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SPORT PRACTICE AND IMPROVEMENT IN EXECUTIVE FUNCTION

ATTIVITÀ SPORTIVA E MIGLIORAMENTO DELLE FUNZIONI ESECUTIVE

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Abstract

The executive functions refer to a family of top-down mental processes that intervene when a subject must focus and pay attention, or when relying on instinct or intuition is insufficient, or impossible to maintain. Recently, an increasing number of studies aimed to investigate further associations between exercise and cognitive and executive functions. Although, existing evidence has revealed that fitness and exercise have important relationships with multiple aspects of cognitive functions, studies also suggest that the beneficial effects of exercise are larger and more solid for executive functions. Consequently, this brief report tried to define robust and wide accepted relations between sport practice, improvement in executive functions, and, in turn, better academic achievement. The findings suggest that elite athletes in open skills sports display more beneficial executive functions in comparison to elite athletes in closed skills sports. Mixed skills would seem to improve executive functions less than open skills but more than closed skills. Also, executive functions improve mathematics and geometry performance. With respect to physical fitness, athletes must consistently perform highly complex or difficult tasks to acquire sport success and must also maintain optimal mental state to ensure the best possible performance. From this sport advantage, constant practice leads to improved cognitive performance.

Le funzioni esecutive si riferiscono a una famiglia di processi mentali top-down che intervengono quando un soggetto deve concentrarsi e prestare attenzione, o quando fare affidamento su istinto o intuizione è insufficiente, o impossibile da mantenere. Recentemente, un numero crescente di studi ha cercato di indagare associazioni tra esercizio e funzioni cognitive ed esecutive. Anche se le prove esistenti hanno rivelato che la forma fisica e l'esercizio fisico hanno relazioni importanti con molteplici aspetti delle funzioni cognitive, gli studi suggeriscono anche che i benefici dell'esercizio sono più grandi e più solidi per le funzioni esecutive. Di conseguenza, questo report ha cercato di definire relazioni ampiamente accettate tra la pratica sportiva, il miglioramento delle funzioni esecutive e, a sua volta, un migliore rendimento scolastico. I risultati suggeriscono che gli atleti negli sport di abilità aperte mostrano funzioni esecutive più efficaci rispetto agli atleti d'élite negli sport di abilità chiuse. Le abilità miste sembrano migliorare le funzioni esecutive meno delle abilità aperte ma più delle abilità chiuse. Inoltre, le funzioni esecutive migliorano le prestazioni in matematica e geometria. Per quanto riguarda la forma fisica, gli atleti devono eseguire costantemente compiti altamente complessi o difficili per

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acquisire il successo sportivo e mantenere uno stato mentale ottimale per garantire le migliori prestazioni possibili. Da questo vantaggio sportivo la pratica costante porta alle migliori prestazioni cognitive.

Key-words

Executive function, academic achievements, open skills, closed skills, sport
Funzioni Esecutive, risultati scolastici, abilità di situazione, abilità di prestazione, sport

Introduction

The beneficial effects of physical activity and exercise on physical health were well-demonstrated among all age groups (Booth et al., 2013; Mackey et al., 2011), and, recently, an increasing number of studies (Scharfen & Memmert, 2019) aimed to investigating further associations between exercise and cognitive and executive functions (EFs).
Although existing evidence has revealed that fitness and exercise have important relationships with multiple aspects of cognitive functions (Åberg et al., 2009; Chaddock et al., 2011; Kramer & Erickson, 2007), studies also suggest that the beneficial effects of exercise are larger and more solid for EFs (Chaddock et al., 2011; Kramer & Erickson, 2007). Indeed, sport-specific motor actions that are performed in a relatively dynamic and changing environment involve high perceptual–cognitive demands (Nuri, et al., 2013).
For example, in children and adolescents, a higher level of physical fitness has been associated with a better EFs and academic performance (Huang et al., 2014; Marques et al., 2018; Westfall et al., 2018) while recent reviews suggested evidence of superior general cognitive functions in expert athletes of team sports than non-expert peers (Voss et al., 2010).
Seem to be evident that prolonged participation in cognitively demanding physical exercise had a positive impact on cognitive functions because within the game the information processing is crucial. In turn, this 'training' of processing leads forward cognitive vitality (Alvarez & Emory, 2006) across the lifespan (i.e. school performance).
But are, also, robust the finding about the relationships between high EFs and academic achievements? The next paragraphs attempt to outline a rationale within scientific report (narrative review) to clarify the most robust consequences-correlations about sport practice-improvement in EFs and then better academic achievements.

