer a good trade-off between accuracy and usability but three main sources of error affect the estimated trajectory relative to a fixed reference frame (FRF) (e.g., the VR environment RF): 1) FRF misalignment with respect to the Direction of Progression (DoP) caused by an incorrect positioning of the IMU on the shoe (misIMU); 2) drift in the orientation estimation due to Angular Velocity Integration (driftAVI) (when the magnetometer cannot be used) [1]; 3) drift resulting from Acceleration Double Integration (driftADI) [1]. This study aims to quantify the contribution of ADI, AVI, and misIMU errors to the estimation of mediolateral (ML) component of foot instantaneous position. While IMU based position estimation errors and relevant correction methods have been extensively dealt with in the literature for the other two components, a limited number of studies dealt with sources of error and correction methods for the ML foot position estimation [2,3].

Methods

Five healthy subjects performed ten straight walking trials (~5.5 m long, comfortable speed) and a total of 300 strides were recorded and analyzed. Subjects wore an IMU (Shimmer, Dublin, Ireland) on each foot, attached to a rigid plate carrying a three-marker cluster. IMU data were recorded and processed in MATLAB R2021a; marker trajectories were recorded using a 12-camera stereophotogrammetric system (100 frame/s, Vicon, UK). Acceleration data from the IMUs were reoriented with respect to a FRF while the subject was still with both feet pointing at the DoP, using the gravity vector and horizontal projections of the remaining sensor axes. Cluster's axes and IMU FRF were then aligned to estimate the initial heading angle of FRF with respect to the DoP. Orientation was computed using accelerometer and gyroscope only as in [4], with pitch and roll components reset at each stance phase [5]. The heading direction was neither reset nor corrected using magnetometer data. The foot ML position expressed in the FRF was estimated as in [6]. The effects on the estimation of the foot ML position due to both driftAVI and driftADI were isolated canceling the misIMU effects, by aligning the FRF anteroposterior axis with the DoP as identified by the cluster orientation. Then the effects of driftADI were isolated by replacing the IMU orientation estimation with the cluster orientation estimation. The Mean Absolute Error (MAE) of the foot ML position was computed on three complete strides on each side for every trial (~ 4m) relative to the estimate obtained using the cluster.

Results

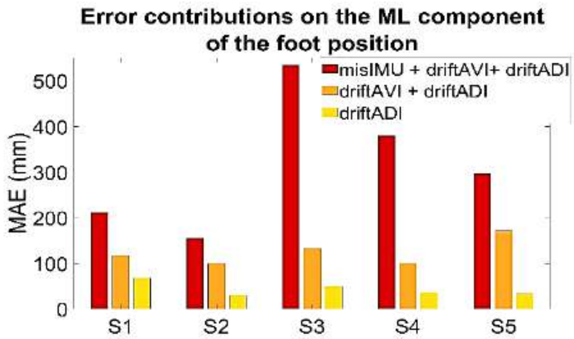

Figure 1. Average MAE of the estimate of the foot ML position when all sources of error are considered (red), when only driftAVI and driftADI are considered (orange) and when only driftADI is considered (yellow).

Discussion

These preliminary results (Figure 1) contribute to a better evaluation of the error sources when the foot position is estimated using an IMU. The most relevant countermeasure appears to be the correct alignment of the IMU reference frame with the DoP and therefore it is the most important action to take to improve foot tracking in a VR environment.

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Influence of preoperative physical activity levels on postoperative recovery in patients with musculoskeletal tumors using wearable sensor-based functional assessment

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Introduction

Bone and soft tissue tumors treatment often requires invasive surgery, causing significant motor impairment [1]. Physical activity (PA) is known to improve quality of life in cancer patients, reduce treatment-related side effects, enhance muscular and cardiovascular function, and support faster recovery [2]. While most studies focus on exercise during or after treatment, limited attention is given on how much preoperative PA levels impact postoperative recovery. This study aims to analyze postoperative recovery differences between physically active and sedentary patients, to determine if preoperative higher PA levels promote faster and more functional recovery.

Methods

Eight active (AP), and 12 sedentary (SP) patients with musculoskeletal tumors were selected based on their PA levels assessed through a self-developed questionnaire and classified using PASSI criteria [3] from an Italian public health surveillance system monitoring adult lifestyle and risk factors for chronic diseases. All participants completed a 2-minute walk test (2MWT), Timed Up and Go (TUG), and 60-second posturography while wearing a set full of 15 inertial measurement units (opal, APDM Inc., 128 Hz). Gait spatiotemporal metrics, TUG time and trunk motion, turn parameters, and postural sway were analyzed.

Results

No significant pre-intervention differences were found between AP and SP except for the stand-to-sit lean angle (TUG). Post-intervention, SP showed longer turn duration and slower turn velocity (TUG), and shorter stride length (both limbs, 2MWT) compared to AP which, in turn, showed no significant pre-post changes. SP showed shorter stride (operated limb) and longer swing duration (healthy limb) post-surgery vs pre-surgery. Levels of decay (%) of each parameter are shown in Figure 1.

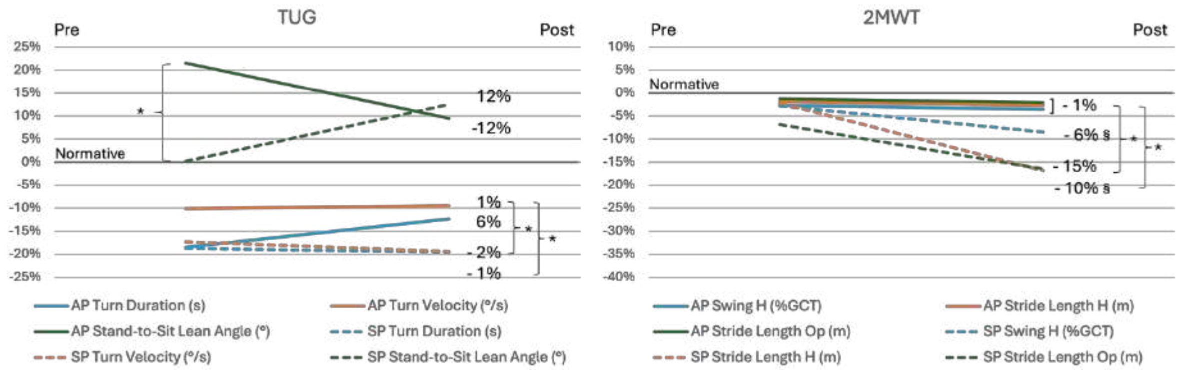

Figure 1. Sig. diff.: * between AP and SP; § between SP Pre-Post. Op: operated limb, H: healthy limb. Improvement in parameter values is shown by upward slopes; decline is shown by downward slopes. Zero indicates the normative (baseline) value.

Discussion

Overall, the parameters indicate a general post-surgical functional decline, although this trend appears mitigated in physically active (PA) patients. Sedentary patients, instead, showed significant impairments post-intervention, suggesting that physical fitness before surgery may reduce the post-surgery functional decline, promoting better recovery outcomes. These findings emphasize the importance of physical preparation in optimizing post-surgical recovery. Nonetheless, it is outlined the fundamental role of instrumental assessments in ecological settings enabled by wearable sensors.

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TELENEURART: AI-Driven Monitoring and Rehabilitation of Congenital and Acquired Brain Injuries Using Digital Biomarkers

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Introduction

The percentage of neurological disorders is about 15% across all age groups, but damage to the central nervous system (CNS) accounts for over 40% of DALYs in newborns, mainly due to the effects of prematurity and hypoxic-ischemic encephalopathy [1]. Childhood is therefore a very vulnerable window of life, and developmental alterations that occur early have a significant impact throughout the lifespan, with far-reaching effects on the individual and caregivers in terms of social participation, quality of life, economic and social costs, and school and work performance. The primary objective is to create an acquisition protocol of all clinical and technological data in the described population, derived from both evaluation protocols and treatment pathways, in order to develop models and identify digital biomarkers with the support of artificial intelligence algorithms, capable of enabling the precise identification of specific functioning profiles [2].

Methods

This research project, TELENEURART, involves clinical and research institutes distributed across the country of Italy, defining the study as a multicenter one. A total of 280 subjects aged between 4 and 25 years with neurodevelopmental disabilities (including individuals with intellectual disabilities, congenital or acquired brain injuries, neuromuscular diseases, and autism spectrum disorder) are expected to be recruited and distributed among the participating clinical centers based on specific expertise. Assignment will be non-randomized, as it will be based on the individual evaluation and rehabilitation needs of the subjects, taking into account their age and functioning profile. The inclusion criteria are as follows: confirmed diagnosis; absence of serious associated pathologies; age between 4 and 25 years at the time of recruitment; cognitive functioning sufficient to understand the proposed activities and cooperate during exercises, assessed through specific evaluation scales (WPPSI-III, WPPSI-IV, WISC-IV, WAIS-IV, LEITER-R, LEITER-3, or RAVEN Matrices); and MACS Level < V. The clinical and technological data obtained will be used to develop artificial intelligence models with the following aims: to identify specific functional groups through clustering techniques to support the development and evaluation of targeted rehabilitation processes; to monitor the progress of rehabilitation sessions and potentially detect abnormal trends during treatment; and to predict clinical indicators of patient functionality based on the data collected during these sessions.

Results

We developed standardized clinical databases shared across all participating institutes, selecting the most relevant outcome measures— including clinical data, functional rating scales, neuroimaging, and technology-based assessments—targeted to the principal neurodevelopmental disorders. Specifically, the assessment protocol for patients with congenital and acquired brain injuries consists of three primary domains: motor function; speech and language abilities; and cognitive, neuropsychological, and behavioral/emotional functioning. In particular, neuromotor assessment includes the following measures: Six-Minute Walk Test (6MWT), Gross Motor Function Measure (GMFM-88), Functional Reach Test (FRT), Melbourne Assessment 2 (MA2), Movement Disorders–Childhood Rating Scale 4–18 Revised (MD-CRS R), Dystonia Movement Scale (Burke-Fahn-Marsden), Range of Motion (ROM), and the Modified Ashworth Scale. Technology-based assessment includes gait analysis and stabilometry.

Discussion

We aim to present an example of a multidisciplinary approach in which various professionals—clinicians, data analysts, and engineers—collaborate to develop a personalized and validated strategy focused on functional diagnosis, the design of tailored neurorehabilitation treatments, and ongoing monitoring.

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Preliminary insights into trunk kinematics in chronic low back pain: a sensor-based cross-sectional study integrating clinical and biomechanical assessment

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Introduction

Chronic low back pain (CLBP) remains one of the most disabling musculoskeletal disorders globally [1]. Its multifactorial nature demands interdisciplinary approaches, where biomechanics and clinical sciences converge to inform rehabilitation strategies. Trunk kinematics, reflecting segmental mobility and neuromuscular control, plays a relevant role in this context. With the advent of wearable inertial measurement units (IMUs), it is now feasible to collect high-resolution, objective motion data in real-world scenarios, enhancing the value of biomechanical research in clinical populations [2].

Methods

This preliminary cross-sectional study included 15 individuals with CLBP and 30 healthy controls. Trunk ROM was quantified using a validated IMU system capable of capturing 3D angular displacements in flexion, extension, lateral bending, and rotation. Additionally, participants performed the Timed Up and Go (TUG) test from which parameters of postural stability (nRMS), smoothness (LDLJ), and gait symmetry (iHR) were extracted across all three axes. Clinical parameters assessed included pain intensity (VAS), disability (ODI questionnaire), and kinesiophobia (TSK questionnaire). Statistical analysis involved Welch's t-tests for group comparisons, Spearman correlations, and multiple linear regression models to investigate associations between biomechanical and clinical variables.

