

RESEARCH ARTICLE

Physical activity promoting teaching practices and children's physical activity within physical education lessons underpinned by motor learning theory (SAMPLE-PE)

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Abstract

Purpose

Movement competence is a key outcome for primary physical education (PE) curricula. As movement development in children emerges through physical activity (PA), it is important to determine the extent of PA promotion within movement competence focused teaching pedagogies. Therefore, this study aimed to assess children's moderate-to-vigorous PA (MVPA) and related teaching practices in primary PE within Linear pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.

Methods

Participants ($n = 162$, 53% females, 5-6y) were recruited from 9 primary schools within the SAMPLE-PE cluster randomised controlled trial. Schools were randomly-allocated to one of three conditions: Linear pedagogy, Nonlinear pedagogy, or control. Nonlinear and Linear pedagogy intervention schools received a PE curriculum delivered by trained deliverers over 15 weeks, while control schools followed usual practice. Children's MVPA was measured during 3 PE lessons (44 PE lessons in total) using an ActiGraph GT9X accelerometer worn on their non-dominant wrist. Differences between conditions for children's MVPA were analysed using multilevel model analysis. Negative binomial models were used to analyse teaching practices data.

Results

No differences were found between Linear pedagogy, Nonlinear pedagogy and the control group for children's MVPA levels during PE. Linear and Nonlinear interventions generally included higher percentages of MVPA promoting teaching practices (e.g., Motor Content) and lower MVPA reducing teaching practices (e.g., Management), compared to the control

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group. Teaching practices observed in Linear and Nonlinear interventions were in line with the respective pedagogical principles.

Conclusions

Linear and Nonlinear pedagogical approaches in PE do not negatively impact MVPA compared to usual practice. Nevertheless, practitioners may need to refine these pedagogical approaches to improve MVPA alongside movement competence.

Introduction

Physical education (PE) should provide varied, meaningful and developmentally appropriate learning experiences for children to acquire the attributes needed to lead physically active lives [1–5]. Given the well-established health benefits of participation in moderate-to-vigorous physical activity (MVPA) for children [6–9], public health arguments have been made that PE lessons should be physically active and involve teaching physical, cognitive, social and emotional skills in and through movement [10]. This health-related rationale led to the development of a goal for students to spend at least 50% of the PE lesson time engaged in MVPA [11], a guideline which has subsequently been adopted by several PE organisations across the globe [4, 12, 13]. Despite this guideline, recent research shows that students only spend between 9.5% and 42.4% of PE time engaged in MVPA [14–17]. While it is important to acknowledge that the focus on MVPA should not come at the expense of other important and meaningful PE learning outcomes [18, 19], monitoring MVPA levels during PE lessons is important to maximise physical activity (PA) opportunities during PE [19, 20].

Children's MVPA levels in PE can be affected by numerous factors, including the proportion of boys and girls in the class, lesson content (e.g., ball games, fitness, dance), and lesson location (e.g., outdoors, indoors) [14, 16, 21]. Teaching practices also play a central role in determining children's MVPA during PE lessons, through teachers' decisions on lesson content, time management (e.g., the amount of time spent explaining a task, or the amount of time before moving to a different task), and delivery (e.g., enthusiastic verbal promotion of PA engagement). Pedagogy, defined as interdependent elements of curriculum design, learning and teaching [22], is also important, with PE teachers possessing higher levels of pedagogic content knowledge (i.e., being able to deliver PE using different pedagogical approaches) and positive attitudes towards PA promotion generally being more effective in promoting PA during PE [21, 23–25]. However, there are concerns that primary PE deliverers (which often include generalist classroom teachers) do not have the required level of pedagogic content knowledge to support learning and foster student's PA [26]. Nevertheless, few studies have examined the association between different pedagogical approaches in PE and student MVPA levels. Thus, to maximise PA opportunities during PE, examining the extent to which teaching practices support students' MVPA under different pedagogical conditions is warranted.

An important feature of meaningful PE experiences and a key objective for PE curricula in young children (5-to-7-years-old) is the development of foundational movement skills needed for a lifetime of diverse PA opportunities [1, 5, 18]. Developing a wide range of foundational movement skills (e.g., catching, jumping, swimming, cycling) supports children to engage in a wide range of PAs [27, 28]. However, movement skills do not develop by maturation alone, children need to be physically active within favourable conditions for movement skills to emerge and progress, such as through structured teaching and learning activities [29]. The

more a child moves the greater the opportunity to develop and acquire competence in movement skills [30, 31], which should lead to enhanced engagement in PA [27, 30, 31]. Therefore, from a PE perspective, pedagogical approaches aimed at fostering movement competence should also seek to maximise opportunities for students to be physically active.

Pedagogical models designed for movement development can be beneficial for teachers as they provide a task structure so students can achieve intended learning outcomes [32–35]. Linear and Nonlinear pedagogy are two pedagogical approaches underpinned by different theories of motor learning that can guide the design of PE lessons aiming to foster the development of movement competence. Linear pedagogy is based on the Information Processing learning theory [36] and, in this perspective, a learner is seen as a system that elaborates perceptual-motor inputs to produce movement outputs [29]. Furthermore, learners participate in a set of planned movement experiences of increasing difficulty to obtain specific learning outcomes [29]. A central aspect of Linear pedagogy is to prioritise learning in the psychomotor domain through the repetition of movement tasks as repetition leads to movement automatization and therefore to increased accuracy and decreased cognitive load while performing the practiced task [37, 38]. Therefore, a key role of the educator is to design activities and provide instructions that are appropriate for children's proficiency level [37, 38]. Accordingly, Linear pedagogy is characterised by a teacher-centred approach to PE, where the teacher is the main source of instructional content and leads the performers through a series of pre-determined learning outcomes [29, 35]. In line with its theoretical foundation, Linear pedagogy includes the following characteristics: a) children should demonstrate mastery of the teacher-led movement patterns; b) movement skills should be broken down into simpler movements to facilitate movement proficiency; c) movement variability within a task is seen as detrimental for learning and therefore should be reduced [35, 38]. Interventions presenting Linear pedagogy characteristics were found to be effective at improving movement competence in children and adolescents [39–42].

Nonlinear pedagogy is based on ecological dynamics theoretical and philosophical foundations [43, 44]. From an ecological dynamics perspective learners are seen as complex neurobiological systems in mutual and reciprocal synergy with the environment that learn through perception and action coupling processes [34, 43, 44]. More specifically, perception and action coupling (or information-movement coupling) processes consist in the continuous creation of functional affordances (opportunities for action) within a cyclical process of perception and action leading to the emergence of goal-directed behaviours [45]. Based on this approach, learners are invited to explore different movement solutions within carefully designed learning environments. Proponents of this theory argue that it is the invitation for actions that leads to a continuous process of perceptual action coupling between the individual and the environment for intended movement solutions [34, 46]. Consequently, Nonlinear pedagogy is reported as a learner-centred PE approach where children are provided with high levels of autonomy and are invited to explore different movement solutions, while educators channel learning by modifying constraints [47]. Assumptions of Nonlinear pedagogy include the following: a) movement skills should be practiced in a situation that is representative of a game environment or performance condition, b) movement skills should emerge by the interaction between individual and environment in a movement perception action coupling; c) teachers modify individual, task and environmental constraints to channel movement skills learning; d) functional movement variability is encouraged; e) teachers should foster an external focus of attention [47, 48]. Recent studies showed that interventions following Nonlinear pedagogy principles can lead to improvement in movement competence within children and adolescents [49–51].

In summary, determining MVPA levels of children in PE and examining associated teaching practices can provide important information to assess adherence to guidelines associated with high quality PE. Movement competence is a key outcome for primary school PE and a feature of meaningful PE experiences for children. As movement development emerges through PA, our aim was to examine MVPA promotion within PE that use pedagogical approaches focused on movement competence. Our research could inform strategies to maximise meaningful opportunities to be physically active within PE lessons taught through these pedagogies. To date, no study has examined children's MVPA and teaching practices during PE using Linear and Nonlinear pedagogical approaches. Furthermore, no study has evaluated whether Linear and Nonlinear pedagogy would be associated with higher levels of children's MVPA and PA promoting teaching practices, compared to current PE. Therefore, this study aimed to assess children's MVPA and teaching practices in primary PE within Linear pedagogy and Nonlinear pedagogy and to compare this to current practice within PE delivery in primary schools.

Materials and methods

Design

This study was approved by the University Liverpool John Moores Research Ethics Committee (Reference 17/SPS/031) and formed part of the process evaluation of the Skill Acquisition Methods fostering Physical Literacy in Early Primary Education (SAMPLE-PE) cluster randomised controlled trial (ClinicalTrials.gov identifier: NCT03551366), which is described in detail elsewhere [52]. Specifically, this study was designed to evaluate the implementation of the interventions and explore PA promoting teaching practices during PE lessons and participants' responsiveness (that concerns the measurement of how far participants respond to, or are engaged by, an intervention [53]) in terms of children's MVPA engagement, rather than to evaluate changes in these constructs from baseline to post-intervention. Briefly, SAMPLE-PE aimed to investigate the efficacy of PE curricula based upon different pedagogical principles and motor learning theories in promoting physical literacy amongst 5-6-year-old children. One hundred and nineteen primary schools situated in deprived areas of a large metropolitan city in North West England were invited to take part in the study. Head-teachers from 12 primary schools provided gatekeeper consent and written parental consent and child assent were obtained for 360 5-6-year-old children (55% girls) from year 1 classes to participate in the research. Children without informed consent continued to participate in the PE lessons as normal. Children who were not able to take part in PE due to reasons such as medical conditions, profound learning disabilities or special educational needs were not eligible to take part in this study. Using a computer-generated procedure, schools were randomly allocated to one of three groups: i) Nonlinear pedagogy PE intervention ($n = 3$ schools); ii) Linear pedagogy PE intervention ($n = 3$ schools); or iii) control group ($n = 6$ schools). Following baseline assessments, intervention schools received a 15-week PE curriculum intervention delivered by trained coaches, while control schools followed usual practice (described in detail below). All groups were asked to provide the same dose of PE (i.e., 2×60 min weekly PE lessons, for 15 weeks).

Outcome data were collected at baseline (T0), immediately post-intervention (T1), and 6 months after the intervention has finished (T2). The process evaluation methods have been published in the study protocol [52], and only relevant methods for the current study analyses are outlined below. For feasibility and time constraint reasons and in line with sample size calculations reported below, a convenience sample of 50% of the children who provided consent to participate in the SAMPLE-PE project within 9 schools (comprising 3 Nonlinear

intervention schools, 3 Linear intervention schools and 3 randomly selected control schools) were recruited for this study.

Sample size and statistical power

Sample size and power calculations for the SAMPLE-PE cluster-randomised controlled trial are reported elsewhere [52]. For the purposes of this study, an a priori power calculation was undertaken using G*Power software to detect differences between 3 groups including a large effect size based on the review by Fairclough and Stratton [54], 90% power, alpha levels set at $p < 0.05$ and multiple covariates recommended a minimal sample size of 83 children. It was not possible to account for clustering factors (e.g. school) in the power calculation as the mixed model analysis reported in previous literature did not report ICCs associated with clustering factors. Previous studies that have assessed MVPA during PE included a sample size similar or higher than 83 children (e.g. up to 168 children) [55–60]. Therefore, in line with the power calculation and the sample sizes observed in previous research, and after accounting for potential dropout, we aimed to recruit 50% of the research participants, amounting to 157 children, which was considered adequate for the purpose of this study [52]. Due to the lack of previous research reporting effect sizes about SOFIT+ outcomes and feasibility factors such as time and resource constraints and school burden, we aimed to collect data about teaching practices in 3 lessons per class participating in the project.

Intervention

Intervention deliverers were recruited and trained to deliver Linear or Nonlinear pedagogy interventions [52]. Both Linear and Nonlinear pedagogy PE curricula were delivered over 2 lessons a week for 15 weeks leading to a total of 30 PE lessons per class divided into 3 content blocks of 10 lessons (each block lasting 5 weeks) focusing sequentially on dance, gymnastics and then ball skills, respectively. Teachers and sport coaches within control schools delivered PE as usual 2 lessons a week for 15 weeks.

Deliverer training and intervention delivery

Intervention deliverers were recruited from a University in the North-West of England with a longstanding reputation for delivering high quality BA (Hons) Physical Education and BSc (Hons) Sport Coaching undergraduate and postgraduate degree programmes. As a result, two sport coaches from the research team and three sport coaches who each possessed at least a level 2 coaching qualification, were recruited and agreed to participate in a series of training sessions, to support the delivery of the SAMPLE-PE interventions. Before commencing the training, each one of the coaches was observed by a member of the research team while delivering a PE lesson in a primary school not involved in the SAMPLE-PE project. The coaches were then assigned to either a Linear ($n = 2$) or Nonlinear ($n = 3$) curriculum training programme based on their observed pedagogical approaches. The training for each pedagogy was designed to incorporate both practical and theoretical elements and was delivered by members of the research team with expertise in these approaches. Each training session lasted approximately 180 minutes and was conducted over a period of five weeks. During the training programme the coaches had the opportunity to be observed leading a PE lesson with Year 2 children (6-7-years-old) within a primary school not participating in the SAMPLE-PE project. Following these lessons, the coaches received augmented feedback from members of the research team. They were also encouraged to reflect on their pedagogic practice and encouraged to develop strategies to improve their own self-analysis. Following the training period coaches received a pedagogical framework and a resource pack together with the material used

during the sessions and recordings of the practical sessions. The PE lessons were planned considering equipment available or that could be made available in each one of the participating schools.