1. Executive Function and their improvements

The EFs refer to a family of top-down mental processes that intervene when a subject must focus and pay attention, or when relying on instinct or intuition is insufficient, or impossible to maintain (Burgess & Simons, 2012; Miller & Cohen, 2001).
The intervention of the EFs is effortful from a brain point of view because is easier and quicker to let an action continue than to change, it is also easier to let yourself be tempted than to resist it, and it is easier to go on "automatic pilot" than to consider what to do next (i.e. plan forward).
The general scientific agreement defines three core for EFs (e.g.,Lehto et al., 2003; Miyake et al., 2000): inhibition, working memory (WM) and cognitive flexibility (CF).
In particular, inhibition is completely defined as an inhibitory control (IC) including self-control (behavioral inhibition) and interference control that, in turn, could be subdivided in selective attention and cognitive inhibition.
WM, on the other side, is a skill that allows us to work with information without losing track of what we are doing. WM could be as a temporary sticky note in our brain. It holds new

information so the brain can work with it briefly and connect it with other information. For example, in math class, WM lets us "see" the numbers the teacher is saying helping to tackle the task at hand. WM helps the brain to organize new information for long-term storage.
The CF, instead, is also defined set shifting, mental flexibility, or mental set shifting and is closely related to creativity.
From these core EFs the mental process builds a second order of function that is composed by reasoning, problem solving, and planning (Collins & Koechlin, 2012; Diamond, 2013; Lunt et al., 2012). These last functions do not fully overlap the concept of quotient of intelligence but are essential skills for mental and physical wellbeing, success in school achievement and in life practice, and cognitive, social, and psychological development (Cappuccio, 2019). Indeed, in the popular identification the fluid intelligence is the ability to reason, to solve problem, and to see patterns or relations among people, objects, space, time-tempo and formulas (Ferrer et al., 2010). It includes inductive/deductive logical reasoning and the capacity to figure out the relations between things and apply analogies following robust analysis between the 'actors'.

1.1 Practice improves executive functions

EFs are not a monolithic brain condition but can be ameliorated (Diamond & Lee, 2011; Klingberg, 2010). In fact, there is strong evidence for activities improving children's EFs especially for computer-based task-switching (Bergman Nutley et al., 2011), interactive games (Mackey et al., 2011) and sport practice (Lakes & Hoyt, 2004). Moreover, a plethora of studies (reference review) found important transfer to one or more objective measures of EFs on which the children had not been trained before.
Some authors found benefits for children's EFs from aerobics (Davis et al., 2011; Kamijo et al., 2011), traditional martial arts (Lakes & Hoyt, 2004) and soccer training (Lovecchio et al., 2021) whereas the repeated practice is the key-factor for EFs development and the exposition to bilingual input preserve EFs longer during aging (Bialystok & Viswanathan, 2009).
Particularly, the EFs gain relies on the amount of time spent intensely working on those skills and on the most EFs demanding task (Davis et al., 2011; Diamond, 2013).
Also, in adults/elderly, refine on EFs were found by improving physical fitness (Erickson & Kramer, 2009; Voss et al., 2011), increasing computerized training or exposing to bilingual input (Kovács & Mehler, 2009; Wass et al., 2011).
In general, the authors convey that the chief benefit regards the speed of processing during decision making, in fact, the EFs outcomes can be described as the skill to make a decision to act or to stay according to adequate relationship with the environment.
In conclusion, EFs are critical for many of the skills that people would develop for a successful world-interaction: creativity, flexibility, self-control, discipline and high academic achievements could make the 'difference' in actual society. Open mind approach to play with ideas, quick and flexible adaption in changing circumstances, save time to planning, resist to temptations, stay focused, and meet novel and prediction of unanticipated challenges are essential skills in everyday life.
In light of these, the insights of improve the function that support this people behavior is crucial and innovative.