Results

Significant between-group differences were observed in trunk ROM. Compared to healthy controls, CLBP subjects demonstrated reduced lateral bending (8.89° ± 2.20 vs. 16.87° ± 3.19, $p < 0.001$, $d = -1.86$) and increased extension (25.68° ± 6.05 vs. 14.77° ± 5.12, $p < 0.001$, $d = 1.77$), with no significant differences in rotation ($p = 0.43$). Correlational analysis revealed weak, non-significant associations between ROM and clinical metrics. In the regression model, BMI ($p = 0.025$) and VAS ($p = 0.008$) emerged as significant predictors of trunk extension. No variables significantly predicted flexion or rotation. Regarding TUG-derived parameters, multiple regression analysis identified ODI ($p = 0.004$) and TSK Tot ($p = 0.002$) as significant predictors of postural instability along the Y-axis (nRMS_Y), while no meaningful associations were found for symmetry or smoothness metrics.

Discussion

These preliminary results emphasize the relevance of motion analysis in characterizing motor adaptations in CLBP, particularly in the frontal and sagittal planes. The integration of IMUs enables a data-driven perspective on movement impairments, contributing to the profiling of functional phenotypes. The additional insight offered by TUG-based metrics further supports the utility of dynamic assessments in this population. Nevertheless, the low explanatory power of clinical predictors and the variability across subjects reflect the intrinsic heterogeneity of CLBP, which transcend purely biomechanical models. These findings highlight the need for multidimensional models that couple clinical assessment with quantitative biomechanics to support tailored rehabilitation paradigms.

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Towards ecologically valid functional gait assessments: integrating motor complexity in Parkinson's disease and stroke rehabilitation

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Introduction

Combining clinical assessment and instrumented analysis allows for objective, quantitative evaluation of motor changes following rehabilitation, offering deeper insights into the functional limitations in neurological disorders [1]. However, standard motor assessments are often conducted in simplified settings that fail to replicate the complex demands of everyday functional mobility, potentially leading to an underestimation of functional deficits. This applies also when evaluating the efficacy of rehabilitation treatments. Therefore, it is critical to incorporate evaluation protocols that more accurately reflect real-world challenges faced by neurological patients [2]. Thus, this study aims at verifying the effectiveness of more complex assessment methods in patients with Parkinson's disease (PwPD) and stroke (PwST) undergoing different therapeutic protocols.

Methods

Fifteen people with PwST and 15 PwPD underwent two different rehabilitation protocols: 8 PwST and 7 PwPD were allocated in a conventional therapy group (PwST_CG: 66.1±9.7y, Fugl-Meyer_LowerExtremity - FMLE:22; PwPD: 70±10.3y, Hoehn&Yahr:1.5), while the remaining patients in an experimental therapy group (PwST_EG: 56.8±16.2y, FMLE:28; PwPD: 68±7.2y, Hoehn& Yahr:2). Participants underwent 12 individual sessions of 50 minutes each of conventional or experimental intervention, 3 days per week/4 week. Before (T0) and at the end of the intervention (T1) all participants performed 2 different motor tasks repeated in two different protocols, indoor and simulated real-life, respectively. The motor tasks consisted in 1) curvilinear walking: standard clinical evaluation (Figure-of-8 walk test, Fo8WT), and curved mountain walk (CMW) on a led floor in mountain scenery; 2) timed up and go test (TUG): standard clinical TUG and TUG mirroring kitchen chores (RTUG). A set of spatio-temporal parameters was extracted from 16 inertial measurement units (Captiks srl, Italy, 100Hz) through Motion Analyzer validated algorithms [3]. A Wilcoxon Test was performed (SPSS, v29, IBM Corp).

Results

Figure 1 includes TUG findings between EG and CG for PwST from each protocol for the purpose of readability, but similar results were found for curved tasks. While statistical differences were observed for two parameters in the EG at T0 and T1, all patients generally exhibited improved performance, irrespective of the assigned treatments. However, the real struggle is visible when the task is more complex (CMV-RTUG) with respect to simpler tasks. Consequently, the motor performance declines as the complexity of the activity increases.

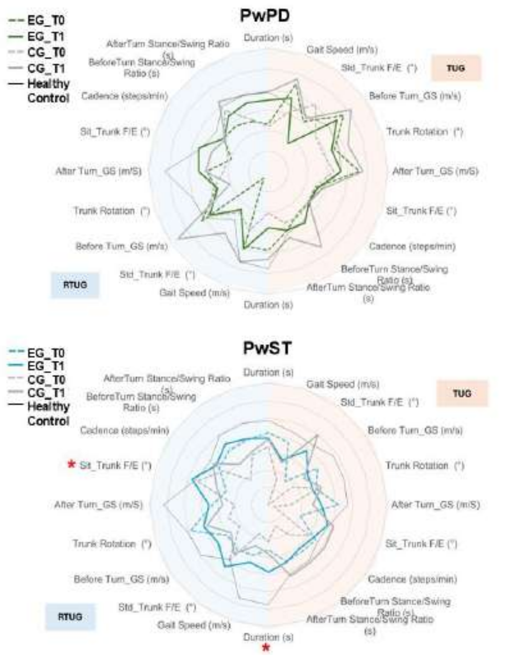

Figure 1. Radar plots of TUG motor tasks for indoor (pink fill) and real-life (blue fill) protocols. The larger the radar, the better the performance. Mean values and standard error were considered for each parameter. *****, statistically significant differences between T1 and T0 for EG (p<0.05).

Discussion

Real-life tasks bring out motor impairments of PwST, as evidenced by CMW and TUG data, consistently across all tasks. These preliminary results reflect the importance of incorporating real-world tasks that better point out the experienced functional limitations.

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Evaluation of botulinum neurotoxin treatment for dystonic head tremor: role of the gyroscope.

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Introduction
Inertial sensors, such as accelerometers and gyroscopes, are used to quantitatively assess tremor.[1] Dystonic head tremor (DHT) is a hallmark feature of cervical dystonia (CD),[2] with Botulinum neurotoxin (BoNT-A) being a first-line therapy for CD. We assume that such devices possess an unfulfilled potential that could greatly benefit clinical practice. We aim to evaluate DHT characteristics and BoNT-A treatment effectiveness in DHT using gyroscope.

Methods
We evaluated patients with DHT attending the botulinum toxin clinic at IRCCS Fondazione Don Gnocchi from January to July 2024. Clinical and instrumented assessments were performed at baseline (T0) and 4–6 weeks post-treatment (T1), after US/EMG-guided BoNT-A administration. TWSTRS, Tsui scale, Tremor Rating Scale (TRS) head score, CDQ-24, HADS, subjective disability (VAS-disability, PGIC) assessed clinical impact. Gyroscope, placed on the forehead, recorded angular velocity (deg/s) of each tremor axis during different tasks (rest with eyes closed/opened, seated with outstretched arms, standing with eyes closed/opened). [Figure 1]. Data derived from the recordings included: mean frequency, power spectral density (PSD), mean rotation (MR) and maximum burst rotation (MBR). Power spectra were visually analyzed for each axis and compared with clinical findings to identify the predominant tremor axes. Finally, the inter-cycle variation of frequency (ICVF) and its interquartile range (ICVFiqr) were calculated, to obtain a quantification of the frequency variability of DHT.

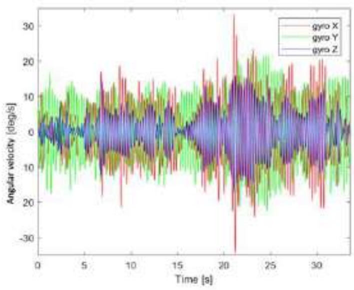

Figure 1 - Gyroscope signal measured at the head of a patient with DHT for each of the tremor axis. Angular velocity is plotted versus time and is expressed in deg/s.

Results
Seventeen out of nineteen patients with DHT recruited, completed the assessment. The analysis of the gyroscope-derived power spectra led to a change in the clinically predicted muscle pattern for BoNT-A injection in 64.7% of patients (11/17). Significant improvements were observed in clinical scales ($p<0.05$). Gyroscope data showed significant reductions in tremor PSD and MR during rest seated tasks ($p<0.05$), and in tremor MBR during all tasks ($p<0,05$). ICVFiqr remained unchanged after treatment suggesting that BoNT-A treatment does not influence tremor frequency instability.

Discussion
Despite the limited sample size, our pilot study demonstrates that BoNT-A is an effective treatment for DHT when assessed at maximum pharmacological effect. Our findings support the use of gyroscope as a valuable tool in clinical setting. Inertial sensors provide quantitative data that is useful for assisting clinicians in optimizing muscle selection for BoNT-A treatment in the cervical region. This allows for precise treatment monitoring and provides quantitative insight into the phenotypic features of DHT. Further research is needed to confirm the effectiveness of using gyroscopes in patients with DHT.

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Unmasking Subtle Posture and Gait Deficits: The Role of Ecological Assessments and Complex Tasks in Neurological Rehabilitation

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Introduction

Balance and gait assessments often rely on standardized tests which provide valuable insights [1] but may lack the complexity required to uncover subtle deficits, particularly in individuals who compensate well under controlled conditions but struggle in daily life. It is therefore mandatory to integrate more complex and ecologically valid tasks into clinical practice [2]. Thus, this study aims to assess whether incorporating challenging, real-world-inspired motor and postural tasks into clinical evaluations enhances the detection of functional impairments in patients with Parkinson's disease (PwPD).

Methods

Nineteen healthy subjects (HS, 60±11 years, 12 females) and fifteen PwPD (69±9, 4 females), equipped with 16 inertial measurement units (Captiks srl., 100Hz, Italy), were assessed while standing for 60s on the ground and on mats with different textures: no elastic resistance, embedded pebbles, and root-like surface. Furthermore, gait was assessed through a standard 10m linear walking task (10MWT) and a 6m walk on a mat with no elastic resistance (MatWalk). Data were extracted using Motion Analyzer software and implemented algorithms [3]. Differences across tasks of different complexity were assessed through a Repeated Measure ANOVA (SPSS, v29, IBM Corp).

Results

In graph A, the results of the four postural tests are shown in the four coloured sections, with the dotted polygon representing HS and the solid polygon representing PwPD. In graph B, the roles are reversed: the right section shows PwPD results and the left section shows HS results, with the dotted polygon representing the MatWalk test and the solid one representing the 10MWT.

Subplot A shows that, on the different textured mats, PwPD, who appeared to perform relatively well during standard ground-based postural tasks, showed a marked decline in balance performance. Similar results were observed in Subplot B for walking tasks, where there was a significant decrease in all spatio-temporal parameters during the MatWalk test compared to ground-based walking. Noteworthy, even HS showed a significant decrease in both gait and postural mat tasks.

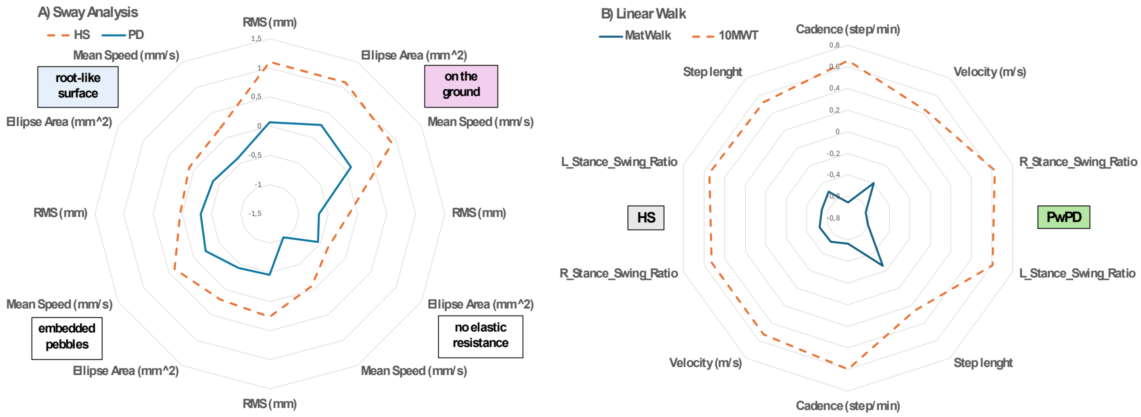

Figure 1. Radar Plot of Postural and Gait test. Some of the reported data have been inverted and then normalized to match a larger radar area with a better condition.