Linear pedagogy intervention delivery

Linear pedagogy PE lessons were designed following the principles of Information Processing theory, informed by concepts of direct instruction [35], and followed a task structure involving: 1) a teacher-led warm-up activity, 2) practicing movement skills within drills, 3) a performance or game activity to apply the movement skills learnt during the lesson 4) a cool down (S1 Table). The coaches were expected to plan learning tasks and provide clear verbal instructions and visual demonstrations to provide the children with a 'picture' of what proficient movement looked like. During early learning of a movement skill the coaches were encouraged to review previously learned material and to provide corrective feedback during each activity with particular attention to children reiterating mistakes. The coaches were trained to use Fitts and Poster's cognitive stages (cognitive, associative, autonomous) [38] to evaluate children's progression in movement skills proficiency and to change the difficulty of the tasks based on children's skill level. Children were invited to perform and repeat movement skills as previously demonstrated by the educators and once the skill showed signs of automaticity were encouraged to practice independently in increasingly open environments. Gentile's taxonomy principles together with the Challenge Point framework [61, 62] were used by the teachers to facilitate these progressions of skill practice into more open environments.

Nonlinear pedagogy intervention delivery

The Nonlinear pedagogy intervention was designed in line with an ecological dynamics framework [34]. For instance, each PE lesson started with children exploring the PE hall and different equipment within the environment (e.g., benches, mats, hoops, cones). The lesson continued with activities where teachers introduced variability by changing constraints and tasks designed to be representative of a real game, sport or performance. The children were invited to explore opportunities for action (affordances) and encouraged to create functional movement solutions (S2 Table). Educators were asked to use the Space, Task, Equipment, People (STEP) framework to identify and modify constraints within the lessons [63]. Furthermore, coaches were trained to use Newell's stages of motor learning (coordination, control and skill) to monitor children's progress in movement learning and to modify and individualise constraints based on the motor learning stages observed [64]. Demonstrations or corrective feedback were not used during activities, alternatively, coaches invited children to observe their peers in action, or prompted children to try to find different movement solutions (increasing exploration). Coaches were encouraged to use dialogue as a strategy to foster an external focus of attention in the child to infuse variability in the task and channel children learning (e.g., how can you make a pass that is easier to catch for your teammate? How many ways to move on the mat can you find?).

Measures and procedures

Child anthropometric and demographic data were collected at schools during baseline assessments (between January and February 2018), within a two-week period before the start of the intervention. Children's PA levels (accelerometers), teaching practices related to PA (video observation) and pedagogical fidelity (video observation) were assessed during PE lessons as part of the SAMPLE-PE process evaluation between February and June 2018 [52]. Specifically, three PE lessons in each year 1 class (1 lesson every 5 weeks) were randomly selected for data

collection. Each of the intervention groups and the control group included five Year 1 classes. Therefore, 45 lessons (15 per group) were scheduled to be evaluated. Schools were informed about the data collection schedule before the beginning of the trial.

Anthropometrics

Body mass was assessed to the nearest 0.1 kg using scales (model 760, Seca, Hamburg, Germany) while stature was assessed using stadiometers to the nearest 0.1 cm (The Leicester Height Measure, Child Growth Foundation, Leicester, United Kingdom) [65]. All anthropometric measurements were taken twice while a third measurement was taken in case the first two measurements differed by more than 1% and subsequently the mean between the measurements was taken. Body mass index (BMI) was calculated using stature and mass measurement and then it was converted to standardised BMI z-scores following international Obesity task force (IOTF) classification [66].

Demographics

Children's demographic data (i.e., date of birth, sex, ethnicity, household postcode) were collected using questionnaires that parents filled and returned together with the consent form. Children's neighbourhood deprivation rank and decile were calculated from household postcode using the English indices of deprivation [67].

Physical activity measurement

ActiGraph GT9X (ActiGraph, Pensacola, FL, USA) were used to assess PA in children during PE. Before the beginning of each lesson, ActiGraph GT9X accelerometers were fitted on each participant's non-dominant wrist to assess their PA levels during the lesson. If one of the randomly selected children was absent another participant to the SAMPLE-PE project was randomly selected to wear an accelerometer. Accelerometers were set to record accelerations at 100Hz over 1 second epochs within a range of ± 8 g on x, y and z axes. Raw acceleration data were downloaded from accelerometers in 1 s epochs and exported as .csv files using ActiLife software (ActiGraph, Pensacola, FL, USA). Raw data were then transformed into Euclidean Norm Minus One (ENMO) acceleration data using GGIR package [68] from R software Version 4.0.2 (www.r-project.org). Lastly, age appropriate cut-points by Crotti et al. (2020) were used to classify ENMO accelerations equal or higher than 189 mg into time spent in MVPA [69].

Teaching practices related with physical activity: SOFIT+

PE video-recordings were analysed by one researcher using the modified version of the System for Observing Fitness Instruction Time to measure teacher practices related with PA (SOFIT+) [70]. SOFIT+ is a valid and reliable observation tool designed to classify multiple teaching practices related with children's PA during PE [70]. The teaching practices within the SOFIT+ are divided in 4 categories comprising *Lesson Context*, *Activity Context*, *Teacher Behaviours* and *Activity Management* and more information about the definition of each teaching practice can be found in [S3 Table](#). Each SOFIT+ scan lasts 40 seconds divided in two 20 seconds phases each one comprising 10 seconds of observation and 10 seconds of recording [70]. During the phase 1 of SOFIT+, *Lesson Context* and *Activity Context* teaching practices are assessed while during phase 2 *Teacher Behaviours* and *Activity Management* are assessed [70].

Fidelity

Intervention fidelity in terms of Linear and Nonlinear pedagogy were independently assessed through the video analysis of recorded PE lessons using a checklist developed by the research team (S4 Table) [71]. The checklist comprised 9 items including 7 motor learning related items and 2 global items. Each item was rated using a 1 to 5 Likert scale where values of 1 and 2 corresponded to the observation being in line with Linear pedagogy while values of 4 and 5 corresponded to the observation being in line with Nonlinear pedagogy. Motor learning related items were assessed 4 times within each lesson (once for each quartile of the PE lessons) while global items were assessed only once per lesson observed. Two researchers that were not part of the research team and that were blinded to intervention allocation independently coded the fidelity of the PE lessons following training. The training consisted in 1) reading specific literature concerning Linear and Nonlinear pedagogy, 2) reading the fidelity checklist, 3) consulting the research team about doubts concerning the checklist, 4) independently coding 2 PE lessons, 5) consulting a pedagogy expert to check the coded lessons and clarify any doubts, 6) collaborating to assess 6 PE lessons, 7) independently assessing 6 lessons and then compare the results. The coders then assessed fidelity using the fidelity checklist within a total of 13 randomly selected PE lessons from Linear pedagogy (5 lessons), Nonlinear pedagogy (5 lessons) and control group (3 lessons).

Data analysis

All data analysis was carried out using R Software (Version 4.0.2, www.r-project.org) and RStudio Software (Version 1.3.1056, www.rstudio.com). Multilevel models were used to analyse PA outcomes to account for MVPA data (level 1) being nested within child (level 2), class and teacher (level 3). Multilevel models were fitted using “Lme4” package [72]. To assess the association between pedagogy and MVPA during PE, two models were designed with children's MVPA during PE as the dependent variable: i) an unadjusted model including group (i.e., Linear pedagogy, Nonlinear pedagogy and control) as the independent variable with data nested by child (random intercept), and ii) a fully adjusted model including group (i.e., Linear pedagogy, Nonlinear pedagogy and control) as the independent variable and controlling for sex [14], age [14], lesson duration [16], lesson content (e.g., ball games) [14], lesson environment (i.e., indoor, outdoor) [21] with child id code, school and teacher included as nesting variables. During the modelling process, we decided to include variables that significantly increased the fit of the model and to exclude the nesting level of school class as it did not lead to an improved model fit or led to overfitted models. IOTF BMI z-score, ethnicity and deprivation decile variables were excluded from the fully adjusted multilevel analysis as they did not improve model fit and led to issues with listwise deletion of missing data and the loss of 21 participants and 50 corresponding valid MVPA observations within the multilevel models. The unadjusted and fully adjusted models were fitted using control group or Nonlinear pedagogy group as the ‘group’ reference category to evaluate whether Linear and Nonlinear interventions were associated with increased or decreased MVPA minutes or percentage of MVPA (MVPA%) compared to the control group and each other. Outliers were identified using absolute deviation around the median [73] and then removed from the dataset used for the final analysis.

It was not possible to use multilevel models to analyse the PA teaching practices data as most teaching practices variables did not present a normal distribution of the residuals or led to overfitting problems within the multilevel models. PA teaching practices observations collected using SOFIT+ are count data (representing counts of events over a discrete time span) [74–76]. Therefore, Poisson and Negative Binomial were initially considered for data analysis.

The dispersion of the data was assessed using Dean's test [77]. Given that all the distributions of teaching practice data were over-dispersed, Negative binomials were used to evaluate differences in PA teaching practices between Linear pedagogy, Nonlinear pedagogy and control group within PE. In some cases (i.e., *Partner Activity* and *Small Sided Activity*), negative binomial models could not fit the data as an elevated proportion of zero counts were observed. In these cases, hurdle negative binomial models were employed to analyse teaching practices data [74–76, 78]. To account for differences in lesson duration an offset factor was included in Negative binomial and Hurdle Negative binomial models. The statistical model fit of count data models were assessed using McFadden's pseudo R squared [79]. Due to the relatively small number of lessons observed within each group and for each PE deliverer, it was not possible to add covariates to the Negative binomial models as it was leading to overfitting (models failing to converge).

The datasets and related metadata (statistical analysis codes used to analyse the data) are publicly available within an open access repository (link to the data and metadata: <https://doi.org/10.24377/LJMU.d.00000102>).

Results

Participants in the current study ($n = 162$; 53% girls) presented a mean age of 6.0 (Standard Deviation (SD) = 0.3) years, 49% were white British, and 84% of the children lived in areas ranked as within the most deprived tertile for deprivation in the England. IOTF BMI z-scores were calculated for the 146 children and, based on IOTF thresholds [66], 24% of children were overweight or obese (Table 1). Parents did not report neighbourhood deprivation for 1 child in the control group, while ethnicity information was not provided for 2 children in the Linear pedagogy group and 2 children in the Nonlinear pedagogy group. Due to time constraints, we were not able to measure the BMI of 3 children from the Linear pedagogy group, 4 children from the Nonlinear pedagogy group and 9 from the Control group.

Each of the 15 participating classes were observed 3 times during PE. In total, 44 PE lessons were recorded as two classes within the control group did one PE lesson together. Audio was

Table 1. Participants' descriptive data by group.

	Linear pedagogy		Nonlinear pedagogy		Control	
	(n = 55)		(n = 65)		(n = 42)	
	Mean (SD)	Missing or % data	Mean (SD)	Missing or % data	Mean (SD)	Missing or % data
Decimal Age (years)	6.0 (0.3)	0	5.9 (0.3)	0	5.9 (0.3)	0
Girls	56%	0	49%	0	55%	0
White British	62%	2	56%	2	24%	0
Living within the 30% most deprived areas	93%	0	71%	0	95%	1
IOTF SDS BMI	0.4 (1.2)	3	0.5 (1.1)	4	0.2 (1.1)	9
IOTF SDS BMI classification						
Thinness grade 3	0%		0%		0%	
Thinness grade 2	4%		2%		0%	
Thinness grade 1	2%		3%		6%	
Healthy weight	67%		75%		67%	
Overweight	25%		8%		21%	
Obese	2%		11%		6%	

IOTF SDS BMI: standardised BMI z-scores following international Obesity task force classification.

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not recorded in one of the control PE lessons because of technical problems. 43 PE lessons were assessed using SOFIT+ and combined with children's corresponding PA data for analyses. PA levels during PE were assessed in 42 (23 girls) children from the Control group, 65 (32 girls) children from the Nonlinear pedagogy group and 55 (31 girls) children from the Linear pedagogy group. Due to child absence from school, 114 (56 girls) children were assessed over 3 lessons, 32 (24 girls) children were assessed over 2 lessons, and 16 (6 girls) children were assessed over 1 lesson.

Pedagogic fidelity

Pedagogic Fidelity scores were reported in Table 2. Nonlinear pedagogy average intervention fidelity scores ranged from 3.95 (SD = 0.78) to 5 (SD = 0.00), Linear pedagogy intervention average fidelity scores were all lower than 1.77 (0.94), while control group average scores were comprised between 1.44 (SD = 0.97) and 2.50 (SD = 0.54) [71]. Fidelity scores of 1 and 2 on the Likert scale correspond to the observation being more in line with Linear pedagogy and scores of 4 and 5 correspond to the observation being in line with Nonlinear pedagogy. Therefore, the fidelity observations indicated that Linear and Nonlinear interventions were delivered in line with their respective pedagogical principles. The control group presented fidelity scores indicated closer alignment with Linear pedagogy principles.

