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"Effects of fitlight training on cognitive-motor processes in open skill sports"

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Abstract

Background: Executive functions (EFs) are a family of cognitive processes that include inhibition, working memory and cognitive flexibility and are crucial for many daily activities, from childhood to later stages of life. Physical activity and sports practice have been identified by researchers as activities that could improve EFs.

The relation between EFs and motor training still raises many unanswered research questions. Future studies should investigate which EFs are improved by a particular cognitive-motor training (CMT) to better understand the potential effects of higher EFs on various sports, possibly with a motor task to better stimulate EFs activation, as well as the duration of these improvements.

Aims: This thesis aimed to verify whether a cognitive-motor massed training using Fitlight^{TM} induces improvements in EFs and physical fitness in young athletes practicing open-skill sports (specifically basketball and judo) compared to a non-intervention group. This thesis is composed of two different studies.

The aims of study 1 were: 1) to verify whether the Fitlight^{TM} training system, used to cognitively enrich a massed basketball training program, could improve young athletes' EFs (specifically, response inhibition, working memory, and cognitive flexibility) and motor performance (specifically, agility and aerobic capacity); 2) to verify if CMT induced changes on the rate of perceived effort and enjoyment of training in the experimental group compared to a non-intervention group.

The aims of study 2 were: 1) to determine whether a 5-week CMT program using Fitlight^{TM} improved EFs in young adults élite judo athletes when compared to a non-intervention group; 2) to verify whether CMT had an impact on BDNF and IgA levels in the experimental group when compared to the non-intervention group; 3) to verify whether the CMT changed physical fitness in the experimental group; 4) to verify if CMT induced changes on the enjoyment of training in the experimental group compared to a non-intervention group; 5) to verify if CMT induced greater fatigue in the experimental group compared to the non-intervention group; 6) to verify if the

CMT induced changes in psychobiosocial states in the experimental group; 7) to determine whether CMT results were related to athletes’ performance in competition.

Methods: In the first study, 49 male basketball players (age = 15.0 ± 1.5 yrs) were assigned to the control and Fitlight-trained (FITL) groups, which performed 3 weeks of massed basketball practice, including 25 min per day of shooting sessions or Fitlight training, respectively. Anthropometric parameters, fitness tests and cognitive tasks were assessed.

In the second study, 27 élite judo athletes (14 males and 13 females; age = 19.5 ± 2.0 years) were assigned to the Fitlight (FG) and control (CG) groups which performed 5 weeks of CMT, including 25 min per day of Fitlight training or traditional judo training, respectively. Anthropometric parameters, fitness tests and cognitive tasks were assessed. In addition, BDNF was collected by saliva sampling and competitive results after the intervention period were considered.

Results: Study 1: RM-ANOVA showed significant EFs scores increased in both groups over time, without differences between the groups. Moreover, an increased sRPE and eRPE appeared in the FITL group ($p = 0.0001$; $p = 0.01$), with no group differences in activity enjoyment and fitness tests.

Study 2: RM-ANOVA showed significant differences in FG for the accuracy of flanker ($p=0.028$) and backward digit span ($p<0.001$). Moreover, significant differences in FG were found for relative dynamic chin up ($p=0.027$) and counter movement jump ($p=0.05$). In addition, a significant difference in FG was found for competitive results after the intervention period ($p<0.01$). No significant differences were found for BDNF and other cognitive and fitness measures ($p>0.05$).

Conclusions: The first study reported that three weeks of massed basketball training improved EFs and motor performance in young players. The additional Fitlight training increased the perceived cognitive effort without decreasing enjoyment, even if it seems unable to induce additional improvements in EFs.

The second study is the first that investigated cognitive-motor training using Fitlight™ in judo. Results showed that a 5-week judo-specific CMT improved EFs and motor performance in élite judo athletes. The additional Fitlight training increased the enjoyment without decreasing perceived effort. Finally, regarding competitive results obtained by FG athletes after the end of the intervention, it was observed a significant difference in terms of won matches. Therefore, it seems that CMT with Fitlight™ could be considered an additional support to coaches during the training period.

Riassunto

Stato dell'arte: Le funzioni esecutive (FE) sono una famiglia di processi cognitivi che comprendono l'inibizione, la memoria di lavoro e la flessibilità cognitiva e sono fondamentali per molte attività quotidiane, dall'infanzia alle fasi successive della vita. L'attività fisica e la pratica sportiva sono state identificate dai ricercatori come attività che potrebbero migliorare le FE. La relazione tra le FE e l'allenamento motorio solleva ancora molte domande di ricerca senza risposta. Gli studi futuri dovrebbero indagare quali FE vengano migliorate da un particolare allenamento cognitivo-motorio (CMT) per comprendere meglio i potenziali effetti di elevati livelli di FE su vari sport e quale compito motorio sia in grado di favorire al meglio l'attivazione delle FE, nonché la durata di questi miglioramenti.