Discussion

These results suggest that the adoption of more complex balance and gait tests may better identify hidden gait and postural instabilities. Unmasking subtle deficits may enhance the precision of assessments, leading to more targeted and effective intervention strategies.

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New deep brain stimulation settings to improve gait in patients with parkinson's disease: preliminary results.

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Introduction

Subthalamic nucleus (STN deep brain stimulation (DBS) is an established treatment to alleviate motor symptoms in advanced Parkinson's disease (PD). However, STN-DBS-implanted patient may suffer from gait disorder resistant to medications or stimulation. Notably, gait and balance may deteriorate after implant on conventional stimulation parameters (130 Hz frequency, 60 µs pulse width), possibly due to unintended current spread to adjacent neural structures [1]. This study investigates whether non-conventional stimulation parameters (low frequency or short pulse width) may enhance gait quality in PD patients after STN-DBS.

Methods

This multicenter, randomized, double-blind, crossover study recruited 14 (9 M, 5 F, age mean 60,28 years) Parkinson's disease (PD) patients treated with bilateral STN-DBS. Participants were randomized to undergo to either low-frequency (80 Hz; LF) or short pulse width (30 µs; SPW) stimulation arm during 4 weeks and then switch to the other stimulation paradigm. During this 8-weeks period the medications were unchanged. Assessments were conducted in single motor-task, in dual motor-task and in dual cognitive-task at the baseline in OFF (A) and ON conventional stimulation (B) and at 1 month after LF or SPW stimulation. All the assessment were performed in ON-medication condition. Data were collected using three inertial units (Opals, APDM Inc.) worn on the posterior trunk at the L5 level and on the right and left shanks, sampled at 128 Hz [2]. Spatio-temporal gait parameters were calculated during walking trials in all conditions. Statistical analysis was performed using the Friedman test with Bonferroni correction for multiple comparisons for each outcome measure recorded in all therapeutic conditions (A,B, LF, SPW).

Results

Preliminary findings revealed statistically significant differences across the four assessment time points ($p \leq 0.0001$) in all testing conditions. Specifically, during the single motor task, a significant difference in single support time was observed between conventional stimulation and SPW ($p = 0.009$). In the dual motor task condition, significant differences were detected in both double support and terminal double support phases between conventional stimulation and SPW ($p = 0.008$). Finally, during the cognitive dual-task condition, gait speed showed a statistically significant difference between conventional stimulation and LF ($p = 0.0016$).

Discussion

Preliminary results demonstrated that, in patients undergoing STN-DBS, SPW stimulation led to improvements in single and double support phases during both single and dual motor tasks, while LF in gait speed during the cognitive task. To date, no single experimental setting has emerged as superior; however, these preliminary findings are promising and warrant further investigation in order to uncover a potential individualized patient-specific programming.

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Preliminary biomechanical assessment of stair negotiation in a post-stroke patient and a healthy control using wearable sensors and EMG

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Introduction

Stair negotiation is a fundamental daily activity for autonomy and has been proposed as a possible predictor of fall risk in patients with motor disability such as stroke patients [1]. However, its quantitative assessment remains poorly investigated, despite the growing potential of wearable sensor-based approaches to analyze stair negotiation biomechanics in neurological populations [2]. Quantitative biomechanical assessment may help identify specific compensatory patterns, contributing to tailored rehabilitation and fall prevention strategies.

Methods

Two male participants were assessed: a 76-year-old post-stroke patient (left hemiparesis, MiniBESTest 3/28, TUG 38.26 s) and a 36-year-old healthy control. Tests included stair ascent and descent on a 10-step staircase, and level walking at self-selected speed. Data were acquired using an inertial sensor positioned at L5 (G-WALK, BTS Bioengineering), foot switches for gait phase detection, and surface EMG (rectus femoris, semitendinosus, tibialis anterior, medial gastrocnemius bilaterally). Spatiotemporal, kinematic, asymmetry indices and muscle activation patterns were extracted.

Results

During stair ascent, the patient showed reduced cadence (80.4 vs 97.3 steps/min), prolonged cycle time (2.39 vs 1.24 s), and increased stance time asymmetry (AI: 64.7%). In stair descent, cadence was 85.9 vs 94 steps/min, cycle time 1.67 vs 1.28 s, with asymmetry index 20%. EMG analysis revealed prolonged co-contractions and phase-unspecific activation of distal muscles, especially tibialis anterior and gastrocnemius.
During walking, the patient showed reduced cadence (80.4 vs 114 steps/min normative), prolonged cycle time (1.5 s), increased stance time asymmetry (GSI: 10.2%), and reduced gait cycle quality (81% on the paretic side). Coactivation indices were elevated, indicating poor neuromuscular coordination.

Table 1. Spatiotemporal parameters and asymmetry indices during walking and stair negotiation in the patient and control

Parameter	Patient (Walking)	Patient (Ascent)	Patient (Descent)	Control (Ascent)	Control (Descent)
Cadence (steps/min)	80.4 ± 7.1	80.4 ± 25.8	85.9 ± 10.0	97.3 ± 1.8	94 ± 3.3
Cycle time (s)	1.50	2.39 ± 0.07	1.67 ± 0.56	1.24 ± 0.02	1.28 ± 0.04
Asymmetry Index (Stance time, %)	13.3%	64.7%	20.0%	1.3%	19.0%
Double support - Right (% cycle)	5.2 ± 2.6	12.2 ± 1.6	19.5 ± 19.7	13.6 ± 0.5	11.5 ± 4.1
Double support - Left (% cycle)	6.8 ± 3.1	33.2 ± 6.5	47.7 ± 25.4	12.3 ± 0.7	12.7 ± 1.6

Discussion

This preliminary multi-sensor assessment identified relevant motor control impairments and compensatory strategies in stair negotiation and walking after stroke. Combining spatiotemporal, kinematic, asymmetry and EMG data may enhance clinical evaluation and guide individualized rehabilitation and fall risk management.

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Minimizing wearables, maximizing insight: fusing complementary strength of IMUs and RGB-D for upper body kinematics in home rehabilitation

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Introduction

Wearable inertial measurement units (IMUs) and RGB-Depth cameras enable the monitoring of joint angles and trajectories, but each has limitations. IMUs provide only indirect estimates of joint positions. Achieving full upper limb kinematics with IMUs requires placing sensors on anatomically challenging areas, such as the clavicle or hand, reducing comfort and requiring assistance for accurate placement, thereby limiting their suitability for unsupervised home use. In contrast, RGB-D cameras offer direct estimates of joint centre positions but struggle with axial rotations and occlusions. This study proposes a method to reconstruct full upper body kinematics by integrating a reduced set of IMUs with a single RGB-D camera. The hypothesis is that their complementary strengths can compensate for individual limitations, enabling complete motion estimation with minimal wearable instrumentation.

Methods

An unaffected participant performed a one-minute planar hand movement on a table, involving coordinated motion of the upper limb, while equipped with three IMUs (Xsens MTw, 100 Hz) placed on the sternum, upper arm, and forearm, and recorded by a frontal RGB-D camera (Azure Kinect, 1080×1920, 30 Hz). The IMU orientations were computed as in [1], while 3D coordinates of sternum, clavicles, shoulders, elbows, wrists, and hands joint centres (keypoints) were extracted using the Azure Kinect Body Tracking SDK [2]. To integrate complementary measurements, the biomechanical model in [1] was adopted and extended to include nine rigid segments (thorax, clavicles, upper arms, forearms, hands) and eight revolute joints. The model was scaled to the subject's segment lengths. Relevant joint angles were estimated by fitting the model segments to measured orientations and joint centre positions through constrained optimization to preserve functional anatomy. A Vicon system (24 markers, "Upper Limb Model" plug in, 100 Hz) was used as reference. The process was repeated using IMU orientation only (A), keypoints only (B), and both data (C). Accuracy was assessed by computing the root mean square error (RMSE) of joint angles against the reference after offset removal. Since the reference lacked sternoclavicular angles, RMSE was computed on the shoulder joint centre positions, which was derived by rigidly propagating the thorax orientation and the clavicle length in the IMU-only case.

Results

Table 1 shows joint and center RMSE values; black entries mark angles not estimable by the method. **Table 1**. A (IMU only), B (camera only), and C (IMU + camera).
ML = mediolateral, AP = antero-posterior, V = vertical. EP = elevation plane, EL = elevation, IE = intra/extra rotation. FE = flexion/extension, PS = pronation/supination. AA = abduction/adduction.

	Thorax-world (deg)			**Shoulder center (cm)**			**Sholder (deg)**			**Elbow (deg)**		**Wrist (deg)**	
	ML	AP	V	x	y	z	EP	EL	IE	FE	PS	FE	AA
A	1.5	1.5	4.2	12.1	2.1	4.4	13.6	3.6	20.7	4.7	16.1		
B	16.6	9.2	6.2	5.6	3.1	1.4	26.7	15.3		19.8		28.6	23.5
C	1.9	2.5	5.1	9.4	2.4	1.2	18.1	3.4	23.9	4.7	16.1	11.9	14.3

Discussion

Angles estimated from B are less accurate than those from A. A shows limitation in shoulder joint centre localization and does not enable wrist angle estimation. C improves wrist angles compared to keypoints alone and balances the higher accuracy of IMUs with improved wearability. A promising direction is to exploit the temporal stability of keypoints to compensate for IMU drift over longer durations [1].

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Assessment of upper limb kinematics using 3D markerless and marker-based motion capture: a preliminary comparative study

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Introduction

As space exploration advances, understanding how altered gravity impacts human motor behavior becomes critical. Virtual and mixed reality (VR/MR) technologies facilitate the simulation of environments with controllable gravity, enabling motion analysis studies under these conditions. A serious game, recently developed for this purpose, allows participants to throw a virtual ball at a target subject to altered gravity, visually simulated, to investigate consequent motor strategies [1]. Kinematic analysis is typically conducted using a marker-based (M-b) motion capture system which is considered the motion analysis gold standard. However, M-b systems generally demand extensive preparation, and reduced participant comfort. Markerless (M-l) motion capture offers a quicker preparation and a less intrusive alternative. This study compares 3D upper limb kinematics estimated by a M-l and a M-b systems, aiming to simplify the experimental setup for tasks performed in VR/MR environments such as the serious game mentioned above.

Methods

Two healthy male subjects with different anthropometry (S1: 21 y.o., 62 kg, 1.78 m; S2: 34 y.o., 74 kg, 1.70 m) performed a set of upper limb movements involving a single degree of freedom (1-DoF) at a time: shoulder flex-extension (S_{FE}), ab-adduction (S_{AA}), intra-extra rotation (S_{IER}), elbow flex-extension (E_{FE}), forearm prono-supination (F_{PS}), wrist flex-extension (W_{FE}), radio-ulnar deviation (R_D). Participants performed also a ball-throwing task, in line with the studies conducted in conditions of visually simulated altered gravity. Each participant performed 10 repetitions of each movement. M-b data was acquired using a 14-camera optoelectronic stereophotogrammetric system (Vicon, Oxford, UK) at 100 frames/s, and simultaneously M-l data was captured using a 9-video camera motion capture system (The Captury GmbH, Saarbrüken,Germany) at 50 frames/s. The analysis of M-b data was performed adopting an existing upper limb model [2]. M-l data were processed using the Captury Studio 2 Ultimate (v 2.9), from which 3D pose estimates of trunk and upper limb segments were obtained. Joint angles were then obtained from both the M-b and M-l data and compared using the Mean Absolute Difference (MAD).