Children's moderate to vigorous physical activity during physical education lessons

The mean and standard deviation for MVPA minutes, MVPA% and number of children spending 50% of PE time in MVPA can be found in Table 3. On average, children in the different groups engaged in MVPA during PE lessons for between 9.1 and 11.9 minutes, with the proportion of lesson time spent in MVPA ranging from 29.1% and 38.4%. The percentage of children engaging in MVPA over at least 50% of PE time ranged from 5.3% to 14.4% (Fig 1).

Associations between pedagogy and children's physical activity

Results from the multilevel model analyses evaluating the associations between pedagogy group and children's average time spent in MVPA minutes during PE are reported in Table 4, while results concerning MVPA% during PE can be found in Table 5. Both Linear and Nonlinear interventions were associated with significantly higher minutes in MVPA and MVPA% percentage compared to the control group within the unadjusted models. However, within the fully adjusted models, Linear and Nonlinear pedagogy were not associated with increased MVPA or MVPA% compared to control group. Furthermore, Linear and Nonlinear pedagogy were not associated with higher MVPA or MVPA% compared to each other both in the unadjusted and fully adjusted model.

Table 2. Pedagogical fidelity checklist results.

	Category							Global	
	Category Mean (SD)							Global Mean (SD)	
	1	2	3	4	5	6	7	1	2
Nonlinear	5.00 (0.00)	5.00 (0.00)	4.90 (0.28)	3.95 (0.78)	4.05 (0.77)	4.73 (0.41)	4.58 (0.43)	5.00 (0.00)	5.00 (0.00)
Linear	1.40 (0.64)	1.48 (0.85)	1.20 (0.41)	1.77 (0.94)	1.20 (0.41)	1.63 (0.88)	1.63 (0.75)	1.40 (0.74)	1.33 (0.82)
Control	2.10 (0.83)	2.15 (1.04)	2.19 (0.88)	1.44 (0.97)	2.33 (0.87)	2.21 (0.75)	2.50 (0.54)	2.00 (1.08)	1.92 (1.11)

SD: standard deviation

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Table 3. Physical activity outcomes derived from accelerometers and teaching practices assessed using SOFIT+.

	Linear pedagogy		Nonlinear pedagogy		Control	
	Mean	SD	Mean	SD	Mean	SD
Physical activity during PE						
MVPA (minutes)	11.4	3.7	11.9	4.3	9.1	4.0
MVPA (%)	35.1	10.1	38.4	10.9	29.1	11.4
Children spending $\geq 50\%$ of PE time in MVPA (%)	9.0	13.1	14.4	17.9	5.3	16.6
SOFIT+ Lesson Context						
Management (%) -	23.9	7.7	22.2	9.2	40.2	17.2
Knowledge (%) -	25.5	12.6	14.9	9.9	22.5	8.3
Motor Content (%) +	50.6	10.5	62.8	14.7	37.3	15.1
Fitness (%) +	2.7	4.9	0.2	0.9	2	4.8
Skill Practice (%) +	45.1	9.7	0.6	2	17.2	22.6
Game Play (%) +	2.7	4.3	21.2	34.8	18.1	12.7
Free Play (%) -	0	0	0	0	0	0
Discovery Practice (%) +	0.1	0.4	40.8	27.8	0	0
SOFIT+ Activity Context						
Individual Activity (%) +	25.9	16.1	24.3	20.3	4.7	12.8
Partner Activity (%) +	14.8	16.7	13.6	25.1	14.9	21.6
Small Sided Activity (%) +	4.5	8.6	3.7	8.3	3.8	9.3
Large Sided Activity (%) -	0	0	15.9	32.9	2.2	5.5
Whole Class Activity (%) +	5.4	6.2	5.3	10.6	11.7	12.6
Waiting Activity (%) -	9.5	11.1	0.3	0.8	7.9	13.2
Elimination Activity (%) -	0	0	0	0	3.5	8.6
Girls Only Activity (%) -	0	0	0	0	0	0
Children Off Task (%) -	6.8	7.1	6.6	6.2	2	2.7
SOFIT+ Teaching Behaviours						
Supervises (%) +	24.3	8	16.6	11.9	20.7	15.1
Instructs Single Child (%) -	17.7	11.3	31.7	14.7	27.1	12.9
Instructs Group (%) -	6.4	6.7	24.7	17.8	7.7	7.8
Instructs Class (%) -	41	14.1	26.5	13.7	38.5	11.2
Promotes PA (%) +	0	0	0.2	0.6	0.6	1.6
PA as Punishment (%) +	0	0	0	0	0	0
Withholding PA (%) -	0.1	0.4	1.4	5.5	0.9	3.3
PA Engaged (%) +	8	6	0	0	3	4.4
Off Task (%) -	2.6	2.8	0.5	0.9	3	2.6
SOFIT+ Activity Management						
Signalling (%) -	5.9	4.5	4.7	4.6	3.1	2.6
Retrieving equipment M* (%) -	0	0	0	0	0	0
Retrieving equipment O* (%) -	1.3	2.1	0.3	0.7	1.7	2.6
Interruption Public (%) -	3.8	2.4	4.7	3.7	5.6	5.6
Interruption Private (%) -	1.5	1.8	6	4.5	4.6	4.2

SD: standard deviation; PE: physical education; M*: multiple points; O*: one point; +: the teaching practice was theorised to foster children's moderate to vigorous physical activity; -: the teacher practice was theorised to reduce children's moderate to vigorous physical activity.

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Within the fully adjusted models, sex was significantly and negatively associated with both MVPA minutes and MVPA%, meaning that girls were generally less active than boys during PE. Age was not significantly associated with MVPA minutes and MVPA%. PE lessons

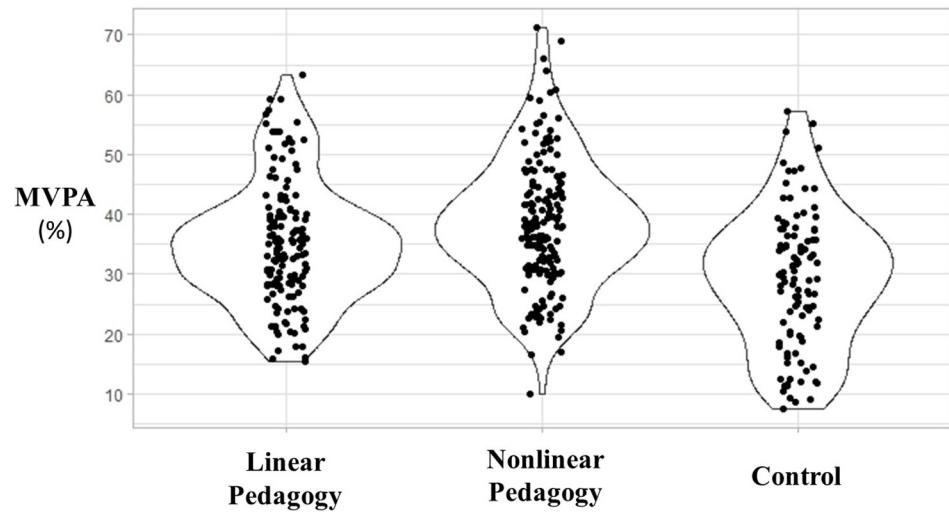


Fig 1. Percentage of time spent in moderate to vigorous physical activity in physical education. Fig 1 presents a violin density plots (shapes delimited by line) and dot plots concerning percentage of time spent in MVPA during PE; Each dot represents a single unadjusted MVPA measurement in one child during one lesson and dots were randomly scattered on the horizontal axis.

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delivered outdoors were associated with higher MVPA minutes in children compared to lessons indoors. Ball games lesson content was found to be associated with higher MVPA minutes and

Table 4. Association between pedagogy group and children's minutes of moderate to vigorous physical activity during physical education.

Predictors	Unadjusted model			Fully adjusted model		
	Estimate	CI	p-value	Estimate	CI	p-value
Group [Nonlinear vs Control]	2.58	1.56 – 3.60	<0.001	1.54	-2.45–5.53	0.450
Group [Linear vs Control]	2.37	1.32 – 3.41	<0.001	0.73	-3.58–5.04	0.740
Group [Linear vs Nonlinear]	-0.21	-1.15 – 0.72	0.652	-0.81	-3.18–1.56	0.503
Sex				-1.12	-1.74 – -0.50	<0.001
Decimal Age				1.03	-0.06 – 2.13	0.068
Lesson Location				2.45	0.54 – 4.35	0.012
Lesson content [Ball Games]				2.49	1.42 – 3.57	<0.001
Lesson content [Dance]				1.18	-1.45 – 3.82	0.379
Lesson content [Gymnastic]				2.65	-0.14 – 5.45	0.063
Lesson Duration				0.26	0.21 – 0.32	<0.001
σ^2	12.75			4.86		
τ_{00} /ICC Participants	1.76			1.83/0.14		
τ_{00} /ICC Schools				1.04/0.08		
τ_{00} /ICC Teachers				5.63/0.42		
ICC random factors	0.12			0.64		
Participants	162			162		
Schools				9		
Teachers				9		
PA Observations	416			416		
Marginal R ² / Conditional R ²	0.075 / 0.187			0.371 / 0.771		

σ^2 : Intercept variance; τ_{00} : Random factor variance; ICC: intraclass correlation index; PA: physical activity.

<https://doi.org/10.1371/journal.pone.0272339.t004>

Table 5. Association between pedagogy group and children's percentage of moderate to vigorous physical activity during physical education.

Predictors	Unadjusted model			Fully adjusted model		
	Estimate	CI	p-value	Estimate	CI	p-value
Group [Nonlinear vs Control]	8.68	5.82 – 11.55	<0.001	7.30	-3.80–18.40	0.197
Group [Linear vs Control]	6.17	3.23 – 9.10	<0.001	5.54	-6.62–17.70	0.317
Group [Linear vs Nonlinear]	-2.52	-5.14 – 0.11	0.060	-1.76	-8.21–4.69	0.594
Sex				-3.60	-5.57 – -1.64	<0.001
Decimal Age				2.99	-0.50–6.47	0.093
Lesson Location				4.82	-1.12–10.75	0.112
Lesson content [Ball Games]				7.54	4.15 – 10.93	<0.001
Lesson content [Dance]				-0.35	8.58–7.89	0.934
Lesson content [Gymnastic]				6.81	-1.90–15.51	0.126
Lesson Duration				-0.34	-0.51 – -0.17	<0.001
σ^2	89.15			48.39		
τ_{00} /ICC Participants	18.09			18.44/0.16		
τ_{00} /ICC Schools				5.29/0.04		
τ_{00} /ICC Teachers				43.87/0.38		
ICC random factors	0.17			0.58		
Participants	162			162		
Schools				9		
Teachers				9		
PA Observations	416			416		
Marginal R ² / Conditional R ²	0.100 / 0.251			0.239 / 0.682		

σ^2 : Intercept variance; τ_{00} : Random factor variance; ICC: intraclass correlation index; PA: physical activity.

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MVPA% compared to locomotor activities (reference category). Lesson duration was significantly and positively associated with MVPA minutes and negatively associated with MVPA%.

Teaching practices associated with physical activity

The characteristics of PE lessons in terms of lesson content, lesson duration, lesson location, and teacher delivery are reported in Table 6. PE lessons lasted 32:07 mins on average (SD = 06:14 mins) and 14 out of 44 lessons took place outdoors. The observed PE lessons were delivered by 4 teachers and external sports coaches in the control group while 5 trained sports coaches delivered the observed PE lessons between interventions as reported in Table 6. Due to the restricted availability of deliverers during the intervention period, the two coaches recruited from the research team delivered both Nonlinear pedagogy and Linear pedagogy as they were trained in both pedagogical approaches (Table 6).

The mean and standard deviation concerning teaching practices divided by group can be found in Table 3. Furthermore, Table 3 indicates whether the teacher practice was theorised to foster or to hinder children's engagement in MVPA during PE [70, 80, 81]. SOFIT+ teaching practice variables comprising *Free play*, *Girls Only activity*, *PA as Punishment* and *Retrieving equipment from multiple access points* were never observed during the PE lessons (Table 3), while *Withholding PA* and *Large Sided Activity* teaching practices were only observed in 3 and 6 lessons, respectively. Therefore, a statistical analysis could not be completed for these variables.

The results from the analysis of teaching practices can be found in Table 7. Regarding *Lesson Context* variables, Linear pedagogy included higher incidences of *Motor Content* and *Skill*

Table 6. Lesson characteristics.

	Linear pedagogy	Nonlinear pedagogy	Control
Lesson duration mean \pm SD (minutes)	34.2 \pm 6.6	30.8 \pm 6.8	31.2 \pm 5.0
Lessons observed	15	15	13
Locomotor activities			8
Gymnastic	5	5	
Dance	5	5	
Ball games	5	5	5
<i>Number of Physical education lesson by deliverer</i>			
Deliverer 1			3
Deliverer 2			3
Deliverer 3			6
Deliverer 4			1
Deliverer 5		3	
Deliverer 6		7	
Deliverer 7	4	1	
Deliverer 8	2	4	
Deliverer 9	9		

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Practice as well as lower incidences of *Management* and *Game Play*, compared to the control group. Nonlinear pedagogy group included higher incidences of *Motor Content* and *Discovery Practice* together with lower incidences of *Knowledge*, *Management*, *Skill Practice*, compared to the control group. Additionally, Linear pedagogy group involved higher incidences of *Knowledge* and *Skill Practice* and lower *Motor Content*, *Game Play* and *Discovery Practice*, compared to Nonlinear pedagogy group.