2. Sport classification and cognitive demanding

Within a wide world as the sport practice, is important to define the trials, activity and challenge in a robust way. In particular, the modern definition based on a neuroscientific approach will

be proposed in the following rows to emphasize the cognitive demanding that occur during different practices.
Sports can be classified according to how much they are affected by the environment such as the action and the decision making could be modified (Schmidt & Lee, 2005).
The variation of stimulus during a competition are the key factors that determine the success. Examples of environmental stimuli are:

- terrain/surface: a cross-country runner running on muddy and dry ground
- weather: a golfer playing on a windy day
- situation: the venue and crowd

These examples are explanatory: ipso-facto underlying that the players need to have a good perception of the stimuli to adapt their skills to better suit the environment.
In point of this, two principal characteristics of the environmental continuum are 'closed' and 'open' identifying a situation where the environment is static or changing.
More precisely, closed skills (CS) are not affected by the environment, usually self-paced and occur in fixed or predictable situations. The CS performers use, exactly, the same technique every time and are in control of what is happening next. An example could be a gymnast performing a floor routine (Singer, 2000).
Open skills (OS) are affected by the environment, mainly perceptual and usually externally paced. They occur when performers must make decisions and adapt their skills to a changing or unpredictable environment. The performers are not in control of what will happen next (Schmidt & Lee, 2005). An example could be making a pass in a rugby match.
Between CS and OS sport there is other kind of sports defined mixed skills (MS) where the situation is changeable in point of the opponent's action but within a context closed by the internal laws or the space. An example would be the tennis or volley sport.
In the real practice, most skills are not totally closed or open but range between the two somewhere on the environmental continuum between open and closed. In turn, environmental conditions or movement offers could impact the cognitive skills of practitioners.

3 Approach to the problem

As before defined, different sport conditions (environment: OS, CS, MS) lead the skills with both external or self-paced nature and different cognitive demands. Indeed, athletes need to respond and adapt to a static/dynamic and changing/predictable/fixed environment.
For example, Furley and Memmert (Furley & Memmert, 2013) showed that skilled basketball players can face a competing stimulus and focus on the task better than novices and are able to make better tactical decisions. CS sports, instead, are performed in primarily constant conditions, known (predictable) or irrelevant for the course (modification) of movement. Thus, the athletes do not have to adapt to changing environmental conditions as often as in OS sports situations. In other words, for CS, the decision making is null.
For these reasons CS, OS or MS have different demands on cognitive skills. In particular, the goal-directed behavior, reasoning, problem-solving, and planning, are the most influenceable outcomes.
From this state of art, a broad skill transfer hypothesis become actual. This supposition approach assumes that the cognitive skills achieved practicing a particular sport will also be transferred to other cognitive tasks (i.e. academic achievement; Pascual et al., 2019).
Indeed, multiple studies suggest that a long-term participation in physical activity/sport seem to improve "higher-level" cognitive functions (Diamond, 2013). Within this fascinating phenomenon, Diamond & Ling (Diamond & Ling, 2016) emphasized that exercise with low

cognitive demand, such aerobic exercise, yields performance or no improvement in cognitive abilities. Conversely, cognitively demanding physical activity showed stronger effects on EFs. Then, if different type of sports imposed different kind of cognitive demands, different improvements on EFs are consequent (Jacobson & Matthaeus, 2014). Again, if different EFs are improved, different advantage in academic achievements become effective.
This report following recent scientific findings (narrative review) tried to define robust and wide accepted relations between sport practice, improvement in EF and, in turn, better academic achievement.