Results

Table 1. Mean absolute difference for upper limb joint angles

	1-DoF movement							Ball-throwing task		
	S_{FE} (°)	S_{AA} (°)	S_{IER} (°)	E_{FE} (°)	F_{PS} (°)	W_{FE} (°)	R_D (°)	S_{FE} (°)	S_{AA} (°)	E_{FE} (°)
S1	4.9	3.7	2.6	6.2	80.5	18.2	8.4	6.3	7.7	7.9
S2	3.1	4.2	8.7	9.9	47.1	20.3	17.3	5.2	7.4	9.3

Discussion

The M-l system showed good agreement with M-b estimates for some 1-DoF movements (e.g. S_{FE}, E_{FE}). Joint angle differences were limited, indicating reliable tracking of large segment motions except for F_{PS} (see relevant column in Table 1). This was expected since prono-supination is a movement difficult to quantify without direct access to anatomical landmarks. The lower quality tracking of the hand results in high MAD of W_{FE} and R_D. Consistently with the results from the 1-DoF movements, joint kinematics during the ball-throwing task, was estimated better for the shoulder (S_{FE}, S_{AA}) and the elbow (E_{FE}). The limited capability of estimating the kinematics of joints formed by smaller segments may be partially attributed to the need of most M-l techniques to identify the whole human body within the image, which inevitably reduces the number of pixels forming the image of smaller segments. Improvements in this respect would refine the M-l based estimate of upper limb joint kinematics resulting in simpler experimental protocols.

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Investigating visual cue effects on gait and posture in healthy populations

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Introduction
Scientific literature supports the effectiveness of external sensory cueing, like visual cues, in improving kinematic parameters of gait in patients with neurological disorders, such as Parkinson's disease [1,2]. However, it remains unclear whether visual cues contribute to improve functional performance, specifically static and dynamic balance, also in individuals without neurological conditions, such as older adults or even younger adults. This study aims to contribute to understanding the role of visual cues in these populations. To this end, balance training incorporating visual cues was administered to both older and younger adults, and its effects were assessed on static posture and locomotion.

Methods
Nineteen healthy adults (AG; 30±13 years) and eight healthy elderly participants (EG: 63±3 years) were recruited in this study (CE 2024_07_05). Participants were tested at baseline (T0) and after ten training sessions (45 minutes for 10 days) (T1) based on the use of the Q-Walk system (QUICKLYPRO s.r.l., Bergamo, Italy), consisting in a pair of knee pads that incorporate a LED spotlight that projects a customized circular light beam on the floor, in front of the subject. Static and dynamic balance were assessed by means of instrumented postural and gait analyses, the latter both with and without the Q-Walk system. In particular, postural stability was assessed through a balance test performed on a stabilometric platform (Khimeya, Padua, Italy), and dynamic balance through a gait test involving an optical infrared detection system (OptoGait, Microgate, Bolzano, Italy). A set of posturographic parameters and spatiotemporal gait parameters were extracted. Significant differences between sessions and between conditions were assessed through t-test or Wilcoxon signed-rank test with Holm Bonferroni correction after checking for normality distribution using the Kolmogorov-Smirnov test.

Results
Table 1. Descriptive and inferential statistical results of gait spatiotemporal parameters.

		Parameter	T0	T1	p-value	t-stat or z-val
			Mean±Std Dev			
Without Q-Walk	AG	Stance [%]	64.3±1.7	63.3±2.1	**<0.001**	4.271
		Swing [%]	35.6±1.3	36.5±1.5	**0.002**	-3.490
		Double Supp. [%]	29.0±2.5	27.5±2.5	**0.002**	3.304
		Froude Nr [dimless]	0.45±0.1	0.49±0.1	**0.015**	-2.454
	EG	Stance [%]	64.5±1.3	63.9±1.4	0.620	1.445
		Swing [%]	35.5±1.3	36.1±1.4	0.465	-1.445
		Double Supp. [%]	29.1±2.5	28.1±2.6	0.342	1.389
		Froude Nr [dimless]	0.44±0.1	0.44±0.1	0.732	-0.343
With Q-Walk	AG	Stance [%]	64.7±1.7	63.7±1.7	**0.003**	3.060
		Swing [%]	35.2±1.4	36.2±1.6	**0.002**	-3.440
		Double Supp. [%]	29.8±2.8	27.9±3.0	**0.002**	3.406
		Froude Nr [dimless]	0.42±0.1	0.47±0.1	**<0.001**	-4.339
	EG	Stance [%]	65.0±1.2	64.2±1.6	0.157	1.992
		Swing [%]	35.0±1.2	35.8±1.6	0.105	-1.992
		Double Supp. [%]	30.2±2.1	28.6±2.8	0.114	2.263
		Froude Nr [dimless]	0.41±0.1	0.42±0.1	0.562	-0.583

No significant difference was found in postural parameters between T0 and T1. For gait, AG showed significant improvements (Table 1, green cells in bold), while EG exhibited non-significant but consistent trends toward better functional performance.

Discussion
Visual cue-based training led to significant improvements in spatiotemporal gait parameters in healthy adults, supporting its effectiveness in enhancing motor performance. While no significant changes were detected in the elderly group, observed trends suggest potential benefits, likely limited by the small sample size. These findings highlight the value of visual cues in gait training, with ongoing recruitment and future studies needed to confirm effects in older adults and assess long-term retention.

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Toward a patient digital twin for personalized robot-assisted stroke rehabilitation

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Introduction

Robotic technologies have advanced rehabilitation by facilitating high-intensity training, which is critical for promoting functional recovery [1]. However, the observed functional improvements are likely mediated by compensatory strategies rather than true recovery. Compensation, if present, should be accounted for to maximize recovery. To do this, the robot control strategy should account for the movements of the whole upper body, not just hand trajectories. Here we propose an experimental apparatus and a processing pipeline that integrates a planar manipulandum, multiple inertial measurement units (IMUs), and a personalized upper-body musculoskeletal model to assess the kinematics of the upper body and to capture human-robot coupling.

Methods

The experimental apparatus includes a planar manipulandum (HMAN; Articares) with a 32×32 cm workspace, used to record hand trajectories and to provide assistive forces. Six IMUs (MTw Awinda; Xsens) were placed on the torso, the upper limb involved in training (arm, forearm, hand) and the other limb (arm, hand). The robot-hand interaction forces are also recorded with a force sensor place on the robot handle. Participants grasped the hand of the manipulandum with one hand; the other hand was placed on the table performed reaching tasks toward randomized targets at varying angles and distances. A musculoskeletal model (OpenSim) with 22 joints and realistic muscle geometry was adapted to individual subjects based on body weight and selected anthropometric measurements (lengths of arm, forearm, hand; distance between the left and right acromion) [2]. We then reconstructed the whole upper body kinematics by combining IMU orientations and the trajectory of the robot handle (treated as a virtual marker) [3].

Results

The combination of sensors and musculoskeletal model correctly captures the upper body kinematics during interaction with the robot – see Figure 1 – and allows to characterize the coordination between shoulder, elbow, hand movements; in particular, compensatory strategies such as excessive trunk displacement or shoulder abduction. In addition, inverse dynamics allows to estimate the joint torques associated to the movement.

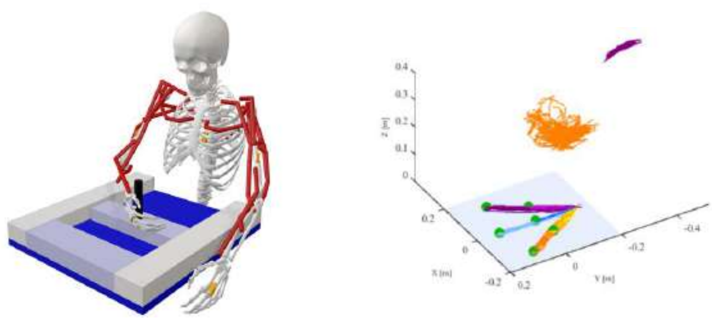

Figure 1: Left: subject-specific model during interaction with the robotic interface. Right: reconstructed kinematics of the shoulder, elbow, and robot handle during a reaching task

Discussion

Future work will include incorporating a model of impairment and recovery. This would lead to a patient digital twin, which can be used to plan patient-specific rehabilitation interventions or to control patient-adaptive interaction in personalized rehabilitation settings.

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Automatic detection of motor stereotypies in Rett Syndrome using wearable sensors

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Introduction

Rett syndrome (RTT) is a rare genetic neurodevelopmental disorder characterized by a wide range of clinical symptoms, emerging in early childhood. Hand stereotypies, characterized as involuntary, rhythmic, repetitive, and seemingly purposeless movements, represent a peculiar symptom that may, in some cases, lead to unintentional self-injury if not properly monitored and controlled. [1]. This study, conducted in the framework of the STOPme project (Supporting Termination Of stereotyPies in patients with Rett syndrome by advanced ambient intelligence), reports on the preliminary exploration of the use of Magneto-Inertial Measurement Units (MIMUs) to characterize the patients' movements and detect the different types of stereotypies.

Methods

Nine female RTT patients (14 ± 9 years) participated in the study, which was conducted in collaboration with the Italian Association for Rett Syndrome (AIRETT). Recordings were performed using five Xsens MTw MIMUs (by Movella, Henderson, NV, USA), streaming at 100 Hz, and placed on the trunk, both upper arms, and both wrists. Data were live-annotated using a dedicated MATLAB user interface during acquisition [3] (Figure). Annotated data were offline segmented into 150-sample windows with 50% overlap [2]. Tri-axial accelerometer and gyroscope data were used to create a dataset including both time-domain and frequency-domain features. Four classifiers (Fine Tree, Boosted Tree, k-Nearest Neighbors (kNN, k=10), and Narrow Neural Network (NNN)) were trained to distinguish motor stereotypies from normal movements. A Leave-One-Patient-Out cross-validation approach was used.

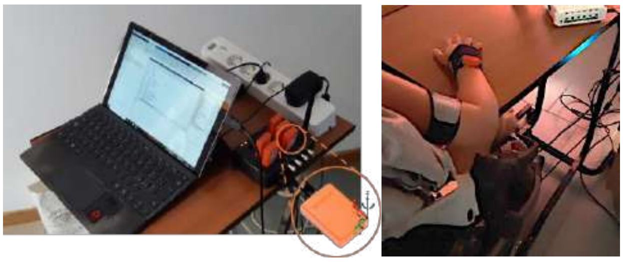

Figure 1 On the left, the Xsens Awinda station, wireless MIMUs, and a laptop running a custom MATLAB interface for real-time acquisition and annotation; on the right, a patient during the recordings.

Results

A final dataset composed of 38388 samples (19194 representing stereotypies and 19194 normal movements) was used for this preliminary assessment. Results revealed an accuracy up to 99±1.1% for the best classifier (Fine Tree), a mean F1-score of 99.3±1.3% and a mean TPR of 99.3 ±1.6%.

Discussion

The limited sample size and the inhomogeneous representation of stereotypies across the participants constrain both the robustness and the generalizability of the results. Patient-specific variability in stereotypic and normal behaviors poses an additional challenge. A more extensive data acquisition campaign, featuring an improved setup, is planned for summer 2025. Discrimination of specific stereotypies is currently being pursued. Despite the limitations, this study highlights the potential of AI-based movement analysis from wearable sensors for the automatic recognition of stereotypies in RTT, representing an important step towards prevention of self-injuries and automated monitoring.