Obiettivi: Questa tesi ha lo scopo di verificare se un allenamento cognitivo-motorio di massa utilizzando Fitlight™ induca miglioramenti nelle FE e nella forma fisica nei giovani atleti che praticano sport di situazione (in particolare basket e judo) rispetto a un gruppo di non-intervento. Questa tesi è composta da due diversi studi. Gli obiettivi dello studio 1 erano: 1) verificare se il sistema di allenamento Fitlight™, utilizzato per arricchire cognitivamente un programma di allenamento di massa di basket, potesse migliorare le FE di giovani atleti (nello specifico, inibizione della risposta, memoria di lavoro e flessibilità cognitiva) e le prestazioni motorie (nello specifico, agilità e capacità aerobica); 2) verificare se il CMT inducesse cambiamenti nel gradimento dell'allenamento nel gruppo sperimentale rispetto a un gruppo di non-intervento.

Lo studio 2 mirava a: 1) determinare se un programma CMT di 5 settimane utilizzando Fitlight™ migliorasse le FE in giovani adulti atleti di judo d'élite rispetto a un gruppo di non intervento; 2) se il CMT avesse un impatto sui livelli di BDNF e IgA nel gruppo sperimentale rispetto al gruppo di non intervento; 3) se il CMT cambiasse i livelli di forma fisica nel gruppo sperimentale; 4) verificare se il CMT inducesse cambiamenti nel gradimento dell'allenamento nel gruppo sperimentale rispetto a un gruppo di controllo; 5) verificare se il CMT inducesse una maggiore fatica nel gruppo sperimentale rispetto al gruppo di non intervento; 6) verificare se il CMT inducesse cambiamenti negli stati psicobiosociali nel gruppo sperimentale; 7) determinare se i risultati del CMT fossero correlati alle prestazioni degli atleti in competizione.

Metodi: Nel primo studio, 49 giocatori maschi di basket (età = 15,0 ± 1,5 anni) sono stati assegnati ad un gruppo di controllo e a un gruppo Fitlight e hanno eseguito 3 settimane di allenamento di massa di basket, costituito, rispettivamente, da 25 minuti al giorno di sessioni di tiro o di allenamento Fitlight. Sono stati valutati parametri antropometrici, test di forma fisica e compiti cognitivi.

Nel secondo studio, 27 atleti di judo di élite (14 maschi e 13 femmine; età = 19,5 ± 2,0 anni) sono stati assegnati ai gruppi Fitlight (FG) e controllo (CG) e hanno eseguito 5 settimane di CMT, costituito, rispettivamente, da 25 minuti al giorno di allenamento Fitlight o di allenamento tradizionale di judo. Sono stati valutati parametri antropometrici, test di forma fisica e compiti cognitivi. Inoltre, il BDNF è stato raccolto mediante campionamento della saliva e sono stati considerati i risultati competitivi dopo il periodo di intervento.

Risultati: Studio 1: RM-ANOVA ha mostrato un aumento significativo dei punteggi sulle FE in entrambi i gruppi nel tempo, senza differenze tra i gruppi. Inoltre, nel gruppo FITL è emerso un aumento di sRPE ed eRPE (p = 0,0001; p = 0,01), senza differenze di gruppo nel gradimento dell'attività e nei test di forma fisica.

Studio 2: RM-ANOVA ha mostrato differenze significative nel FG nell'accuratezza del flanker (p=0,028) e nel backward digit span (p<0,001). Inoltre, sono state riscontrate differenze significative nel FG per il dynamic chin up relativo (p=0,027) e nel counter movement jump (p=0,05). Inoltre, è stata riscontrata una differenza significativa nel FG per i risultati competitivi dopo il periodo di intervento (p<0,01). Non sono state riscontrate differenze significative per il BDNF e per le altre misure cognitive e di forma fisica (p>0,05).