4. Results

In general, the agreement within scientific community and not contradictory outcomes between the different analysed studies have shown that the greater the time spent in sports activities with a greater cognitive load corresponds to a large benefit to the primary nucleus of EF, especially if there is a sporting background from childhood (Gu et al., 2019). Indeed, top-level players have showed superior cognitive functioning in certain areas (Jacobson & Matthaeus, 2014; Mann et al., 2007): soccer players in the first-tier league have demonstrated better EFs than second-tier league players (Huijgen et al., 2015), with the same holding true for top ultramarathon runners relative to lower-ranked runners (Cona et al., 2015). A lot of investigations reported positive relationship between EFs and sports performance in football (Huijgen et al., 2015; Lovecchio et al., 2021; Verburgh et al., 2014; Vestberg et al., 2012), volleyball (Alves et al., 2013), ice hockey (Lundgren et al., 2016), marathon running (Cona et al., 2015), gymnastics (Schmidt et al., 2015), fencing (Chan et al., 2011), table tennis (Wang, Chang, Liang, Shih, Muggleton, et al., 2013) and tennis (Wang, Chang, Liang, Shih, Chiu, et al., 2013). In particular, the OS sport seem to improve more the aspects of the EF than the CS sport and are associated with outcomes of superior cognitive flexibility because they require to reach a decision in a short time during rapid and unexpected environmental changes (Becker et al., 2018).
Indeed, general cognitive functions are important components of team sports, where perceptual–cognitive demands are high and in turn 'stressed' the action of the pre-frontal and parietal lobes (Nougier et al., 1991).
Specifically, athletes involved in OS sport demonstrated better inhibitory control (Wang, Chang, Liang, Shih, Chiu, et al., 2013; Wang, Chang, Liang, Shih, Muggleton, et al., 2013) and cognitive flexibility (Yu et al., 2017) than athletes in CS sport and non-athletes; while no differences emerged in working memory (Holfelder et al., 2020), processing speed (Yu et al., 2017), or spatial ability (Jansen & Lehmann, 2013). In a study comparing self-paced athletes (e.g., swimmers) with externally paced athletes (e.g., soccer players), self-paced athletes exhibited higher inhibitory control abilities but had lower scores in problem solving than externally paced athletes (Jacobson & Matthaeus, 2014). Strong correlations are found within associations between involvement in OS sport and EF scores relative to involvement in CS sport. Moreover, the greater an athlete's past participation in CS sports, the more errors they tended to score in cognitive inhibitory. Also, confirmed by other author: there was a positive correlation between involvement in CS sport and the conducted error simple reaction test while a greater involvement in OS sport was associated within complex reaction test with fewer errors. In the sports classified as interceptive, strategic, or based on teamwork (Mann et al., 2007), athletes tend to be faster information processors than the others (Voss et al., 2011). Considering the aim of the current study, that is to clarify the differences in EF between athletes

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of OS and CS sports and to contribute to the understanding of how specific involvement in sports affect, the EFs measures (inhibition, working memory and cognitive flexibility) of athletes in OS sports showed significantly higher performance in working memory and cognitive flexibility (Krenn et al., 2017; Yu et al., 2017). In inhibition, not significant differences between athletes in OS and CS sports were found. Overall, these findings suggest that elite athletes in OS sports display more beneficial EFs in comparison to elite athletes in CS sports. Indeed, in this kind of sport the predetermined movement patterns take place in a predictable and stable environment reducing the environment analysis and then the stimuli to pre-frontal cortex (Burgess & Simons, 2012).
MS experience would seem to improve EF less than OS's but more than CS's. This appears as an intuitive finding since a MS (Gentile, 2000) as tennis implies pre-determined action (the unique and immediate shot of the opponent) and un-predictable outcome (speed and direction of the ball).