Acknowledgement

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In-field analysis of running temporal parameters: comparing 36 IMU algorithms across speeds and sensor placements

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Introduction

Accurate estimation of stance and stride phase durations is essential in running analysis for their association with performance. IMUs are widely used for gait event detection in outdoor settings, but IMU-based methods vary considerably depending on sensor placement and computational approaches. Some previous studies have evaluated their performance for running within a limited number of sensor placements [1]. This study evaluates 36 algorithms identified from a systematic literature review for estimating temporal parameters during running at three different speeds, from IMU placed on foot, lower limb, and lower back, using photocells as ground truth reference.

Methods

Ten amateur runners (9M1F, age: 26±4 years) performed sprints at 15, 20 and 25 km/h. Six IMUs (OPAL, APDM Wearable Technologies, 800 Hz) were positioned on the dorsal surface of each shoe, the right 5th metatarsal head, the heel (laterally on the shoe), the right shank (medial surface of the tibia and above lateral malleolus), and the lower back (at L5 level). OptoJump Next (MicroGATE Srl, 1000 Hz, 10 meters) served as the reference system. A total of 1034 strides were collected across all subjects. Statistical analysis was conducted to evaluate the influence of speed on the estimation errors of stance and stride parameters, while performance was compared in terms of median error (Med) and interquartile range (IQR, 75th percentile-25th percentile).

Results

Overall, stride time estimation was less affected by running speed compared to stance time. Moreover, a general reduction in stance estimation error was observed at higher speeds. The best-performing algorithm for stride was the foot-based one proposed by Blauberger (2021) (Med = 0 ms, IQR = 2 ms). Stance estimation was more speed-dependent (Figure 1). The shank-based algorithm proposed by Schmidt (2016) was the only algorithm not affected by speed (MED = 4 ms, IQR = 29 ms).

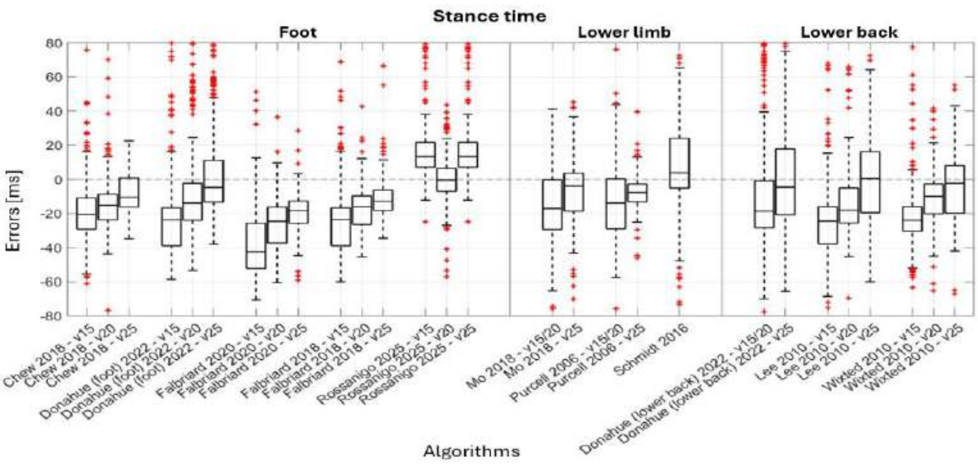

Figure 1. Estimation errors of the best-performing algorithms for stance time, grouped by sensor location. Where statistical analysis revealed a speed-related effect on performance, separate boxplots are shown for each running speed (v15: 15 km/h, v20: 20 km/h, v25: 25 km/h).

Discussion

This performance analysis on IMU-based estimation of temporal parameters in running supports practitioners in making informed choices across different sensor locations and speeds. Foot-mounted sensors are recommended for the best accuracy and repeatability. Stride time estimation is in general more reliable than stance time across locations and less affected by running speed.

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Lumbar spinal laminectomy with and without fixation: an IMU-based ambulatory follow-up assessment

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Introduction

Lumbar spinal stenosis (LSS) causes chronic pain and disability. LSS outcomes seem better for surgical neural decompression than for non-operative treatment. The many different described surgical techniques can be divided in: i) microsurgical decompression alone (MiD); ii) decompression plus instrumentation of the spine (MiD-F). Several prospective studies have suggested that MiD is associated with excellent outcomes [1]. Since LSS can also present instability, in the last 10 years the number MiD-F has increased. The lack of definitive evidence complicates efforts to guide and standardize practice. Given the significant implications of LSS treatment [2], tools to evaluate the effectiveness of treatment options are a matter of priority [3]. In addition to radiological and clinical assessment, IMU-based methods can provide quantitative functional assessment for routine clinical application, due to their portability and ease of use. The present work presents an IMU-based ambulatory assessment of the pre- and post-intervention functional alteration of LSS patients undergoing instrumented (MiD-F) and non-instrumented (MiD) laminectomy.

Methods

Forty patients with diagnosis of LSS, for whom surgical decompression was prescribed (13 MiD, 27 MiD-F based on standard clinical practice), were recruited. On hospital admission (T0) and 90 days post-op (T90), patients were assessed by a physical therapist using 3 triaxial IMUs (MetamotionR, mBientLab, USA) for: 1) Posture (Eyes Open and Closed, 60 s each); 2) Normal Walking (15m 3 times); 3) Tandem Walking (15m). EO and EC postural parameters [4], NW and TW temporal parameters, variability, and nonlinear indexes [5-6] were calculated and statistically compared (Mann-Whitney, 0,01 significance) at T0 and T90 for MiD and MiD-F patients vs healthy subjects.

Results

<u>At T0, LSS vs healthy</u>: i) postural CoM-CoP oscillation increased amplitude for EO in ML, for EC in AP direction too, mean frequency was reduced; ii) NW resulted slower, with increased DS, Stance, and temporal variability, and increased recurrence; iii) TW resulted slower, with increased temporal variability and recurrence, and decreased entropy in all time scales.

<u>At T90</u>: i) postural parameters normalized for EO in MiD, but not in MiD-F, no improvement was observed for neither procedure for EC; ii) in NW, temporal variability decreased in both MiD and MiD-F temporal parameters, but stride, stance and DS did not improve, recurrence decreased but entropy in V direction increased out of healthy reference in MiD, while no change in non-linear parameters resulted in Mi-F; iii) in TW, temporal variability normalized in both MiD and MiD-F, but stance and DS increased in both, while stride duration increased only in MiD, on the other hand non-linear parameters moved closer to healthy reference in MiD, showing no change in MiD-F.

Discussion

The proposed ambulatory protocol allowed to quantify significant functional alterations in LSS patients at T0 and to differentiate Mid-F and Mid results at T90. LSS patients showed a slower and less ready control in posture, as well as a slow, less stable, more variable and automatic and less complex gait. In the limited population analyzed, MiD seemed more effective in improving postural parameters for EO and control of gait pattern, although locomotion remained slow and signs of instability persisted.

Acknowledgements: ARCHIMEDE - FIN-RER

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Comparative analysis of wearable IMUs and optical motion capture systems for ballet jump kinematics: a case report

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Introduction

Inertial Measurement Units (IMUs) for kinematic assessment have been successfully used in gait analysis, furthermore several studies have examined other physical activities such as running [1], swimming [2], and countermovement jump (CMJ) [3]. However, validation of joint angle estimation with IMUs in ballet jumps is still missing. Although the optoelectronic system is widely recognized as gold standard for motion analysis, it requires a laboratory setting for data acquisition. In contrast, wearable sensors enable the evaluation of specific sport/activity movements within natural environment, such as stage or dance studio. The aim of this study is to assess the validity and reliability of a commercial IMU system (XSens, Movella) for the analysis of jump kinematics in ballet, through comparison with an optoelectronic system (Vicon).

Methods

A female ballet dancer participated in the assessment. Fifteen inertial (Xsens, sample rate: 60Hz) sensors were applied to body segments. Concurrently, 21 reflective markers (diameter 14 mm) were placed according to a custom marker set derived from the Plug-in-Gait model and acquired by 14 cameras (Vicon, 100 Hz). After warm-up and familiarization with the lab setup, participant performed three repetitions of two different classical ballet jumps, namely, "first position" and "fifth position". Xsens data were resampled to 100 Hz for direct comparison. Agreement between systems was evaluated using the Coefficient of Multiple Correlation (CMC) and Root Mean Square Error (RMSE) were calculated for sagittal angular excursion of hip, knee and ankle. One-dimensional Statistical Parametric Mapping (1D-SPM) with paired-sample *t*-test was used to detect differences across the entire movement cycle. The statistical significance was set at $\alpha = 0.05$.

Results

An acceptable agreement was found between the two systems for both jump types. CMC ranged from 0.72 to 0.98, and RMSE values remained below 12.5° across all joints and conditions, except for knee excursions in "fifth position". The 1D-SPM revealed statistically significant differences only in knee joint angle in braking, propulsive and, landing phases in both jumps.

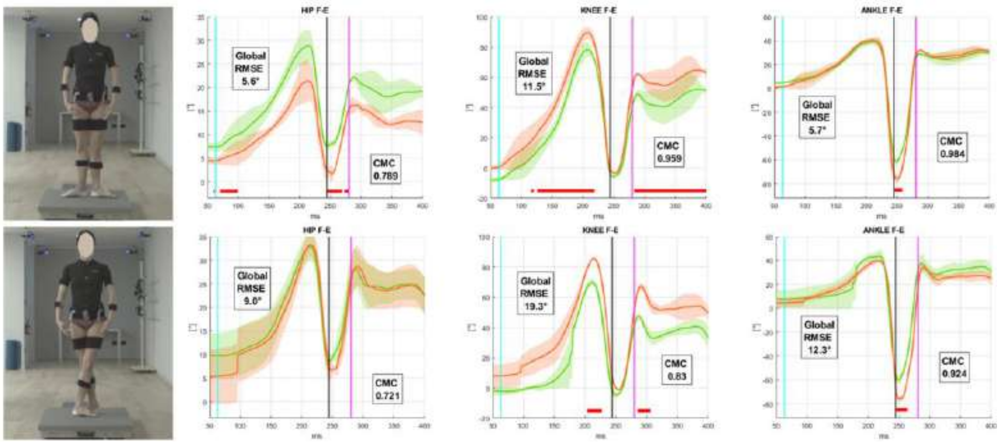

Figure 1. Hip, knee and ankle kinematics in the sagittal plane during jumps in "first" and "fifth" position. IMU's (orange), optoelectronic (green): mean ± sd. Vertical lines: start moving (cyan), take off (black), landing (pink). Red bars in the lower part of the plots represent the statistical differences ($p < 0.05$) in the 1D-SPM analysis.

Discussion

These preliminary results suggest that IMU systems may serve as a viable alternative for assessing ballet jump kinematics, particularly in field settings where optoelectronic systems are impractical. Further studies with a larger sample of dancers and a wider variety of jump types are warranted to generalize findings. Long-term applications could include performance monitoring and early detection of movement patterns associated with injury risk in dancers.

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Reproducibility of joint kinematics in alpine skiing using on-snow wearable IMUs system

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Introduction

On-snow alpine skiing motion analysis offers high ecological validity but also introduces variability (e.g. weather, snow texture, athlete consistency, sensor stability). Lab tests can't replicate skiing's dynamic nature, making field data essential for performance and equipment analysis. The use of wearable inertial measurement units (IMUs) allowed researchers to record joint kinematics during real skiing manoeuvres with minimal disruption of technique. However, the reproducibility of such data remains a key concern. Establishing the reliability of joint angle profiles is crucial for enabling longitudinal studies, comparing different equipment or configurations, and detecting subtle technique changes. Statistical measures such as the Intraclass Correlation Coefficient (ICC, [1]) provide robust methods for quantifying measurement consistency over time and across repetitions.