For *Activity Context* variables, Linear pedagogy included higher incidences of *Individual Activity* and *Children Off Task* as well as lower incidence of *Elimination Activity*, compared to the control group. Furthermore, Nonlinear pedagogy group involved higher incidences of *Individual Activity* and *Children Off Task* together with lower incidences of *Waiting Activity* and *Elimination Activity*, compared to the control group. Lastly, Linear pedagogy group involved an increased incidence of *Waiting Activity* compared to the Nonlinear pedagogy group.

For *Teaching Behaviours* variables, Linear pedagogy included higher incidence of *PA Engaged* and lower incidence of *Instructs Single Child*, compared to the control group. Furthermore, Nonlinear pedagogy group involved higher incidence of *Instructs Group*, as well as lower incidences of *Instructs Class*, *PA Engaged* and *Off Task*, compared to the control group. Additionally, Linear pedagogy group involved increased *Instructs Class*, *PA Engaged* and *Off Task* together with lower *Instructs Single Child* and *Instructs Group* compared to Nonlinear pedagogy group.

As regards *Activity Management* Variables, Linear pedagogy included lower incidence of *Interruption Private* compared to control group and Nonlinear pedagogy group while no other significant differences were found.

Discussion

This study aimed to evaluate and compare children's MVPA, and teaching practices associated with MVPA, during primary school PE within different PE pedagogical approaches (Linear and Nonlinear) and current practice in PE. The results suggest that primary PE

Table 7. Difference in teaching practices between the interventions and control group.

Teaching practice	Linear vs Control			Nonlinear vs Control			Linear vs Nonlinear			McFadden
	Incidence	Std. Error	p-value	Incidence	Std. Error	p-value	Incidence	Std. Error	p-value	
Lesson Content										
Knowledge	1.14	0.23	0.513	0.66	0.14	0.049	1.74	0.36	0.007	0.039
Management	0.59	0.08	<0.001	0.54	0.08	<0.001	1.08	0.16	0.609	0.065
Motor Content	1.36	0.15	0.005	1.70	0.18	<0.001	0.80	0.08	0.020	0.114
Fitness	1.35	1.37	0.769	0.13	0.17	0.104	10.06	12.04	0.054	0.037
Skill Practice	2.62	1.18	0.033	0.03	0.02	<0.001	76.29	49.79	<0.001	0.725
Game Play	0.15	0.10	0.006	1.18	0.78	0.806	0.13	0.09	0.002	0.042
Activity context										
Individual Activity	5.81	3.02	0.001	5.43	2.83	0.001	1.07	0.51	0.886	0.532
Partner Activity	0.71	0.29	0.399	0.75	0.31	0.496	0.94	0.35	0.877	0.020
Small Sided Activity	0.68	0.31	0.400	0.53	0.25	0.184	1.29	0.53	0.538	0.028
Whole Class Activity	0.45	0.26	0.162	0.46	0.26	0.175	0.98	0.56	0.969	0.012
Waiting Activity	1.19	0.93	0.820	0.04	0.04	0.002	32.08	32.66	0.001	0.066
Children Off Task	3.74	1.91	0.010	3.48	1.78	0.015	1.08	0.46	0.866	0.054
Teaching Practices										
Supervises	1.16	0.25	0.483	0.79	0.18	0.292	1.48	0.32	0.068	0.029
Instructs Single Child	0.66	0.13	0.038	1.17	0.22	0.404	0.57	0.11	0.003	0.040
Instructs Group	0.86	0.31	0.668	3.22	1.11	0.001	0.27	0.09	<0.001	0.080
Instructs Class	1.06	0.16	0.694	0.68	0.11	0.015	1.56	0.24	0.003	0.032
PA Engaged	2.62	1.13	0.025							0.034
Off Task	0.92	0.30	0.791	0.18	0.10	0.003	4.95	2.74	0.004	0.150
Activity Management										
Signalling	1.86	0.65	0.077	1.47	0.53	0.287	1.26	0.40	0.457	0.015
Retrieving equipment O	0.83	0.53	0.767	0.17	0.16	0.052	4.81	4.31	0.080	0.076
Interruption Public	0.70	0.23	0.285	0.85	0.28	0.614	0.82	0.28	0.563	-0.010
Interruption Private	0.31	0.12	0.003	1.24	0.39	0.484	0.25	0.10	<0.001	0.076

Significant results (p-value<0.05) were highlighted using bold font; O: One access point

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interventions focusing on movement competence guided by Linear pedagogy and Nonlinear pedagogy were not associated with different levels of children's MVPA during PE when compared to current practice in PE. Other factors were associated with children's MVPA time and MVPA% in PE including the sex of the participants (boys), lesson duration (longer), lesson location (outdoors), lesson content (ball skills, gymnastic, dance), while the teacher providing the lesson also explained a high proportion of MVPA variance. Furthermore, only a small proportion of children engaged in MVPA for at least 50% of PE time both in the intervention (Linear pedagogy: 9.0%, Nonlinear pedagogy: 14.4%) and control groups (5.3%). As for teaching practices during PE, higher incidences of PA promoting teaching practices (e.g., *Motor Content*, *Skill Practice*, *Discovery Practice*, *Individual PA*, *PA Engaged*) and lower incidences of PA decreasing teaching practices (e.g., *Knowledge*, *Management*, *Instructs Class*, *Off Task*) were found in PE lessons guided by Linear and Nonlinear pedagogical approaches. Lastly, both Linear and Nonlinear interventions were delivered with high fidelity to the respective Linear and Nonlinear pedagogical principles. The results obtained in this study extend knowledge about MVPA promotion in early primary PE under different pedagogies.

Increasing physical activity in physical education

As shown in Fig 1, the majority of children's MVPA levels within both intervention and control groups did not reach the recommended MVPA engagement of 50% of the PE lesson duration [4, 12, 13]. This is in line with the vast majority of studies assessing MVPA in PE using accelerometers and observation tools, even when those PE lessons were led by PE specialists whose aim was to promote high MVPA during PE [21, 23–25]. This suggests that high quality PE targeting other learning outcomes such as movement competence does not necessarily lead to specific thresholds of MVPA engagement. Therefore, future studies should seek to identify additional ways to promote PA whilst providing rich movement competence learning experiences for children.

This study was the first to evaluate the association between Linear pedagogy and Nonlinear pedagogy with children's MVPA and to compare PA engagement in these pedagogies with current practice in PE in primary schools. The results from this study suggest that Linear pedagogy or Nonlinear pedagogy was not a significant predictor of MVPA engagement in PE. The lack of an association between participation in the motor learning pedagogy interventions and children's MVPA in PE could be due to the intervention being designed to improve movement competence in children rather than MVPA [52]. Indeed, the vast majority of previous studies where higher levels of MVPA during PE were observed in the intervention group compared to the control condition included specific strategies to improve MVPA during PE (e.g., teacher training to deliver specific MVPA promoting PE content) and reported MVPA engagement during PE as being the primary outcome of the intervention [17, 25, 56–60, 82–84]. However, results from many of these previous studies should be interpreted with caution as, unlike the present study, they did not account for factors associated with MVPA in PE such as children's sex, age and BMI, lesson content, lesson location and lesson duration [31, 59, 60, 82–84] and/or studies did not account for children being nested within schools, classes or teacher within their statistical analyses [59, 60]. Furthermore, of the studies assessing PA in PE, our study was the first reporting the pedagogical basis guiding the delivery of movement learning activities. As an example, the "Move it Groove it" and "PLUNGE" interventions reported both PA and movement skills development as aims of their PE interventions [55, 85]. However, despite describing strategies to improve MVPA in PE, neither of these two studies clarified the pedagogical basis guiding the delivery of movement learning activities [55, 85]. Therefore, we suggest that future research should further investigate how different pedagogies and PA promotion strategies might affect children's PA during PE. Furthermore, we recommend that clear descriptions of pedagogies and PA promotion strategies should be reported in future PE interventions studies as this could help both practitioners and researchers understanding how to achieve and/or prioritise specific PE outcomes (e.g. children's motor competence development or high MVPA engagement).

Although presenting different research design and aims compared to our study, lessons can be learned from some of the aforementioned primary school PE interventions that targeted the improvement of MVPA and PA promoting teaching practices and measured changes in these outcomes from baseline to post-intervention [17, 58, 59]. Based on the findings from the Partnerships for Active Children in Elementary Schools (PACES) intervention study [17] we suggest that future Linear and Nonlinear pedagogy interventions aiming to improve children's MVPA during PE could seek to increase *Small Sided Activity* as well as teacher *Promotes PA* time and reduce *Children off task* (i.e., time when one or more students are not engaged in the task proposed by the teacher). Furthermore, considering evidence from a follow-up to the PACES study by Weaver et al. (2018) [58] we advise that decreasing *Knowledge* time and increasing *Motor Content* time in future Linear and Nonlinear pedagogy interventions as well

as decreasing *Waiting Activity* in future Linear pedagogy interventions could also be effective and feasible strategies to foster children's MVPA in PE. Finally, the "SHARP" intervention [59] reported a significant increase in MVPA together with increased time in teaching practices such as *Skill Practice* and "in class PA promotion" within the intervention group compared to the control group. The increase in *Skill Practice* observed in the SHARP intervention could be associated with the SHARP principle concerning "high repetition of motor skills" that is also a key principle within the Linear pedagogical intervention delivered in this study suggesting that practicing movement skills can significantly contribute to MVPA in PE [59, 86]. Furthermore, the high percentages of verbal PA promotion within the SHARP (42.3%) intervention compared to that observed in this study (0–0.2%) confirms that future Linear and Nonlinear interventions could focus on improving verbal PA promotion during PE delivery as a strategy to improve children's MVPA in PE [59].

Factors associated with children's physical activity in physical education

The teacher delivering PE explained a high proportion of variance in the fully adjusted models examining children's MVPA minutes (ICC = 0.42) and MVPA% (ICC = 0.37) [87] (Tables 4 and 5), suggesting that teachers are an important predictor of activity levels. More specifically, the high proportion of variance explained by the teachers in our models suggests that children doing PE with the same teacher reached similar levels of MVPA engagement during PA [87, 88]. In other words, some teachers were more effective in promoting MVPA in PE than others irrespective of them being in the intervention or in the control group. This could be due to the teacher's expertise and their knowledge and experience about strategies to engage children in high levels of PA [21, 23–25]. In line with this, PE lessons within the control group were delivered by a class teacher, two coaches (sports coaches hired from external sport coaching organisations), and a PE specialist teacher. This potentially explains why the mean MVPA and MVPA% observed in the control group (9.1 min, 29.1%) was similar or higher than previous studies in which PE was provided by generalist class teacher and reported levels of MVPA during PE ranged from 3.5 min to 10.8 min and MVPA mean percentage ranged 9.5% to 29.7% [14, 15, 89]. Interestingly, the mean MVPA percentages observed in the Linear (35.1%), and Nonlinear (38.4%) intervention groups were similar to the proportion of children's MVPA during PE observed in a study involving specialised PE teachers, with 36.7% of the lessons spent in MVPA [16]. This might be due to the intervention deliverers in the present study having experience in PE delivery in primary school children and to the intervention delivery not including generalist classroom teachers or it might be due to the content of the Linear and Nonlinear pedagogy interventions [21, 23–25].

Consistent with previous literature, it was found that MVPA during PE was associated with several factors with girls engaging in lower levels of MVPA and MVPA% compared with boys [14], longer PE lessons associated with higher minutes spent in MVPA but lower MVPA% [16], lesson content being associated with MVPA and MVPA% with ball games activities led to the highest MVPA and MVPA% engagement [14], and lastly, outdoor lessons being associated with higher levels of MVPA compared to indoor lessons when factoring teachers into the models [90]. In view of these results, researchers and practitioners should account for these factors when designing interventions to foster MVPA in PE. In particular, key aspects to consider should be: 1) finding strategies to engage girls in MVPA, for example, proposing activities that are meaningful and enjoyable for them [91]; 2) including relevant high intensity game activities with the PE lesson [14, 15]; 3) using outdoor spaces when the weather conditions allow as outdoor PE is associated with higher MVPA levels in children compared to indoor PE

[21], and 4) finding strategies to maximise lesson duration (e.g. making sure that the lesson starts and ends as established by the school curriculum) [16].

Teaching practices in pedagogies underpinned by movement learning theories

The SOFIT+ data provided valuable information about the characteristics of Linear and Non-linear pedagogy approaches in terms of teaching practices, which can be used to improve PE delivery to promote MVPA engagement in the future.

As expected from a teacher-centred pedagogical approach, the Linear pedagogy intervention involved higher *Skill Practice* and less *Game Play* compared to the Nonlinear pedagogy and control groups, as well as higher *Individual Activity* compared to the control group [35, 38, 71]. Furthermore, Linear pedagogy intervention involved a higher proportion of *Instructs Single Child* compared with other groups, and a higher proportion of instructing the class compared to the Nonlinear group in line with teacher-centred PE approaches [92, 93]. When compared to the control group, the Linear pedagogy intervention involved a higher proportion of time spent in *Motor Content* and teacher PA engagement that are associated with increased MVPA levels during PE together with less time spent in *Management* activities and *Elimination Activity* that are associated with decreased MVPA. However, within previous literature *Game Play* was found to be associated with the highest MVPA engagement in PE compared to other type of *Lesson Contexts* and within this study *Game Play* was observed less frequently in Linear intervention compared to the control group [14, 70, 80]. Furthermore, a higher percentage of *Children Off Task* was observed in Linear pedagogy group compared to control group. Therefore, future interventions guided by Linear pedagogy should consider increasing the proportion of time children spend in *Game Play* and find strategies to decrease *Children Off Task* within PE lessons to improve MVPA engagement.