In figure 1, a qualitative representation of the major relationships is presented.

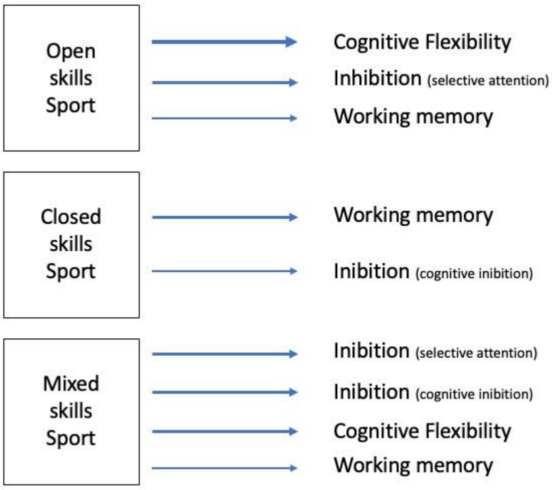

Fig.1 Improvements in EF according to type of sport

According to the second purpose of this narrative report, the literature provides multiple cases of the importance of EFs in achieving academic success (Willoughby et al., 2019): i.e. low reading ability demonstrated some deficiencies in these cognitive efficiencies (Engel et al., 2014). For example, a recognized problem of language is associated with a poorer working memory and, in turn, affects normal language development (Im-Bolter et al., 2006). Furthermore, distraction (as the contrary of attention) can influence the ability to focus on and adequately capture an external stimulus (Gray et al., 2015). Thus, the neuroscience community affirms that the verbal component and reasoning are the foundation for higher academic performance and are, in turn, related to the development of EFs.
In particular, Welsh et al., (2010) presented strong evidence demonstrating predictive reciprocity between mathematics and the EFs of working memory and attention.
The inhibition explains the lack of attention and highlights the visuo-spatial component of the memory function for performance in mathematics (Aarnoudse-Moens et al., 2013; Gray et al.,

2015; Mulder et al., 2017) while (Gerst et al., 2017) suggest that cognitive flexibility and planning are good predictors for this area.
Engel et al., (2014) found that working memory and cognitive flexibility establish good relationships with reading while Koch & Krenn, (2021) did not find significant improvement in documented literacy.
The study of English reveals an increase in written production but not in reading, although improvements in working memory may be positive for relieving specific language problems.
Conversely, EF more clearly improves mathematics and geometry performance.
The figure 2 propose a resume about these findings.

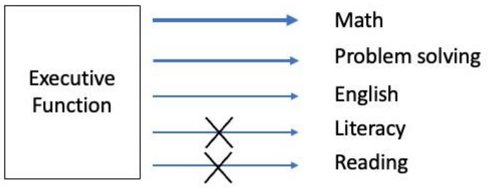

Fig.2 Relationship between EF and academic performance

Conclusions

World-class athletes showed three key characteristics: physical fitness, motor skills and psychological advantages. With respect to physical fitness (including muscle strength, cardiovascular endurance, agility, and power), athletes must consistently perform highly complex or difficult tasks to acquire sport success. Athletes must also maintain optimal mental state to ensure the best possible performance. From this sport advantage the constant practice leads to high cognitive performances even if, in different ways and magnitude, the EFs had new spurts (Ballester et al., 2019; Wang, Chang, Liang, Shih, Chiu, et al., 2013): a special and no-cost gains.
Thus, high cognitive functions remain a resource for long life skills: in school, social or job context.
Further investigations and comparisons are necessary to solve differences in the measured aspects and the choice of the assessment test for EFs. Indeed, certain responses to a stimulus, in order to make a more appropriate response, depend on the tests construct.

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