Methods

16 competitive alpine skiers (7 males, 9 females) performed multiple carving turns on a standardized slope while wearing IMUs (Xsens, 100Hz) on the trunk and lower limbs. Each athlete completed multiple passes using two boot models (Tecnica Group), with skis preassigned based on stature. Raw joint kinematics (hip, knee, ankle) in the sagittal plane were synchronized, segmented (from medio-lateral trunk-pelvis alignment), and normalized over the full turn cycle. At each normalized time point, ICC(3,k) values were calculated using a two-way mixed-effects model for mean ratings. This metric quantifies the reliability of the average of repeated trials, offering insight into the robustness of derived biomechanical patterns.

Results

Mean ICC values computed across the entire turn cycle demonstrated excellent reproducibility for all joints analysed. Specifically, average ICC values were 0.961 for the hip, 0.957 for the knee, and 0.960 for the ankle. Notably, ICC values remained above 0.90 throughout the majority of the turn cycle for all three joints, indicating strong consistency of kinematic patterns when data were averaged across multiple trials. For illustrative purposes, figure displays joint angle curves, for two participants, with standard deviation envelopes, highlighting both the within-subject variability and the robustness of the mean profiles across repetitions. Despite complex conditions and postural variations, consistent patterns emerge with proper replication and signal normalization.

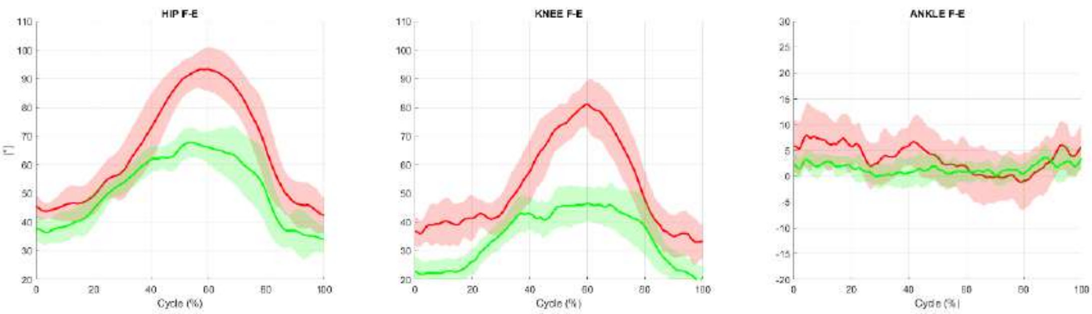

Figure 1. Representative plot showing mean ± SD of hip, knee, and ankle sagittal-plane kinematics across turns and repetitions for two participants (subj_01: red, subj_10: green).

Discussion

Joint kinematic profiles acquired on snow using IMUs show excellent reliability when multiple trials are averaged, as confirmed by the high ICC values. These findings support the methodological robustness of on-snow field assessments High reproducibility is achievable with rigorous protocols: consistent sensor placement, subject familiarization, and standard calibration. Low joint angle variability supports longitudinal and between-subject comparisons in real conditions.

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Sagittal posture in parkinson's disease and role of back active corset evaluated by 3d motion analysis.

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Introduction

Postural abnormalities in the sagittal plane are common in Parkinson's disease [1,2], increasing gait disorders and risk of falls. Previous studies have reported short-term benefit of corrective corsets in PD patients assessed by clinical and instrumental methods [3], while long-term effects on sagittal posture in upright standing and during walking remain unexplored.

Methods

Fifteen PD patients with postural abnormalities on the sagittal plane, evaluated via the NeuroPostureApp, and ten healthy subjects matched for age and BMI were assessed in upright posture by 3D motion analysis using DB-Total marker set. Then, the PD patients were evaluated with and without the corset (K1 Posture Keeper) during standing and walking at baseline (T0) and after three months of use (T1). Wilcoxon Mann–Whitney test or t-test were used to assess sagittal postural differences between PD and control groups. Moreover, multiple comparison across four conditions (T0 e T1 with and without corset) in PD group were tested by repeated measure ANOVA with post hoc ($\alpha < 0.05$).

Results

The results showed an anteriorization of the head–cervical region with respect to the sacral region and to the feet in PD patients compared to healthy controls. Moreover, the use of the K1 Posture Keeper induced a back shift of the nasion with a better alignment of the head with respect to the trunk, pelvis, and feet in upright standing and during walking, underlining an improvement in the sagittal alignment of the entire body in PD (Figure 1).

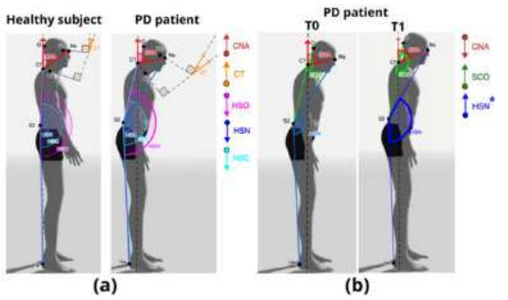

Figure 1. Significant differences in sagittal whole-body parameters were observed between (a) healthy and PD groups in upright standing, and (b) within the PD group with and without K1 during upright standing and walking.

Discussion

This study highlighted a whole-body misalignment with anteriorization of the head-cervical region on sagittal plane in PD patients with respects to healthy controls. Moreover, the K1 Posture Keeper seems to improve sagittal posture of PD patients in both static and dynamic conditions, likely due to proprioceptive reorganization. These findings are useful in rehabilitation treatment in order to contain the progression of sagittal unbalance and the risk of falls.

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IMU-based standing balance and 6-min walking test with follow-up in subjects with late-onset Pompe disease

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Introduction

Late-onset Pompe disease (LOPD) is a rare condition characterized by a progressive accumulation of lysosomal glycogen mainly resulting in muscle weakness and respiratory problems. As a result, key motor abilities required for daily life, such as standing and walking, may be significantly compromised. The present study aimed to assess standing balance and gait in patients with LOPD using a waist-mounted wireless inertial sensor, with a five-month follow-up during enzyme replacement therapy.

Methods

Two male and two female subjects (aged 35-62 years) affected by LOPD during treatment with enzyme replacement therapies were assessed with a 6-min walking test (6MWT) and a standing balance test performed with a 5-month interval (T1 and T2). A waist-mounted inertial measurement unit (IMU) was used for assessing body sway [1] during a 30-s quite standing in three stance conditions (20 cm and 10 cm parallel feet stance, and a 30° V-stance) with eye opened and closed [2]. Spatio-temporal parameters of straight walking including step velocity, length and duration, and their respective variability and symmetry [3], as well as turning metrics (duration, mean angular velocity, and SPARC as a smoothness index) [4], were extracted from a 6MWT performed along a 25-m walking path. The Wilcoxon signed-rank test was used to assess test-retest differences. Kendall's Tau was used to evaluate during the 6MWT, while the Friedman test was adopted to assess the effect of different postural conditions in the standing balance assessment.

Results

Within the 6MWT, significant trends were observed at T1 in step duration ($\tau = 0.53$, $p = 0.027$), and at T2 in walking velocity ($\tau = –0.66$, $p = 0.002$), step length ($\tau = –0.78$, $p = 0.0003$), and step length variability ($\tau = 0.51$, $p = 0.017$). Spatio-temporal parameters, turning metrics, and trend coefficients did not differ significantly between T1 and T2 (all $p > 0.05$). Time- and frequency-domain stability parameters also showed no significant differences between T1 and T2. Some stability parameters (jerk, RMS, sway area, and total power) differed significantly across postural conditions ($p < 0.05$), and tended to worsen with eye closure and a reduced medio-lateral and antero-posterior base of support, although no significant differences emerged in post-hoc comparisons between specific pairs of conditions.

Table 1. Median (IQR) values of spatio-temporal and turning metrics computed over the 6MWT and averaged across subjects, shown for both T1 and T2

	gait speed [m/s]	step length [m]	step duration [s]	step length var [%]	step length sym [%]	step duration var [%]	step duration sym [%]	turn duration [s]	turn velocity [°/s]	turn SPARC [a.u.]
T1	1.33 (0.21)	0.72 (0.08)	0.52 (0.05)	3.2 (1)	1.07 (1.29)	3.13 (0.93)	1.76 (2.35)	2.53 (0.28)	75.63 (8.77)	-4.77 (0.56)
T2	1.41 (0.19)	0.73 (0.1)	0.52 (0.01)	3.24 (1.02)	1.47 (1.18)	3.21 (0.73)	2.06 (1.96)	2.43 (0.29)	75.93 (7.96)	-4.75 (0.48)

Discussion

In line with previous finding, changes in foot position and visual input did not increase the postural instability associated with Pompe disease [2]. Similarly, levels of symmetry and variability in spatio-temporal parameters during the 6MWT were comparable to those reported by [5]. The consistency of both 6MWT and balance metrics over five months supports the therapeutic effect of ongoing treatment. In LOPD, the instrumented 6MWT may offer an objective means to track fatigue during the test and monitor treatment response longitudinally.

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Out-of-the-lab assessment of VR-guided reaching movements in Rett patients

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Introduction

Rett Syndrome (RTT) is a rare genetic disorder that primarily affects females (1:10000), characterized by the regression of cognitive and motor skills and stereotypic hand movements. While no cure currently exists, high-frequency, low-intensity rehabilitation programs can improve developmental outcomes. However, low motivation often limits their effectiveness. Pilot studies using Virtual Reality (VR) have shown increased engagement and response accuracy, suggesting potential benefits from technology-driven interventions. This study aims to evaluate the potential of a training system designed to promote space exploration by reaching tasks, featuring out-of-the-lab movement analysis capabilities.

Methods

A non-immersive Virtual Reality application was developed [1]. In one exercise, participants reached for a virtual target using an avatar that mirrored their real posture, estimated through an RGB-D camera (ZED Mini by Stereolabs Inc). In the physical environment, the gesture corresponded to touching a touch-sensitive pad, connected to the PC through an interface board (Click4All by Fondazione ASPHI), which provided a timestamp for the target hit. Among the data collected, wrist, elbow, and shoulder positions were used to compute the elbow joint angle and wrist–shoulder distance. A pilot study involved ten patients (17 ± 11 years old) who underwent at least three sessions per week (12 reaching movements each), for a total of 40 sessions, in supervised out-of-the-lab contexts, while formal assessments were conducted once every four sessions. The arm extension (elbow joint angle and wrist–shoulder distance) was evaluated at the moment of target contact. The estimated poses were post-processed to remove artifacts: data from successful trials were retained only if the values were deemed plausible, based on the participants' anthropometric characteristics. An example of the computed statistics from one participant's training sessions is presented in Table 1.

Table 1. Computed statistics for wrist-shoulder distance (in cm) for a selected participant.

Tr. session	Mean ± SD	Median	Min	Max	Correct perf.
1	17 ± 6	20	7	21	4/12
2	31 ± 9	31	14	42	10/12
3	30 ± 9	29	21	42	8/12
4	20 ± 5	19	11	30	12/12
5	25 ± 13	25	12	55	10/12
6	23 ± 8	22	17	40	7/12
7	32 ± 10	34	19	47	10/12
8	32 ± 9	32	19	44	8/12
9	26 ± 11	29	10	41	12/12
10	28 ± 11	28	9	41	7/12

Results and Discussion

The pilot study registered two dropouts. Data revealed improvements over time for several participants: six improved their wrist–shoulder distance (min +8%, max +70%), and two of these also improved the elbow joint angle (min +7%, max +37%). The discrepancies between the two measurements pinpoint the limitations of the technology, suggesting the use of alternative or complementary solutions to enhance robustness. Data variability suggests longer training periods to assess performance trends. The pathological complexity of RTT, including symptoms such as dyspraxia and stereotypies, represents a challenge for out-of-the-lab recordings in the absence of an experienced therapist.