As expected from a learner-centred pedagogical approach, the Nonlinear pedagogy intervention included a lower proportion of time in *Knowledge* and *Instructs Class* compared to other groups and it was practically the only intervention group where *Discovery Practice* was observed though *Skill Practice* was not [47, 48, 92, 93]. The lack of *Skill Practice* and the high proportion of *Game Play* is in line with the Nonlinear pedagogy principle of learning movement skills in a representative learning design [47, 48]. The Nonlinear intervention presented a higher proportion of MVPA promoting teaching practices (i.e. *Motor Content*) and a lower proportion of MVPA decreasing teaching practices (i.e. *Knowledge*, *Management*, *Waiting Activity*, *Elimination Activity*, *Instructs Class* and teacher being *Off Task*) compared to the control group. However, compared to the control group, the Nonlinear pedagogy intervention involved a higher proportion of *Children Off Task* (associated with decreased MVPA in PE) while teachers never engaged in PA with students, which is considered an MVPA promoting teaching practice. Therefore, future Nonlinear intervention should take in consideration aspects to decrease *Children Off Task* and for teachers to participate in PE as an active constraint to promote MVPA engagement. However, the lower levels of *Children Off Task* observed in the control group compared to both Linear and Nonlinear pedagogy could be due to teachers or coaches within the control group having a long relationship with the children leading to well established behavioral management strategies.

Lastly, both Linear and Nonlinear intervention presented none or almost no verbal promotion of PA engagement. This is likely due to these approaches not being focused on increasing MVPA engagement suggesting that this aspect could be improved in future interventions. Nevertheless, taking all the above findings together, the results suggest that Linear and Nonlinear pedagogical interventions both improve time allocated to movement competence practice

but would need to adopt more PA promoting teaching practices to increase children's MVPA in PE [70, 80, 81].

Strengths and limitations

This study included several strengths comprising being the first study to analyse the association between Linear and Nonlinear pedagogy approaches in PE with children's MVPA in PE, and the first study to use accelerometry to report MVPA during PE among 5–6 years old children. A further strength was the simultaneous assessment of children's MVPA together with the observations of MVPA teaching practices by PE teachers within the same lessons. Another strength was that multilevel models accounting for different variables associated with children's MVPA were compared and that the models accounted for the nested structure of the data (i.e., observations being nested in children and children being nested in schools), while teaching practices data were analysed with the most appropriate models for count data. However, this study also has some limitations such as MVPA only being assessed in 50% of the children in the PE class that agreed to take part in the research project due to feasibility constraints. In relation, only 3 of the 6 control schools participating in the SAMPLE-PE project were included in this study. Furthermore, due to the relatively small amount of teaching practices data collected per group and per PE deliverer, it was not possible to account for factors such as teacher and lesson content in the teaching practice analysis and some teaching practices variables were only observed a few times, making it impossible to run a statistical analysis. Lastly, one PE lesson was excluded because of technical problems in the video recording of the lesson.

Future directions

Future research could evaluate the implementation of movement learning pedagogical approaches in older children or adolescents to see if similar results are obtained compared to this study. Furthermore, future studies could include qualitative methods to examine children's PA experiences during PE under different pedagogical approaches and how experiences in PE within movement learning pedagogical approaches could affect children and young people's willingness to maintain high engagement in PE [94]. Future research assessing teaching practices associated with MVPA in PE should consider assessing a higher number of PE lessons per group and PE deliverers compared to this study with a particular attention to observe an adequate sample of PE lessons for each PE deliverer to collect teaching practices data allowing the design of complex statistical analysis models. Lastly, research could evaluate whether teacher professional training to deliver different pedagogies in PE as well as improving teaching practices associated with MVPA in PE might positively enhance their capacity and willingness to promote MVPA in PE sessions to improve movement competence.

Conclusions

The majority of children's MVPA levels within both intervention and control groups did not reach the recommended MVPA engagement of 50% within PE in line with previous literature. Furthermore, compared to current practice in PE, interventions based on Linear and Nonlinear pedagogy were not associated with increased children's MVPA, but they included a higher incidence of MVPA promoting teaching practices (e.g., *Motor content*, *Skill Practice*, *Discovery Practice*). Nevertheless, the findings suggest that utilising Linear and Nonlinear pedagogies in PE could potentially improve movement competences in young children without compromising children's PA levels compared to general practice. Given that PE deliverers were the main predictor of MVPA in PE in this study, future interventions should focus on improving the pedagogic knowledge and skills of PE deliverers about increasing children's MVPA. This

paper provides valuable information about how teaching practices within different pedagogical approaches affect PA in PE and proposes teaching practices that should be targeted to improve MVPA in PE. These findings can be used to help practitioners and researchers who are interested in designing future PE or coaching interventions based on Linear or Nonlinear pedagogies and/or maximizing MVPA engagement in PE.

Supporting information

S1 Table. Linear pedagogy curriculum: Object control skills lesson.

(DOCX)

S2 Table. Nonlinear pedagogy curriculum: Invasion games lesson.

(DOCX)

S3 Table. Table reporting inter-rater reliability results and the definition of each teaching practice.

(DOCX)

S4 Table. Pedagogical fidelity checklist.

(DOCX)

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References

1. UK Department of Education. Physical education programmes of study: key stages 1 and 2 National curriculum in England Purpose of study [Internet]. 2013 [cited 2020 Nov 17]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/239040/PRIMARY_national_curriculum_-_Physical_education.pdf

2. UNESCO. Quality Physical Education (QPE): guidelines for policy makers—UNESCO Digital Library [Internet]. UNESCO, editor. 2015 [cited 2020 Sep 23]. Available from: <https://unesdoc.unesco.org/ark:/48223/pf0000231101>
3. SHAPE America. The Essential Components of Physical Education [Internet]. 2015 [cited 2020 Nov 17]. Available from: www.shapeamerica.org
4. afPE. Health Position Paper—Association for Physical Education [Internet]. 2020 [cited 2021 Feb 18]. Available from: <https://www.afpe.org.uk/physical-education/wp-content/uploads/Health-Position-Paper-2020-Web.pdf>
5. Australian Curriculum Assessment and Reporting Authority. Health and Physical Education | The Australian Curriculum [Internet]. 2013 [cited 2020 Nov 17]. Available from: <https://www.australiancurriculum.edu.au/f-10-curriculum/health-and-physical-education/>
6. Tarp J, Brønd JC, Andersen LB, Møller NC, Froberg K, Grøntved A. Physical activity, Sedentary behavior, And long-term cardiovascular risk in young people: A review and discussion of methodology in prospective studies. *J Sport Heal Sci*. 2016 Jun 1; 5(2):145–50. <https://doi.org/10.1016/j.jshs.2016.03.004> PMID: 30356550
7. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput JP, Janssen I, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab* [Internet]. 2016 [cited 2020 Jun 25]; 41(6):S197–239. Available from: <http://nrcresearchpress.com/doi/suppl/10.1139/apnm-2015-0663> PMID: 27306431
8. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, et al. Physical activity for cognitive and mental health in youth: A systematic review of mechanisms. *Pediatrics* [Internet]. 2016 Sep 1 [cited 2020 Sep 17]; 138(3). Available from: <https://pubmed.ncbi.nlm.nih.gov/27542849/>
9. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, et al. Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Med Sci Sports Exerc* [Internet]. 2016 Jun 1 [cited 2020 Nov 18]; 48(6):1197–222. Available from: <https://pubmed.ncbi.nlm.nih.gov/27182986/> <https://doi.org/10.1249/MSS.0000000000000901>
10. Sallis JF, McKenzie TL, Beets MW, Beigle A, Erwin H, Lee S. Physical education's role in public health: Steps forward and backward over 20 years and HOPE for the future. *Res Q Exerc Sport* [Internet]. 2012 [cited 2021 Mar 22]; 83(2):125–35. Available from: <https://www.tandfonline.com/doi/abs/10.1080/02701367.2012.10599842> PMID: 22808697
11. U.S. Public Health Service. Healthy People 2000: National Health Promotion and Disease Prevention Objectives and Full Report, with Commentary. [Internet]. Washington, DC: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.; 1991 [cited 2021 Mar 22]. Available from: <https://eric.ed.gov/?id=ED332957>
12. Pate RR, Davis MG, Robinson TN, Stone EJ, McKenzie TL, Young JC. Promoting physical activity in children and youth: A leadership role for schools—A scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Physical Activity Committee) in collaboration with the C. Circulation [Internet]. 2006 Sep 12 [cited 2020 Jun 25]; 114(11):1214–24. Available from: <https://www.ahajournals.org/doi/10.1161/CIRCULATIONAHA.106.177052> PMID: 16908770
13. AAHPERD. Comprehensive School Physical Activity Programs: Helping All Students Achieve 60 Minutes of Physical Activity Each Day. *J Phys Educ Recreat Danc* [Internet]. 2013 Nov [cited 2021 Feb 18]; 84(9):9–15. Available from: <https://www.tandfonline.com/doi/abs/10.1080/07303084.2013.838105>
14. Tanaka C, Tanaka M, Tanaka S. Objectively evaluated physical activity and sedentary time in primary school children by gender, grade and types of physical education lessons. *BMC Public Health* [Internet]. 2018 Aug 2 [cited 2020 Jun 10]; 18(1). Available from: <https://pubmed.ncbi.nlm.nih.gov/30068319/>
15. Wood C, Hall K. Physical education or playtime: Which is more effective at promoting physical activity in primary school children? *BMC Res Notes* [Internet]. 2015 Dec 14 [cited 2020 Jun 10]; 8(1):12. Available from: <http://www.biomedcentral.com/1756-0500/8/12>
16. Costa M, Oliveira T, Mota J, Santos MP, Ribeiro JC. Objectively measured physical activity levels in physical education classes and body mass index (Niveles de actividad física medida objetivamente en las clases de educación física y el índice de masa grasa). *Retos* [Internet]. 2016 Nov 21 [cited 2021 Feb 4]; 31(31):271–4. Available from: www.retos.org
17. Weaver RG, Webster C, Egan C, Campos C, Michael RD, Crimarco A. Partnerships for active elementary schools: Physical education outcomes after 4 months of a 2-year pilot study. *Health Educ J* [Internet]. 2017 Nov 24 [cited 2021 Feb 16]; 76(7):763–74. Available from: <http://journals.sagepub.com/doi/10.1177/0017896917713530>
18. Beni S, Fletcher T, Ní Chróinín D. Meaningful Experiences in Physical Education and Youth Sport: A Review of the Literature. *Quest* [Internet]. 2017 Jul 3 [cited 2021 Mar 15]; 69(3):291–312. Available from: <https://www.tandfonline.com/action/journalInformation?journalCode=uqst20>