Conclusioni: Il primo studio ha riportato che tre settimane di allenamento di massa di basket hanno migliorato le FE e le prestazioni motorie nei giovani giocatori. L'allenamento aggiuntivo con Fitlight ha aumentato lo sforzo cognitivo percepito senza diminuire il gradimento, anche se non sembra in grado di indurre ulteriori

miglioramenti nelle FE. Il secondo studio è il primo ad indagare l'allenamento cognitivo-motorio utilizzando Fitlight™ nel judo. I risultati hanno mostrato che un CMT specifico per il judo di 5 settimane ha migliorato le FE e le prestazioni motorie negli atleti di judo d'élite. L'allenamento aggiuntivo con Fitlight ha aumentato il gradimento senza diminuire lo sforzo percepito. Infine, riguardo i risultati ottenuti nelle competizioni, è stata riportata una differenza significativa in termini di vittorie. Pertanto, sembra che il CMT con Fitlight™ possa essere considerato un ulteriore supporto agli allenatori durante il periodo di allenamento.

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Chapter 1. Executive functions

1.1 Executive functions, definitions and classifications

According to Burgess & Simons (2005), Espy (2004), Miller & Cohen (2001), executive functions (EFs; also known as executive control or cognitive control) are a family of top-down mental processes required for concentration and attention when going on automatic or relying on instinct or intuition would be inappropriate, insufficient, or impossible. It's hard to use EFs because it is simpler to carry on doing what you have been doing than to change and to fall into temptation rather than to reject it. Inhibition [inhibitory control, including self-control (behavioral inhibition) and interference control (selective attention and cognitive inhibition)], working memory (WM), and cognitive flexibility (also known as set-shifting, mental flexibility, or mental set shifting and closely linked to creativity) are generally acknowledged as the three core EFs (Lehto et al., 2003; Miyake et al., 2000). These form the foundation for higher-order EFs including planning, reasoning, and problem-solving (Collins & Koechlin, 2012; Lunt et al., 2012).

1.1.1 Inhibitory control

Being able to control one's attention, behavior, thoughts, and/or emotions allows one to ignore a strong internal tendency or external enticement and choose to do what is more suitable or necessary. This ability is known as inhibitory control and is one of the key EFs. Without inhibitory control, we would be at the impulses, ingrained behaviors (conditioned reactions), and/or external cues that nudge us in one direction or another. Thus, inhibitory control enables us to alter and choose our responses and behaviors rather than being routine people. We can selectively attend by restricting attention to other stimuli and concentrate on what we choose thanks to inhibitory control of attention (also known as interference control at the level of perception). For example, when we want to exclude everything but one voice, we require focused attention. Whether we choose to or not, salient stimuli like a loud noise draw our attention.

It is driven by the characteristics of the stimuli themselves and is referred to as exogenous, bottom-up, automatic, stimulus-driven, or involuntary attention (Posner & DiGirolamo, 1998; Theeuwes, 1991). Depending on our aim or goal, we can also consciously decide to ignore (or suppress attention to) some stimuli while attending to others. This has also been referred to as selective or focused attention, attentional control or inhibition, endogenous, top-down, active, goal-driven, voluntary, or executive attention (Posner & DiGirolamo, 1998; Theeuwes, 2010). Suppressing prepotent mental images is another part of interference control (also known as cognitive inhibition). This entails putting up a fight against unnecessary or undesired ideas or memories, such as willful forgetting (Anderson & Levy, 2009), proactive interference from previously acquired information (Postle et al., 2004), and retroactive interference from later-presented material. Cognitive inhibition is typically used to support WM. Self-control is the component of inhibitory control that entails maintaining emotional and behavioral control to maintain behavioral control. The goal of self-control is to avoid impulsive behavior and to resist temptation. Having the self-control to complete a task despite temptations to give up, go on to more interesting tasks, or simply have a nice time instead is another component of self-control. This entails forcing yourself to act or continue even though you'd rather be doing anything else. Delaying an immediate pleasure for a bigger reward later is related to the last feature of self-control (delaying gratification) (Mischel et al., 1989; Louie & Glimcher, 2010; Rachlin et al., 1991). No one would ever accomplish a protracted, time-consuming endeavor like writing a thesis, competing in a marathon, or starting a new business without the discipline to finish what they started and postpone gratification. Such impulsive or early reaction appears to be prevented by the subthalamic nucleus (Frank, 2006).