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Effects of a wrist-articulated prosthetic hand for trans-radial amputees on upper limb compensatory movements during the approach phase preceding a power grasp

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Introduction

In upper limb amputees, the lack of wrist mobility in prosthetic devices can lead to the development of compensatory strategies that could increase the risk of musculoskeletal overload over time. In this study, a novel quasi-passive prosthetic wrist [1] with two degrees of freedom (flexion/extension, and ulnar/radial deviation) was tested aiming to assess its effect on compensatory movements of the upper limb kinematic chain during the execution of a recurrent daily life task: a power grasp.

Methods

Six trans-radial amputees, regularly using a myoelectric prosthesis and not presenting shoulder impairments, were recruited for this study. While standing, subjects performed a standardized power grasp of a cylindrical object resting on a table. Two conditions (wrist joint locked and unlocked) of five trials each were tested in randomized order. Upper limb kinematics were recorded using a 12-camera optoelectronic system (Vicon, UK). Range of motion (RoM) during the approach phase was extracted for trunk, clavicle elevation, shoulder, elbow and wrist. A linear mixed-effects model (fixed factor: wrist condition, random intercept: subject) was used to compare the two wrist conditions, considering the locked one as reference (REF). Effect sizes were calculated as standardized fixed effects (SFE), based on the variance of random and residual components.

Results

Results showed that when the prosthetic wrist was unlocked, the participants engaged both its extension and radial deviation, leading to changes in upper limb kinematics (Table 1). A significant reduction in RoM was observed in the trunk and shoulder flexion, shoulder abduction and shoulder internal rotation, with estimated mean difference (i.e. fixed effects, β) ranging from –2.9° to –16.2° and confidence interval (CI) reaching RoM reduction up to 25° at shoulder flexion.

Table 1. Summary of statistical results. The directions associated with the fixed effect beta values are highlighted in bold in the first column.

	REF estimated mean RoM (°)	**β [95% CI] (°)**	**SFE**	**p-value**
Trunk **Flex**/Ext	**52.3**	**−11.2 [−16, −6.3]**	**1.0 (large)**	**<.001**
Trunk Left/**Right** bending	10.2	-2.3 [-5.8, 1.2]	-	>.05
Trunk Right/Left rotation	21.6	-0.0 [-2.8, 2.8]	-	>.05
Clavicle elevation	12.0	-3.8 [-8.7, 1.14]	-	>.05
Shoulder **Flex**/Ext	**73.1**	**-16.2 [-25.1, -7.2]**	**0.8 (large)**	**<.001**
Shoulder **Abd**/Add	**12.9**	**-2.9 [-5.5, -0.3]**	**0.5 (medium)**	**<.05**
Shoulder **Int**/Ext rotation	**33.3**	**-9.4 [-15.4, -3.4]**	**0.5 (medium)**	**<.01**
Elbow **Flex**/Ext	23.7	-2.0 [-6.9, 2.9]	-	>.05
Wrist **Flex**/Ext	**3.0**	**+10.8 [7.6, 14]**	**2.2 (very large)**	**<.001**
Wrist Uln/**Rad**	**5.2**	**+25.1 [19.3, 30.9]**	**3.1 (very large)**	**<.001**

Discussion

The possibility to activate wrist movement appears to reduce the RoM required from the remaining of the upper limb kinematic chain while approaching an object to be lifted. This suggests a more economical approach to the execution of a grip, potentially enhancing movement quality, supporting a more natural upper body posture, and possibly contributing to the reduction of compensatory movements. Over time, such improvements may help mitigate musculoskeletal strain and promote long-term comfort and usability in hand prosthesis users.

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The impact of Euler sequence choice on shoulder angles interpretation

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Introduction

In ball and socket joint mechanics Euler rotation sequences critically influence joint angle interpretation during both planar and complex motions. This applies also to those human joints often modelled as ball and sockets including the shoulder [1], therefore limiting comparability across studies and potentially influencing clinical assessments. This work stems from a larger study on upper body compensatory movements in users of a robotic prosthetic hand for trans-radial amputees and expands on previous knowledge by exploring the effect of Euler sequence on shoulder kinematics during planar and complex movements.

Methods

One healthy subject performed three planar movements (shoulder flex/ext (FE), abd/add (AA), and int/ext rotation (IE)) as well as one complex movement: a forward-directed power grasp (PW) using a cylindrical object. Each planar movement was performed three times in a single acquisition. Upper limb kinematics were recorded using a 12-camera optoelectronic system (Vicon, UK) and a biomechanical ball and socket shoulder model connecting trunk and humerus. Shoulder kinematic data was processed using three Euler sequences (humerus axes): ZXY, XZY (where Z: flex/ext, X: abd/add, Y: int/ext rotation), and YXY (elevation plane, elevation angle, int/ext rotation), the latter recommended by [2].

Results

For the FE and AA movements (**Fig. 1,** columns 1,2), using a sequence beginning with the axis of the primary movement (ZXY for FE, XZY for AA) resulted in a lower amplitude of the other two angle components. However, in AA, int/ext rotation remains non-negligible. In contrast, the YXY sequence (ISB recommendation [2]) (**Fig. 1**, row 3) showed an ample range of motion, particularly affecting flex/ext and int/ext rotation angles during FE and AA. Similarly, for the PW task (**Fig. 1,** column 4), the sequence that showed the lowest amplitude for the angles the least involved in the task was that featuring as first rotation that around the flex/ext axis (ZXY).

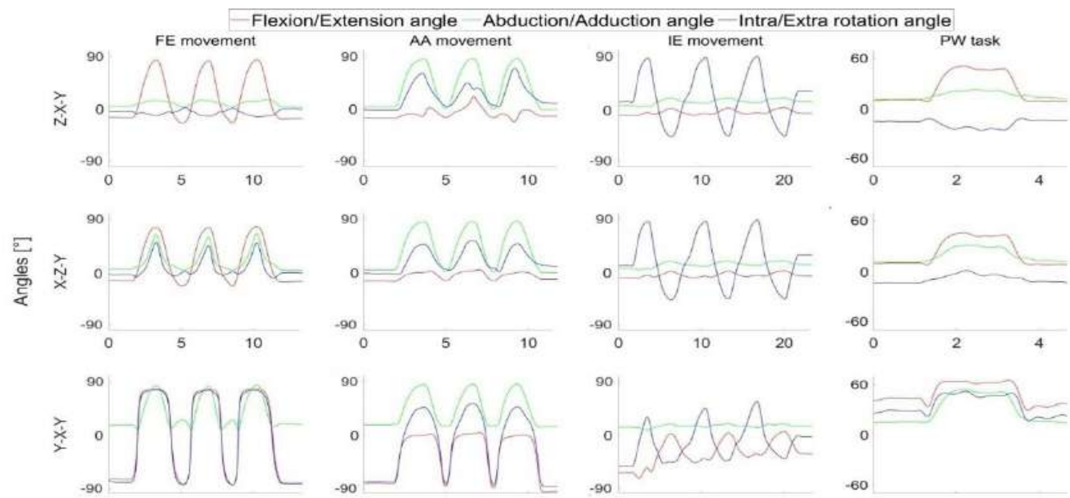

Figure 1. Shoulder kinematics of three Euler sequences (rows) on planar movements and PW task (columns).

Discussion

These findings highlight that the chosen Euler sequence for representing joint kinematics may affect significantly shoulder angles interpretation for planar shoulder movements but also for more complex movements. This also holds for the ISB-recommended standard. While a wise Euler sequence choice reduces the risks of misinterpretation for mainly planar shoulder movements, the criteria for selecting a proper Euler sequence to describe complex shoulder movements remain unclear.

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Inertial sensor-based analysis of motor synchronization strategies in collaborative tasks

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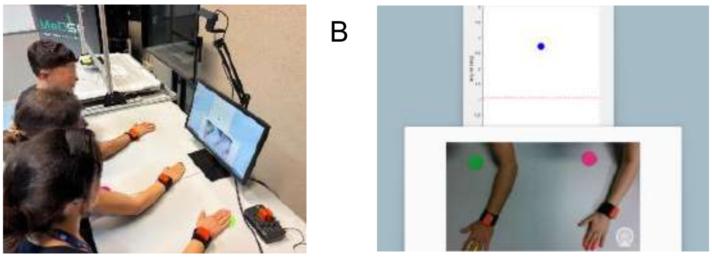
Introduction

Collaborative tasks for motor and cognitive rehabilitation aim to improve individual training by involving participants in active collaboration to achieve a common goal, without predefined role assignments [1]. Although scientific literature reports attempt with pairs of participants (dyads), the upscale of collaborative rehabilitation to more people requires novel approaches and technologies, as those pursued in the MYRTUS EU project to enable several users to participate remotely in real-time training sessions. This preliminary study focuses on the analysis of synchronization strategies adopted by dyads and triads performing a synchronization task at the basis of a VR exergame where the participants are dragon-boat paddlers navigating a maze river.

Methods

A total of six unaffected participants were enrolled and randomly grouped into five groups (three dyads or two triads). Participants performed a planar point-to-point frontal movement, back and forth between two targets (8 cm of diameter, 40 cm of distance) at different speeds. Participants wore an Xsens MTw magneto-inertial measurement unit (MIMU) on the right wrist, live streaming the orientation and angular velocity at 100 Hz. The experimental setup included a monitor, connected to the recording PC, presenting visual feedback and the video of the collaborative motor task from above, as obtained by a webcam positioned over the working area (Fig. 1A). Visual feedback provided the angular velocity around the Z-axis (perpendicular to the movement's plane) as a solid blue circular cursor, representing in real time the average angular velocity of the group, moving with respect to a red line indicating the target angular velocity (Fig. 1B). Participants of the same group were asked to collectively reach the target speed by synchronizing their arm's movements. The protocol started with a 15-second eyes-closed phase. Upon an auditory cue, participants opened their eyes and performed three 60-second sessions, each composed of three 20-second trials, each with a different target angular velocity (100, 140, 60 deg/s). Two synchronization metrics were computed: (1) phase alignment, assessed via cross-correlation (r) of angular orientation signals around Z-axis, with synchronization defined as $r > 0.7$ for at least two consecutive movements; and (2) speed convergence, evaluated as the first time point where the difference between the averaged angular velocity norm and the target angular velocity fell below 14 deg/s.

A



B

Fig. 1- A: Experimental setup; B: Angular velocity visual feedback (top) and the video of the collaborative motor task (bottom).

Results and Discussion

A population-level dataset was analysed to compare synchronization dynamics between dyads and triads. Phase synchronization occurred later in triads (7.01 ± 3.63 s) than in dyads (3.61 ± 1.86 s), with dyads showing a tendency to synchronize phase regardless of target speed. Convergence to the target angular velocity was more variable and not linearly varying with the target, with slower angular velocities requiring longer adjustment times. These findings suggest that group size differently affects phase and speed synchronization. A larger sample size is needed to improve the robustness of these results. Future work will explore scalability beyond triads to investigate potential ceiling effects.

Ackowledgement

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sEMG as a window into anticipatory, predictive, and reactive strategies during walking with expected and unexpected perturbations

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Introduction

Anticipatory, predictive, and reactive strategies (AS, PS, RS) empower individuals to optimize motor responses to perturbations, integrating previous experiences with ongoing tasks and unexpected environmental inputs [1]. According to Feldman's theory [2], the modulation of stretch reflex thresholds represents a key neurophysiological mechanism that underpins these strategies, resulting in different muscle timing and activation levels. Our research aims to highlight AS, PS, and RS in the sEMG activity of lower limb muscles. This abstract focuses on the gastrocnemius medialis (GM) muscle.