19. Dudley D, Beighle A, Erwin H, Cairney J, Schaefer L, Murfay K. Physical Education-Based Physical Activity Interventions. In: *The Routledge Handbook of Youth Physical Activity* [Internet]. Routledge; 2020 [cited 2021 Mar 17]. p. 489–503. Available from: <https://www.taylorfrancis.com/chapters/physical-education-based-physical-activity-interventions-dean-dudley-aaron-beighle-heather-erwin-john-cairney-lee-schaefer-kenneth-murfay/e/10.4324/9781003026426-30>
20. Hollis JL, Williams AJ, Sutherland R, Campbell E, Nathan N, Wolfenden L, et al. A systematic review and meta-analysis of moderate-to-vigorous physical activity levels in elementary school physical education lessons. *Prev Med (Baltim)* [Internet]. 2016 May 1 [cited 2017 Mar 3]; 86:34–54. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S009174351500345X> <https://doi.org/10.1016/j.ypmed.2015.11.018> PMID: 26592691
21. McKenzie TL, Feldman H, Woods SE, Romero KA, Dahlstrom V, Stone EJ, et al. Children activity levels and lesson context during third-grade physical education. *Res Q Exerc Sport* [Internet]. 1995 [cited 2021 Feb 8]; 66(3):184–93. Available from: <https://www.tandfonline.com/doi/abs/10.1080/02701367.1995.10608832> PMID: 7481079
22. Armour KM. Sport pedagogy: an introduction for teaching and coaching [Internet]. 2011. Available from: <http://www.dawsonera.com/depp/reader/protected/external/AbstractView/S9780273732594>
23. McKenzie TL, Sallis JF, Kolody B, Faucette FN. Long-Term effects of a physical education curriculum and staff development program: SPARK. *Res Q Exerc Sport* [Internet]. 1997 [cited 2021 Feb 8]; 68(4):280–91. Available from: <https://www.tandfonline.com/doi/abs/10.1080/02701367.1997.10608009> PMID: 9421840
24. McKenzie TL, Sallis JF, Faucette N, Roby JJ, Kolody B. Effects of a curriculum and inservice program on the quantity and quality of elementary physical education classes. *Res Q Exerc Sport* [Internet]. 1993 [cited 2021 Feb 8]; 64(2):178–87. Available from: <https://www.tandfonline.com/doi/abs/10.1080/02701367.1993.10608795> PMID: 8341841
25. Telford RDRM, Olive LS, Cochrane T, Davey R, Telford RDRM. Outcomes of a four-year specialist-taught physical education program on physical activity: A cluster randomized controlled trial, the LOOK study. *Int J Behav Nutr Phys Act* [Internet]. 2016 Jun 8 [cited 2020 Nov 16]; 13(1):64. Available from: <http://ijbnpa.biomedcentral.com/articles/10.1186/s12966-016-0388-4> PMID: 27267965
26. Griggs G. Spending the Primary Physical Education and Sport Premium: a West Midlands case study. *Educ 3–13* [Internet]. 2016 Sep 2 [cited 2021 Jan 7]; 44(5):547–55. Available from: <https://www.tandfonline.com/doi/abs/10.1080/03004279.2016.1169485>
27. Hulteen RM, Morgan PJ, Barnett LM, Stodden DF, Lubans DR. Development of Foundational Movement Skills: A Conceptual Model for Physical Activity Across the Lifespan. *Sport Med* [Internet]. 2018 Jul 1 [cited 2020 Nov 27]; 48(7):1533–40. Available from: <https://link.springer.com/article/10.1007/s40279-018-0892-6> PMID: 29524160
28. Seifert L, Komar J, Araújo D, Davids K. Neurobiological degeneracy: A key property for functional adaptations of perception and action to constraints. *Neurosci Biobehav Rev*. 2016 Oct 1; 69:159–65. <https://doi.org/10.1016/j.neubiorev.2016.08.006> PMID: 27506266
29. Gallahue DL, Ozmun JC, Goodway J. *Understanding motor development: infants, children, adolescents, adults*. McGraw-Hill; 2012. 461 p.
30. Stodden DF, Langendorfer SJ, Goodway JD, Robertson MA, Rudisill ME, Garcia C, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest* [Internet]. 2008 May 1 [cited 2020 Nov 17]; 60(2):290–306. Available from: <https://www.tandfonline.com/doi/abs/10.1080/00336297.2008.10483582>
31. Robinson LE, Stodden DF, Barnett LM, Lopes VP, Logan SW, Rodrigues LP, et al. Motor Competence and its Effect on Positive Developmental Trajectories of Health. *Sport Med* [Internet]. 2015 Sep [cited 2017 Mar 3]; 45(9):1273–84. Available from: <http://link.springer.com/10.1007/s40279-015-0351-6> PMID: 26201678
32. Kirk D, Haerens L. New research programmes in physical education and sport pedagogy. *Sport Educ Soc* [Internet]. 2014 Oct 3 [cited 2021 Mar 17]; 19(7):899–911. Available from: <https://www.tandfonline.com/doi/abs/10.1080/13573322.2013.874996>
33. Ennis CD. *Routledge International Handbooks: Routledge Handbook of Physical Education Pedagogies*. [Internet]. Taylor and Francis; 2016. Available from: <http://www.myilibrary.com?id=944883>
34. Chow JY, Davids K, Hristovski R, Araújo D, Passos P. Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas Psychol* [Internet]. 2011 Aug 1 [cited 2017 Mar 3]; 29(2):189–200. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S0732118X10000607>
35. Metzler M. *Instructional Models in Physical Education* [Internet]. Instructional Models in Physical Education. Routledge; 2017 [cited 2020 Nov 24]. Available from: <https://www.taylorfrancis.com/books/9781315213521>

36. Schmidt RA. A schema theory of discrete motor skill learning. *Psychol Rev* [Internet]. 1975 Jul [cited 2020 Sep 30]; 82(4):225–60. Available from: <http://doi.apa.org/getdoi.cfm?doi=10.1037/h0076770>
37. Taylor JA, Ivry RB. The role of strategies in motor learning. *Ann N Y Acad Sci* [Internet]. 2012 [cited 2021 May 12]; 1251(1):1–12. Available from: <http://pmc/articles/PMC4330992/> <https://doi.org/10.1111/j.1749-6632.2011.06430.x> PMID: 22329960
38. Fitts P, Posner M. Human performance. [Internet]. 1967 [cited 2020 Oct 1]. Available from: <https://psycnet.apa.org/record/1967-35040-000>
39. Zetou E, Tzetzis G, Vernadakis N, Kioumourtoglou E. Modeling in learning two volleyball skills. *Percept Mot Skills* [Internet]. 2002 Jun [cited 2021 Apr 7]; 94(3 PART 2):1131–42. Available from: <http://journals.sagepub.com/doi/10.2466/pms.2002.94.3c.1131> PMID: 12186234
40. Sullivan KJ, Katak SS, Burtner PA. Motor Learning in Children: Feedback Effects on Skill Acquisition. *Phys Ther* [Internet]. 2008 Jun 1 [cited 2021 Apr 7]; 88(6):720–32. Available from: <https://academic.oup.com/ptj/article/88/6/720/2742313> <https://doi.org/10.2522/ptj.20070196> PMID: 18339797
41. Bedard C, Bremer E, Campbell W, Cairney J. Evaluation of a Direct-Instruction Intervention to Improve Movement and Preliteracy Skills among Young Children: A Within-Subject Repeated-Measures Design. *Front Pediatr*. 2018 Jan 17;0:298. <https://doi.org/10.3389/fped.2017.00298> PMID: 29387681
42. Kalaja SP, Jaakkola TT, Liukkonen JO, Digelidis N. Development of junior high school students' fundamental movement skills and physical activity in a naturalistic physical education setting. <https://doi.org/10.1080/174089892011603124> [Internet]. 2012 Sep [cited 2021 Oct 6]; 17(4):411–28. Available from: <https://www.tandfonline.com/doi/abs/10.1080/17408989.2011.603124>
43. Warren WH. The dynamics of perception and action. *Psychol Rev* [Internet]. 2006 Apr [cited 2020 Oct 1]; 113(2):358–89. Available from: <http://record/2006-04733-006> <https://doi.org/10.1037/0033-295X.113.2.358> PMID: 16637765
44. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. *Psychol Sport Exerc*. 2006 Nov 1; 7(6):653–76.
45. Chow JY. Nonlinear Learning Underpinning Pedagogy: Evidence, Challenges, and Implications. *Quest* [Internet]. 2013 Oct [cited 2017 Mar 11]; 65(4):469–84. Available from: <http://www.tandfonline.com/doi/abs/10.1080/00336297.2013.807746>
46. Rudd JR, Woods C, Correia V, Seifert L, Davids K. An ecological dynamics conceptualisation of physical 'education': Where we have been and where we could go next. <https://doi.org/10.1080/1740898920211886271> [Internet]. 2021 [cited 2021 Oct 6]; 26(3):293–306. Available from: <https://www.tandfonline.com/doi/abs/10.1080/17408989.2021.1886271>
47. Chow JY, Atencio M. Complex and nonlinear pedagogy and the implications for physical education. *Sport Educ Soc* [Internet]. 2014 Nov [cited 2017 Mar 3]; 19(8):1034–54. Available from: <http://www.tandfonline.com/doi/abs/10.1080/13573322.2012.728528>
48. Correia V, Carvalho J, Araújo D, Pereira E, Davids K. Principles of nonlinear pedagogy in sport practice. *Phys Educ Sport Pedagog* [Internet]. 2019 Mar 4 [cited 2021 Feb 18]; 24(2):117–32. Available from: <https://www.tandfonline.com/doi/full/10.1080/17408989.2018.1552673>
49. Ebrahimi Tavakolian M, Mohammadi Orangi B, Ghadiri F, Mohammad Nejad M. The effect of nonlinear pedagogy on motor proficiency and self-esteem of hyperactive obese girls. *J Fundam Ment Heal* [Internet]. 2020 Apr 20 [cited 2021 Oct 6]; 22(3):240–50. Available from: https://jfmh.mums.ac.ir/article_16474.html
50. Pizarro D, Práxedes A, Travassos B, del Villar F, Moreno A. The effects of a nonlinear pedagogy training program in the technical-tactical behaviour of youth futsal players. *Int J Sports Sci Coach* [Internet]. 2019 Feb 6 [cited 2021 Apr 9]; 14(1):15–23. Available from: <http://journals.sagepub.com/doi/10.1177/1747954118812072>
51. Práxedes A, Álvarez FDV, Moreno A, Gil-Arias A, Davids K. Effects of a nonlinear pedagogy intervention programme on the emergent tactical behaviours of youth footballers. <https://doi.org/10.1080/1740898920191580689> [Internet]. 2019 Jul 4 [cited 2021 Oct 6]; 24(4):332–43. Available from: <https://www.tandfonline.com/doi/abs/10.1080/17408989.2019.1580689>
52. Rudd JR, Crotti M, Fitton-Davies K, O'Callaghan L, Bardid F, Utesch T, et al. Skill Acquisition Methods Fostering Physical Literacy in Early-Physical Education (SAMPLE-PE): Rationale and Study Protocol for a Cluster Randomized Controlled Trial in 5–6-Year-Old Children From Deprived Areas of North West England. *Front Psychol* [Internet]. 2020 Jun 17 [cited 2020 Jun 18]; 11:1228. Available from: <https://www.frontiersin.org/article/10.3389/fpsyg.2020.01228/full> PMID: 32625143
53. Carroll C, Patterson M, Wood S, Booth A, Rick J, Balain S. A conceptual framework for implementation fidelity. *Implement Sci* [Internet]. 2007 Nov 30 [cited 2022 Jul 6]; 2(1):1–9. Available from: <https://link.springer.com/articles/10.1186/1748-5908-2-40> PMID: 18053122

54. Fairclough SJ, Stratton G. A review of physical activity levels during elementary school physical education. *J Teach Phys Educ* [Internet]. 2006 Apr 1 [cited 2020 Sep 24]; 25(2):239–57. Available from: <https://journals.humankinetics.com/view/journals/jtpe/25/2/article-p240.xml>
55. Miller A, Christensen EM, Eather N, Sproule J, Annis-Brown L, Lubans DR. The PLUNGE randomized controlled trial: Evaluation of a games-based physical activity professional learning program in primary school physical education. *Prev Med (Baltim)*. 2015 May 1; 74:1–8. <https://doi.org/10.1016/j.ypmed.2015.02.002> PMID: 25668220
56. Fairclough S, Stratton G. Improving health-enhancing physical activity in girls' physical education. *Health Educ Res* [Internet]. 2005 Aug 1 [cited 2021 Apr 1]; 20(4):448–57. Available from: <http://academic.oup.com/her/article/20/4/448/632661/Improving-healthenhancing-physical-activity-in> <https://doi.org/10.1093/her/cyg137> PMID: 15590711
57. Logan SW, Robinson LE, Webster EK, Rudisill ME. The influence of instructional climates on time spent in management tasks and physical activity of 2nd-grade students during physical education. *Eur Phys Educ Rev* [Internet]. 2015 May 31 [cited 2021 Feb 4]; 21(2):195–205. Available from: <http://journals.sagepub.com/doi/10.1177/1356336X14555304>
58. Weaver RG, Webster CA, Beets MW, Brazendale K, Chandler J, Schisler L, et al. Initial Outcomes of a Participatory-Based, Competency-Building Approach to Increasing Physical Education Teachers' Physical Activity Promotion and Students' Physical Activity: A Pilot Study. *Heal Educ Behav* [Internet]. 2018 Jun 1 [cited 2021 Feb 16]; 45(3):359–70. Available from: <http://journals.sagepub.com/doi/10.1177/1090198117731600> PMID: 28927304
59. Powell E, Woodfield LA, Nevill AM. Increasing physical activity levels in primary school physical education: The SHARP Principles Model. *Prev Med Reports*. 2016 Jun 1; 3:7–13. <https://doi.org/10.1016/j.pmedr.2015.11.007> PMID: 26844179
60. Powell E, Woodfield LA, Powell AJ, Nevill AM. Assessing the Wider Implementation of the SHARP Principles: Increasing Physical Activity in Primary Physical Education. *Sports* [Internet]. 2020 Jan 9 [cited 2021 Feb 5]; 8(1):6. Available from: <https://www.mdpi.com/2075-4663/8/1/6> <https://doi.org/10.3390/sports8010006> PMID: 31936560
61. Guadagnoli MA, Lee TD. Challenge Point: A Framework for Conceptualizing the Effects of Various Practice Conditions in Motor Learning. *J Mot Behav* [Internet]. 2004 Jun [cited 2020 Sep 18]; 36(2):212–24. Available from: <https://www.tandfonline.com/doi/abs/10.3200/JMBR.36.2.212-224> PMID: 15130871
62. Adams DL. Develop Better Motor Skill Progressions with Gentile's Taxonomy of Tasks. *J Phys Educ Recreat Danc* [Internet]. 1999 Oct [cited 2020 Oct 2]; 70(8):35–8. Available from: <https://www.tandfonline.com/doi/abs/10.1080/07303084.1999.10605704>
63. STEP Academy Trust. STEP Academy Trust Physical Education Policy. 2015.
64. Newell KM. Constraints on the Development of Coordination. In: *Motor Development in Children: Aspects of Coordination and Control*. Springer Netherlands; 1986. p. 341–60.
65. Dettwyler KA. Anthropometric standardization reference manual, abridged edition. Edited by Lohman Timothy G., Roche Alex F., and Martoll Reynaldo. Champaign, Illinois: Human Kinetic Books. 1991. 90 pp. \$16.00 (paper). *Am J Phys Anthropol* [Internet]. 1993 Oct 1 [cited 2020 Nov 18]; 92(2):239–41. Available from: <http://doi.wiley.com/10.1002/ajpa.1330920214>
66. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes* [Internet]. 2012 Aug 1 [cited 2021 Jan 30]; 7(4):284–94. Available from: <https://onlinelibrary.wiley.com/doi/full/10.1111/j.2047-6310.2012.00064.x> PMID: 22715120
67. UK Government Ministry of Housing Communities & Local. English indices of deprivation—GOV.UK [Internet]. 2018 [cited 2020 Nov 18]. Available from: <https://www.gov.uk/government/collections/english-indices-of-deprivation>
68. Van Hees VT. Raw Accelerometer Data Analysis [R package GGIR version 2.1–0]. 2020 Aug 27 [cited 2020 Nov 16]; Available from: <https://cran.r-project.org/package=GGIR>
69. Crotti M, Foweather L, Rudd JR, Hurter L, Schwarz S, Boddy LM. Development of raw acceleration cut-points for wrist and hip accelerometers to assess sedentary behaviour and physical activity in 5–7-year-old children. *J Sports Sci* [Internet]. 2020 May 2 [cited 2020 Jun 10]; 38(9):1036–45. Available from: <https://www.tandfonline.com/doi/full/10.1080/02640414.2020.1740469> PMID: 32228156
70. Crotti M, Rudd J, Weaver G, Roberts S, O'Callaghan L, Fitton Davies K, et al. Validation of Modified SOFIT+: Relating Physical Activity Promoting Practices in Physical Education to Moderate-to-vigorous Physical Activity in 5–6 Year Old Children. *Meas Phys Educ Exerc Sci* [Internet]. 2021 [cited 2021 Mar 30]; Available from: <https://www.tandfonline.com/doi/abs/10.1080/1091367X.2021.1901714>
71. Crotti M, Rudd JR, Roberts S, Boddy LM, Fitton Davies K, O'Callaghan L, et al. Effect of Linear and Nonlinear Pedagogy Physical Education Interventions on Children's Physical Activity: A Cluster Randomized Controlled Trial (SAMPLE-PE). *Children* [Internet]. 2021 Jan 15 [cited 2021 Jan 30]; 8(1):49.