Methods

Healthy participants walked along a 10-meter pathway, provided with an embedded yielding platform calibrated to lower based on each subject's leg length and weight [3] (Fig 1a). Tasks were randomly sequenced to induce both expected and unexpected platform displacements: baseline walking (BW), expected-displacing (ED), expected-nondisplacing (EN), unexpected-displacing (UD), unexpected-nondisplacing (UN), confounding-displacing (CD), and confounding-nondisplacing (CN). sEMG data from the GM (SENIAM protocol) were collected (Fig 1b). For each trial, three consecutive strides were analyzed: (#1) before, (#2) on, and (#3) after the platform. A mixed-model analysis was used to determine the joint effect of platform behavior and a priori information on RMS amplitude during the stance phase, with tasks and strides as fixed and subjects and strides as random effects. RMS amplitude during stride#1 was used as a covariate to control for amplitude differences due to each individual's characteristics (normalization).

Results

Ten subjects (3/7 M/F), mean age 31 (7), were included. The model had strong explanatory power (conditional R^2=0.81, AICc=3093, BIC=3201). GM RMS amplitude significantly increased in stride#2 compared to stride#1 across all trials ($p<0.02$), except for BW and EN ($p=0.30$). Among subjects it increased by approximately 40-50 µV in trials involving platform movement (i.e., UD, ED, and CD; $p<0.001$) and by approximately 20 µV in trials in which subjects were unaware that the platform would not yield (i.e., UN and CN; $p<0.01$) (Fig. 1c). RMS decreased during stride#3 in all trials ($p<0.01$), due to participants approaching the end of the walkway and decelerating.

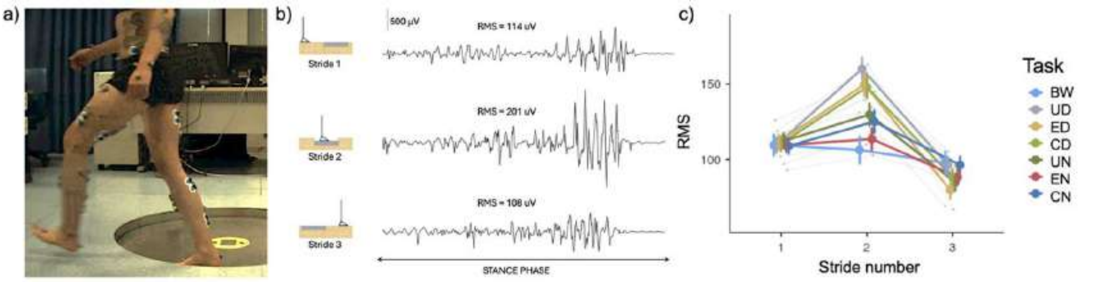

Figure 1: a) Yielding platform; b) GM activity during stance (ED task); c) Plot of the mixed-model analysis of GM estimated RMS in stance (estimated marginal means and standard errors are shown)

Discussion

Both mechanical perturbations and a priori information affected GM activity, suggesting that AS and PS work in tandem to configure muscle behavior prior to displacement and modulate responses to unexpected perturbations. These findings support the use of sEMG as a tool to probe AS, PS, and RS in experimental paradigms exploring neuromuscular control strategies.

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Instrumented Timed Up and Go (iTUG) highlights gait variability across Parkinson's disease genetic subtypes: insights from a mixed model analysis

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Introduction

Mutations in the glucocerebrosidase gene (GBA) are the most common genetic risk factor for Parkinson's disease (PD) [1]. GBA-PD is frequently associated with an earlier onset and faster disease progression and is characterized by a greater cognitive decline [2]. This study aims to investigate whether the iTUG-related parameters of PD patients with different etiologies, as GBA vs. Non-mutated (NM), are affected differently by the administration of levodopa and by a further addition of a cognitive task during TUG.

Methods

The clinical assessment included the MDS-UPDRS motor subscore (Part III) and the Montreal Cognitive Assessment (MoCA). Patients wore an inertial sensor (G-WALK, BTS Bioengineering) secured with an elastic belt at the sacrum level (S1). Three iTUG trials were acquired in each of three different conditions: off-medication (OFF), on-medication (ON), and ON with a cognitive task (DUAL) [3]. Data were visually segmented into subphases (get up, walk, turn, walk back, and sit down). Durations, acceleration peaks, and angular velocity peaks were extracted for each subphase. To address the clinical question of this study, a generalized mixed-model analysis was applied to the iTUG-derived parameters, using etiology and tasks as fixed effects, the iTUG parameter in the OFF condition as a covariate, and subjects and tasks as random effects. Based on the data distribution, the gamma function was used in the model. Results from the iTUG total duration are presented below.

Results

Forty-eight patients (17/31 F/M), mean age 63 (8 SD), 25 GBA and 23 NM-PD were included. Median UPDRS-III score was 30 (22.5 IQR), and MoCA score was 24 (6.5 IQR). The model had strong explanatory power (marginal R^2=0.83, conditional R^2=0.95, AICc=1422, and BIC=1478). As expected, the total iTUG duration was significantly reduced in ON compared to OFF ($p<0.001$) and significantly worsened in DUAL compared to ON ($p<0.001$). GBA status did not affect the total iTUG duration in either OFF, ON, or DUAL (p=0.933, p=0.181, p=0.683). The detrimental impact of the dual task was observed in 18 of 48 patients, irrespective of etiology. Of these, five subjects worsened to levels similar to those shown in the OFF condition.

Discussion

The etiology of PD, NM or GBA status, does not seem to be a significant factor in determining the iTUG duration, corrected by UPDRS and MoCA. Instead, the potential for identifying specific individuals for whom the cognitive task will significantly increase execution time appears to hold particular clinical relevance. Instrumental assessment may help clinicians identify individuals who may face greater challenges in situations requiring attention, potentially leading to a risk of falls, which traditional clinical assessments may overlook.

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Gait abnormalities in tuberous sclerosis complex: a clinical and neurophysiologic study.

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Introduction

Tuberous Sclerosis Complex (TSC) is a multisystemic genetic disorder in which involvement of the central nervous system represents the primary cause of morbidity in the pediatric population. Although musculoskeletal anomalies such as sclerotic bone lesions are recognized and were historically part of the diagnostic criteria, they were excluded from the updated criteria (2013) due to their low specificity and limited clinical relevance. Nevertheless, some patients report gait and balance abnormalities, seemingly in the absence of clear neurological signs or identifiable causal lesions. Many individuals with TSC experience gait difficulties that begin in childhood and tend to worsen over time. However, it remains unclear whether these alterations are correlated with the degree of intellectual disability (ID). The proposed study aims to analyze gait patterns in children with TSC and to correlate the findings with clinical, cognitive, and sensory data, including neurophysiological assessments.

Methods

This 12-month clinical and neurophysiological study will assess gait and balance in a pediatric population with a confirmed diagnosis of Tuberous Sclerosis Complex (TSC). Participants will be compared with a group of healthy controls matched for age and sex. Inclusion criteria for patients include a definitive diagnosis of TSC according to international criteria, age between 6 and 18 years, and availability of informed consent (signed by the patient or caregiver). Controls will be healthy individuals aged 6 to 18 years of both sexes, without known neurological or motor disorders, and capable of providing informed consent. Gait and balance analysis will be performed using a markerless optoelectronic system (Theia Markerless, CA). Ground reaction forces will be measured using a force platform (AMTI, USA). Kinematic and postural parameters will be correlated with demographic data (age, sex, BMI), as well as genetic and clinical information. Additionally, associations between gait and balance characteristics and neurophysiological data particularly motor evoked potentials (MEPs) will be analyzed.

Results

Twenty-five patients with TSC, aged 6 to 18 years, and 25 age- and sex-matched healthy controls were recruited. Gait and balance analyses were conducted under three experimental conditions: free walking, and static upright posture. For each participant, the following parameters were collected: overall body kinematics, spatiotemporal gait variables, center of mass (COM) displacements, and center of pressure (COP) displacements. These data are currently being analyzed.

Discussion

The variables of interest will be analyzed to explore correlations and identify the most sensitive measures that best reflect the residual dynamic strategies in patients with TSC. This analysis will support the development of rehabilitation strategies aimed at optimally enhancing walking and balance capabilities in this population.

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Early longitudinal monitoring of motor development in preterm infants: is gait initiation enough?

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Introduction

The earlier a baby is born the greater the risk of long-term consequences, with over 50% of children born <30 weeks facing motor, cognitive and behavioural impairments. To implement effective interventions, early longitudinal monitoring of motor development is crucial for a timely identification of deviations from the reference path and the prediction of possible neurodevelopmental disorders. Current understanding of the causal pathways of how preterm's motor difficulties prime and evolve is limited by the lack of quantitative interpretative measures for the assessment of infant motor development, beyond the mere monitoring of timing of motor milestones such as gait initiation. Longitudinal functional assessment of gait using inertial measurement units (IMUs) can respond to this need, thanks to their ease of use and portability for ambulatory assessment, and to the availability of metrics that allow to characterize motor control in the developing population [1]. These metrics can integrate longitudinally other functional assessments, such as General Movements (GMs) [2], and clinical data for risk assessment, to support the design and delivery of early intervention. The present work longitudinally analysed 55 preterm children (PT), from birth to 24 month corrected age, relating gait quantitative metrics to GM outcome and clinical risk factors,

Methods

Fifty-five PT were assessed longitudinally: i) at 40 weeks and 3 month corrected age for GMs, via standard evaluation by a certified clinician [2]; ii) at 18 and 24 month corrected age for gait, having the child walk naturally with 3 IMUs (MetamotionRL, mBient Lab, Usa) attached to their lower back and ankles during ambulatory assessment. From IMU data, gait temporal parameters and their variability, harmonic ratio, recurrence, and multiscale entropy (τ = 1..6) were calculated [1]. Children were classified clinically at high risk (HR), if at least one of the following conditions was verified: gestational age < 28 weeks; weight at birth < 1Kg; surgical necrotizing enterocolitis; intraventricular hemorrhage > 3; periventricular leukomalacia; pulmonary bronchodysplasia of any degree at 36 weeks. Gait metrics of all PT, of PT grouped by GM outcome and by risk were analysed versus full-term controls (FT) [1] with respect to corrected age (i.e. 18, 24 months) and walking experience (i.e. 0-2, 3-5, 5 weeks).

Results

All longitudinal PT vs FT by age: no difference for normalised stride, its variability, and stance duration; longer double support and its short- and long-term variability at both 18 and 24 months; increased harmonic ratio in AP and ML at 24 months; reduced entropy (τ = 2..6) and increased recurrence in ML at both 18 and 24 months. All longitudinal PT vs FT by experience: reduced normalised stride and increased double support at 3-5 months; increased short- and long-term variability of double support, increased harmonic ratio in all 3 directions, reduced entropy (τ = 2..6) and increased recurrence in ML independently on experience. HR PT exhibited the same alterations but significantly increased with respect to LR PT. Since all PT but 3 did show fidgety GMs at 3 month corrected age, no significant analysis could be performed with respect to this parameter.

Discussion

PT children showed significant differences in gait vs FT with respect to corrected age, but also considering specific walking experience. In particular, even when for walking experience > 5 months, normalised stride and double support duration reach that of FT controls, increased variability of double support persists as well as altered non-linear metrics, indicating a still unstable and immature control of gait with respect to FT controls. This suggests that the mere identification of the timing of gait initiation is not sufficient to assume a proper development of motor control, and a longer longitudinal monitoring is necessary to monitor gait maturation in PT. In addition, analysis with respect to clinical risk factors shows how other non-neurological risk factors, beyond gestational age and weight at birth can relate to motor alterations in PT. On the other hand, GMs basic outcome lacks specificity, and more detailed analysis of GMs will be performed in the future.

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