Available from: <https://www.mdpi.com/2227-9067/8/1/49> <https://doi.org/10.3390/children8010049>
PMID: 33467568

72. Bates D, Maechler M, Bolker B, Walker S, Christensen RHB, Singmann H, et al. Package lme4 [Internet]. 2020 [cited 2021 Jan 30]. Available from: <https://cran.r-project.org/web/packages/lme4/lme4.pdf>
73. Leys C, Ley C, Klein O, Bernard P, Licata L. Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *J Exp Soc Psychol*. 2013 Jul 1; 49(4):764–6.
74. Friendly M, Meyer D. *Discrete Data Analysis with R: Visualization and Modeling Techniques* [Internet]. 1st edition. Boca Raton: CRC Press: Chapman & Hall Book; 2016 [cited 2021 Jan 30]. 562 p. Available from: <https://www.routledge.com/Discrete-Data-Analysis-with-R-Visualization-and-Modeling-Techniques-for-Friendly-Meyer/p/book/9781498725835>
75. Hilbe JM. *Modeling Count Data* [Internet]. Cambridge: Cambridge University Press; 2014 [cited 2021 Jan 30]. Available from: <http://ebooks.cambridge.org/ref/id/CBO9781139236065>
76. Hilbe JM. *Negative binomial regression, second edition* [Internet]. *Negative Binomial Regression, Second Edition*. Cambridge University Press; 2011 [cited 2021 Jan 30]. 1–553 p. Available from: <https://www.cambridge.org/core/books/negative-binomial-regression/12D6281A46B9A980DC6021080C9419E7>
77. Dean CB. Testing for Overdispersion in Poisson and Binomial Regression Models. *J Am Stat Assoc*. 1992 Jun; 87(418):451.
78. Blasco-Moreno A, Pérez-Casany M, Puig P, Morante M, Castells E. What does a zero mean? Understanding false, random and structural zeros in ecology. O'Hara RB, editor. *Methods Ecol Evol* [Internet]. 2019 Jul 9 [cited 2021 Jan 30]; 10(7):949–59. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.13185>
79. Smith TJ, McKenna C. A Comparison of Logistic Regression Pseudo R2 Indices. *Gen Linear Model J* [Internet]. 2013 [cited 2021 Feb 18]; Available from: http://www.glmj.org/archives/GLMJ_2014v39n2.html
80. Weaver RG, Webster CA, Erwin H, Beighle A, Beets MW, Choukroun H, et al. Modifying the System for Observing Fitness Instruction Time to Measure Teacher Practices Related to Physical Activity Promotion: SOFIT+. *Meas Phys Educ Exerc Sci*. 2016 Apr 2; 20(2):121–30.
81. Fairclough SJ, Weaver RG, Johnson S, Rawlinson J. Validation of an observation tool to assess physical activity-promoting physical education lessons in high schools: SOFIT+. *J Sci Med Sport*. 2018 May 1; 21(5):495–500. <https://doi.org/10.1016/j.jsams.2017.09.186> PMID: 29017834
82. Coleman KJ, Tiller CL, Sanchez J, Heath EM, Sy O, Milliken G, et al. Prevention of the epidemic increase in child risk of overweight in low-income schools: The El Paso coordinated approach to child health. *Arch Pediatr Adolesc Med* [Internet]. 2005 Mar 1 [cited 2021 Feb 5]; 159(3):217–24. Available from: <https://jamanetwork.com/journals/jamapediatrics/fullarticle/485955> <https://doi.org/10.1001/archpedi.159.3.217> PMID: 15753263
83. McKenzie TL, Nader PR, Strikmiller PK, Yang M, Stone EJ, Perry CL, et al. School physical education: Effect of the child and adolescent trial for cardiovascular health. *Prev Med (Baltim)*. 1996 Jul 1; 25(4):423–31. <https://doi.org/10.1006/pmed.1996.0074> PMID: 8818066
84. Sallis JF, McKenzie TL, Alcaraz JE, Kolody B, Faucette N, Hovell MF. The effects of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. *Am J Public Health* [Internet]. 1997 Oct 7 [cited 2020 Nov 16]; 87(8):1328–34. Available from: <http://ajph.aphapublications.org> <https://doi.org/10.2105/ajph.87.8.1328> PMID: 9279269
85. Van Beurden E, Barnett LM, Zask A, Dietrich UC, Brooks LO, Beard J. Can we skill and activate children through primary school physical education lessons? “Move it Groove it”—A collaborative health promotion intervention. *Prev Med (Baltim)* [Internet]. 2003 Apr 1 [cited 2021 Apr 1]; 36(4):493–501. Available from: <https://pubmed.ncbi.nlm.nih.gov/12649058/> [https://doi.org/10.1016/s0091-7435\(02\)00044-0](https://doi.org/10.1016/s0091-7435(02)00044-0)
86. Sacko RS, Brazendale K, Brian A, McIver K, Nesbitt D, Pfeifer C, et al. Comparison of Indirect Calorimetry- and Accelerometry-Based Energy Expenditure during Object Project Skill Performance. *Meas Phys Educ Exerc Sci* [Internet]. 2019 Apr 3 [cited 2020 Jul 21]; 23(2):148–58. Available from: <https://www.tandfonline.com/doi/full/10.1080/1091367X.2018.1554578>
87. Hoffman L. On the Interpretation of Parameters in Multivariate Multilevel Models Across Different Combinations of Model Specification and Estimation. *Adv Methods Pract Psychol Sci* [Internet]. 2019 Sep 2 [cited 2021 Mar 21]; 2(3):288–311. Available from: <http://journals.sagepub.com/doi/10.1177/2515245919842770> PMID: 32719825
88. Park S, Lake ET. Multilevel modeling of a clustered continuous outcome: Nurses' work hours and burn-out. *Nurs Res* [Internet]. 2005 Nov [cited 2021 Mar 21]; 54(6):406–13. Available from: <https://pubmed.ncbi.nlm.nih.gov/16317362/> <https://doi.org/10.1097/00006199-200511000-00007>
89. Nettlefold L, McKay HA, Warburton DER, McGuire KA, Bredin SSD, Naylor PJ. The challenge of low physical activity during the school day: At recess, lunch and in physical education. *Br J Sports Med*

[Internet]. 2011 Aug 1 [cited 2020 Sep 24]; 45(10):813–9. Available from: <https://pubmed.ncbi.nlm.nih.gov/20215489/> <https://doi.org/10.1136/bjism.2009.068072>

90. Kwon S, Welch S, Mason M. Physical education environment and student physical activity levels in low-income communities. *BMC Public Health* [Internet]. 2020 Jan 31 [cited 2020 Jun 11]; 20(1). Available from: <https://doi.org/10.1186/s12889-020-8278-8> PMID: 32005209
91. Peral-Suárez Á, Cuadrado-Soto E, Perea JM, Navia B, López-Sobaler AM, Ortega RM. Physical activity practice and sports preferences in a group of Spanish schoolchildren depending on sex and parental care: A gender perspective. *BMC Pediatr* [Internet]. 2020 Jul 7 [cited 2020 Dec 15]; 20(1):337. Available from: <https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-020-02229-z> PMID: 32635918
92. Goodyear V, Dudley D. "I'm a Facilitator of Learning!" Understanding What Teachers and Students Do Within Student-Centered Physical Education Models. *Quest* [Internet]. 2015 Jul 3 [cited 2021 Feb 18]; 67(3):274–89. Available from: <https://www.tandfonline.com/action/journalInformation?journalCode=uqst20>
93. Mosston M, Ashworth S. Teaching Physical Education [Internet]. 1st Online. 2008 [cited 2020 Jun 9]. Available from: https://spectrumofteachingstyles.org/assets/files/book/Teaching_Physical_Edu_1st_Online.pdf
94. Ennis CD. Educating Students for a Lifetime of Physical Activity: Enhancing Mindfulness, Motivation, and Meaning. *Res Q Exerc Sport* [Internet]. 2017 Jul 3 [cited 2021 Feb 19]; 88(3):241–50. Available from: <https://www.tandfonline.com/doi/abs/10.1080/02701367.2017.1342495> PMID: 28742426

Supplementary material 1. Linear Pedagogy curriculum: Object control skills Lesson

	<p>Key stage 1 Pupils should develop fundamental movement skills, become increasingly competent and confident and access a broad range of opportunities to extend their agility, balance and coordination, individually and with others. They should be able to engage in competitive (both against self and against others) and co-operative physical activities, in a range of increasingly challenging situations.</p> <p><i>Pupils should be taught to:</i></p> <ul style="list-style-type: none"> - Master basic movements including running, jumping, throwing and catching, as well as developing balance, agility and co-ordination, and begin to apply these in a range of activities. - Participate in team games, developing simple tactics.
<i>B3: Lesson No</i>	Lesson 1
<i>Lesson Outcome</i>	Demonstrate mastery over underarm throw.
<i>Desired outcome</i>	To be able to perform an underarm roll at for accuracy while stationary and while moving.
<i>Progression based on Gentiles' taxonomy</i>	<p>Foster children motor skills learning by increasing the difficulty of the task over the lessons using Gentile's taxonomy:</p> <p>Body: from no body transport → to body transport Object: from no object → to manipulation of object Motion: from object still → to object moving Intertrial Variability: from no intertrial variability → to intertrial variability</p>
<i>B8: Whole Class Task Activity</i>	<p>Warm up</p> <p><u>The orchestra</u></p> <p>Children must imitate the teacher who is the orchestra leader.</p> <ul style="list-style-type: none"> • Open and close arms on horizontal plane and clap hands. • Hands close to the ground and then up over the head. • Claps hands on the legs. • Alternate one clap on legs and one with hands. • Alternate one clap on the chest and one with hands. • Clap hands behind the back and on the front • Claps on the floor. <p>Alternate claps.</p> <p>The teacher divides children in groups, each group will perform a different clap. When the director of the orchestra (teacher) gives the signal children start clapping.</p> <p>Drill 1</p> <p><u>Simplification of underarm roll</u></p> <p>Demonstration: The teacher swings an arm from back to front as a pendulum and uses a verbal cue to guide the speed. Children are asked to say “swing back and swing forward” while performing the movement.</p> <p>Subsequently, the teacher demonstrates how to bend and get close to the floor while swinging the arm:</p> <p>“Step forward and caress the grass”.</p> <p>Last the last demonstration the teacher includes a step forward in the action:</p> <p>“Swing back step forward and caress the grass ”.</p>

Drill 2a

After performing drill 1 one correctly each child receives a ball.

Child will repeat the drill one:

“Swing back step forward and caress the grass”.

With a ball in their hand.

Drill 2b

Children repeat drill 2a throwing the ball to a goal.

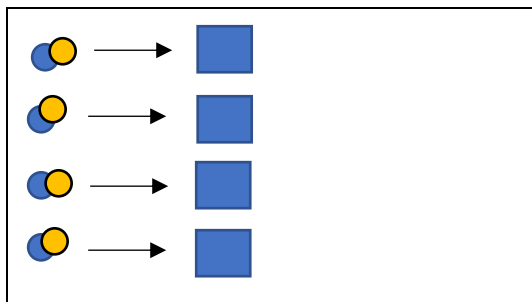
Each child is responsible for one ball and must collect it after throwing it. The target might be placed close to a wall, so the ball does not roll far. Alternatively, children could work in pairs: a child could stand with leg open, and another child could roll the ball between the legs of the companion (goal).

→ Throw

■ Target

● Ball

● Child



Drill 2c

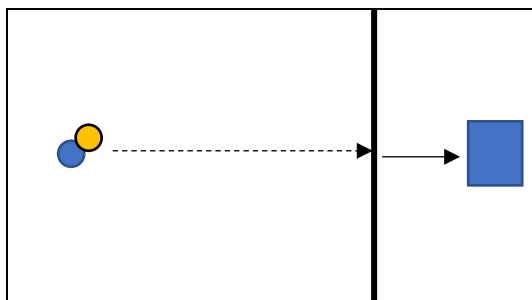
Same as drill 2b but children use different balls/ different targets. Possible gamification, the pair of children that scores the highest number of goals will win (set a precise distance).

Drill 3

Children are asked to walk towards a target and perform an underarm roll without stopping. Subsequently, children are asked to run and perform an underarm roll towards a target while running.

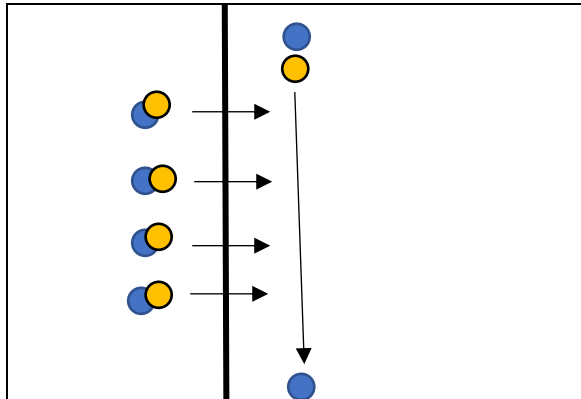
The drill becomes a relay: the team that scores more goals wins. The rules are the following: only a child per team can run.

→ run



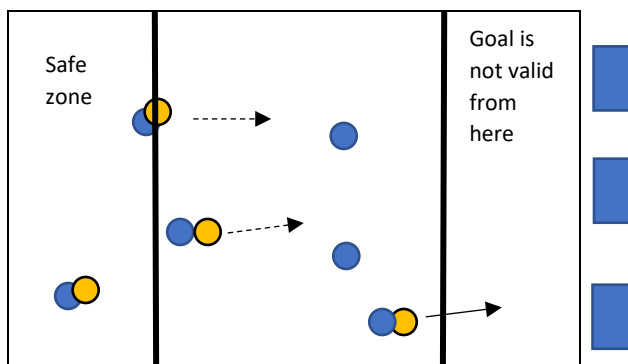
Drill 4

The teacher divides children in groups. Two children roll a ball in front of the rest of a group of children. The other children will try to hit the rolling ball using small balls.



Game

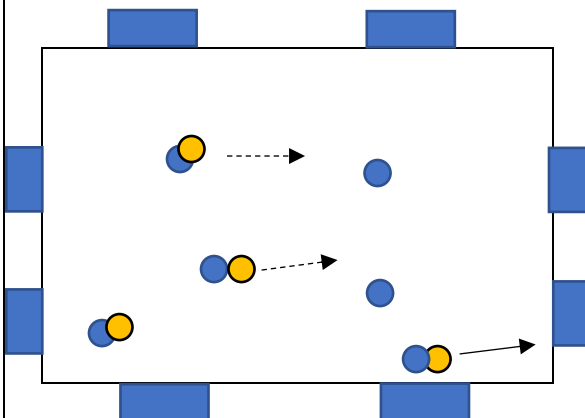
Children are provided with balls within a safe zone and they have to hit in the targets on the other side of the hall. However, other children will try to stop them by tagging them. The children that get tagged must come back to the safe zone before attempting to score a goal again. It is not possible to throw from the safe zone. Only underarm throw is valid.



Alternative game

Stuck in the mud

If children get tagged, they must roll their ball to a target. If they miss it, they are stuck and they must wait for a mate to free them. To free children who are stuck other children must roll a ball between their legs. If the task is too complex, the teacher removes the targets.

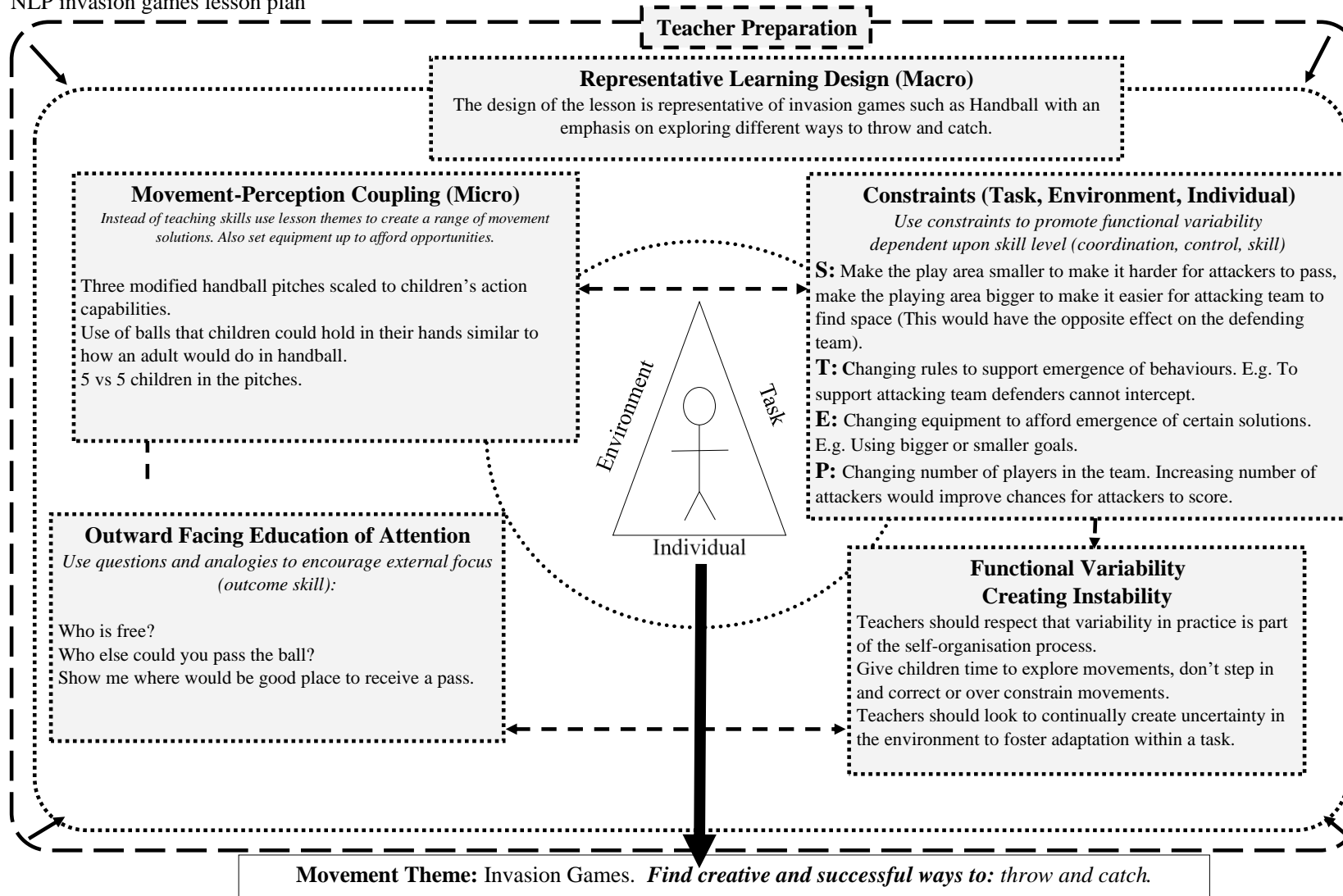


Cool down

Walking around the space, quietly. Take a seat. The teacher asks questions about the lesson.

Supplementary material 2. Nonlinear pedagogy curriculum: Invasion games lesson

NLP invasion games lesson plan



Supplementary material 3. Table reporting inter-rater reliability results and the definition of each teaching practice

	Definition
<i>Lesson Context</i>	
Management-	Lesson time when students are not involved in physical education content, including transition, management, and break times.
Knowledge-	Lesson time focused on student acquisition of knowledge related to physical education.
Motor Content+	Lesson time when students are engaged in activities involving motor content.
Fitness+	Activities where the main purpose is to warm-up or train cardiorespiratory fitness, strength and flexibility.
Skill Practice+	Activities where the main goal is to practice and improve movement skills.
Game Play+	Activities where movement skills are applied in game situations.
Free Play+	Time where children engage in play freely without the need of instruction.
Discovery Practice+	Activities devoted to the exploration of different movement solutions to meet the task, to answer a question or to solve the problem proposed by the teacher.
<i>Activity Context</i>	
Individual Activity+	Students participate in an activity alone.
Partner Activity+	Students participate in an activity in pairs.
Small Sided Activity+	Students participate in activities divided into several small groups of not more than 5 children.
Large Sided Activity-	Students participate in activities divided into groups of more than 5 children.
Whole Class Activity+	Students participate in activities as a large group and interact with each other to accomplish a goal.
Waiting Activity-	Activity where the majority of the children have to wait for their turn to play or participate.
Elimination Activity-	A game that involves the elimination of students from the activity.
Girls Only Activity+	Activities that only include girls.
Children Off Task-	Time when one or more students are not engaged in the task proposed by the teacher.
<i>Teacher Behaviours</i>	
Supervises+	The teacher monitors the activity without intervening.
Instructs Single Child-	Teacher interacts with one student either verbally or nonverbally providing either instructions, demonstration or feedback.
Instructs Group-	Teacher interacts with a group of students either verbally or nonverbally providing either instructions, demonstration or feedback.
Instructs Class-	Teacher interacts with the whole class either verbally or nonverbally providing either instructions, demonstration or feedback.
Promotes PA+	The teacher verbally promotes engagement in physical activity.
PA as Punishment-	When the teacher uses physical activity as a punishment for a misbehaviour.
Withholding PA-	The teacher removes one or more students from an activity,
PA Engaged+	The teacher engages in physical activity together with the children.

Off Task- The teachers engages in duties that are not related with the lesson.

Activity Management

Signalling- The teacher signals students to stop.

Retrieving equipment Students move or collect equipment from/to multiple areas.

Multiple access points

-

Retrieving equipment Students move or collect equipment from/to one area.

One access point -

Interruption Public- Teacher addresses an interruption or misbehaviour publicly.

Interruption Private- Teacher addresses an interruption or misbehaviour privately.

+ : Indicates that the teacher practice is theorised to foster engagement in moderate to vigorous physical activity based on results from Crotti et al. (2021).

- : Indicates that the teacher practice is theorised to hinder engagement in moderate to vigorous physical activity based on results from Crotti et al. (2021).

PA: Physical activity.

Supplementary material 4. Pedagogical fidelity checklist

		Motor-learning-related items					Lesson Quartiles					
		Pedagogy A		Sliding Scale			Pedagogy B		Q1	Q2	Q3	Q4
1	To support learning of fundamental movement skills PE teacher/coach will manipulate the child's movements through breaking the skill into component parts	1	2	3	4	5	To support the emergence of functional movement solutions the PE teacher/coach will manipulate the task or environment but not the child					
2	Children learn skill first in closed decontextualized environments then apply new skills in a performance environment	1	2	3	4	5	Movements are always learnt in context (music, storytelling, scenarios or games)					
3	All children transition between activities and task at roughly the same time	1	2	3	4	5	Transitions may be whole class, group of children or individual child and involve manipulations of tasks and activities but could on the surface be quite minor					
4	PE teacher/coach controls what equipment is used and when it is introduced to the children	1	2	3	4	5	PE teacher/coach allows the children to choose which equipment to use and when they want to use it to help with finding solution to the task					
5	Demonstrations of fundamental movement skill by adult or a competent child is preferred option in closed environment	1	2	3	4	5	Demonstration are done in context to encourage children to explore unique performance solutions					
6	The use of verbal instruction is prescriptive and focused on correct technical movement pattern	1	2	3	4	5	Verbal instruction is short and not prescriptive, focused on the environment or task					
7	Feedback is skill focused and prescriptive to learn ideal template	1	2	3	4	5	Feedback is used to support alternative functional movement solutions					

		Global items						
		Sliding Scale						
	Pedagogy A						Pedagogy B	
1	Teacher prescribes children to perform fundamental movement skill or set of fundamental movement skills. Children learn an optimal movement template or technique of a particular skill or series of skills	1	2	3	4	5	Teacher creates an environment for children to perform functional movement solutions through interaction with the environment and task. Children learn to explore and interact with their environment to find functional solutions	
2	Lesson progression is through clear and linear structure, warm up, drills, game/performance and cool down	1	2	3	4	5	Lesson evolves through storytelling, scenarios or games	