Typical psychological test to evaluate inhibitory control

The Stroop task (MacLeod, 1991), the Simon task (Hommel, 2011), the Flanker task (Eriksen & Eriksen, 1974), the delay of gratification task (Kochanska et al., 2001), the go/no go task (Cragg & Nation, 2008), and the stop-signal task (Verbruggen & Logan, 2008) are examples of psychological tests of inhibitory control. On the Stroop task, incongruent trials feature color words (such as “green”) written in a different ink hue (“red”). People are slower and make more mistakes when forced to pay attention to and report the color of the ink rather than the meaning of the word (to inhibit prepotent response to words). In the Flanker task, you must pay attention to the central stimulus while ignoring the flanking stimuli. According to Eriksen and Eriksen (1974), people react more slowly when the flanking stimuli are mapped to the opposite reaction from the central stimulus (incompatible trials). The go/no-go and stop-signal tasks, two commonly used measures of response inhibition, differ from other measures in that participants do not inhibit one reaction to produce another; instead, they simply inhibit a response to do nothing. Go/no-go tasks request to typically hit a button when a stimulus appears, but should not press when a certain stimulus appears. In the stop-signal task, the go signal is presented on every trial; on a small number of trials, a stop signal (often a sound) emerges after the go signal and just as the subject is about to reply, instructing them not to click the button on that trial. When a circumstance, or an assessment of it, abruptly changes, like when you are about to cross the street and the light abruptly changes, that is a real-world example of when to check a decision that was about to be made.

Development of inhibitory control

Inhibitory control is very difficult for young children and it continues to develop during adolescence (Luna, 2009; Luna et al., 2004). Early-life inhibitory control seems to be a good indicator of outcomes throughout life, especially in maturity. According to Moffitt et al. (2011), children who demonstrated better inhibitory control between the ages of 3 and 11 were more likely to remain in school as teenagers and were less likely to make risky decisions, smoke, or use drugs. They were also better at waiting their turn, were less easily distracted, and were more persistent. Controlling for IQ, gender, social class, and their upbringing and family circumstances, they grew up to have better physical and mental health (were less likely to be overweight or to have high blood pressure or substance abuse problems), earn more, and be more law-abiding as adults 30 years later. As adults, they were also happier (Moffitt, 2012). However, as people age normally, inhibition control significantly decreases (Hasher & Zacks, 1988; Hasher et al., 1991). Indeed, older adults are unable to inhibit visual (Darowski et al. 2008, Gazzaley et al. 2005) and auditory (Alain&Woods 1999, Barr & Giambra 1990) distractions. According to Gazzaley et al. (2005), older persons exhibit normal improvement of the stimuli that need to be attended but less or even no suppression of the stimuli that need to be ignored. This provides very strong evidence of an inhibitory control impairment in aging. According to Zanto et al. (2010), older adults suppress irrelevant information far worse than younger adults do.

1.1.2 Working memory

Working memory (WM) is a key EF that entails retaining knowledge in the mind and manipulating it mentally (dealing with material that is no longer perceptually present; Baddeley & Hitch, 1994; Smith & Jonides, 1999). The difference between verbal and nonverbal (visual-spatial) WM is their content. Making sense of everything that develops through time necessitates the use of WM because doing so always demands remembering the past and linking it to the future. Any mental operation math requires WM, as does mentally arranging things (like rearranging a to-do list), converting instructions into plans of action, updating plans of action with new information, considering alternatives, and mentally correlating data to derive a general principle or seeing relationships between things or ideas. Without WM, reasoning would not be possible. Given that creativity entails taking things apart and reassembling them in novel ways, WM is essential for the capacity to detect connections between what appear to be unconnected items and to separate individual components from an integrated whole.

Short-term memory vs working memory

Short-term memory (simply holding information in mind) differs from working memory (WM), which allows for information manipulation. They connect to several brain subsystems. While keeping information in mind but not changing it does not require the involvement of the dorsolateral prefrontal cortex, working memory (WM) relies more on this region (D’Esposito et al., 1999; Eldreth et al., 2006; Smith & Jonides, 1999). The development of short-term memory is earlier and faster than that of working memory (WM).

Working memory and inhibitory control relationships

They frequently co-occur and are mutually necessary. The cases when to behave against initial tendency based on knowledge stored in mind is one example of when EFs are needed. Infrequently, if ever, is one of WM or inhibitory control required without the other.

Inhibitory control is supported by working memory

You must keep purpose in mind to know what is pertinent or suitable and what to inhibit. By paying close attention to the information you are keeping in mind, it is more likely that it will direct your behavior and less likely that you will make an inhibitory error (emitting the default or normally prepotent response when you should have been inhibiting it).

Working memory is supported by inhibitory control

You must be able to avoid focusing just on one thing in order to combine many ideas or actions, and you must be able to resist repeating old thought patterns in order to combine ideas and actions in novel and creative ways. It is necessary to avoid internal and external distractions if you want to maintain your mind on the task to be performed. Inhibitory control can help WM by preventing the mind from becoming overly cluttered by suppressing unimportant thoughts (deleting irrelevant information from WM), resisting proactive interference by deleting no longer relevant information from that limited-capacity workspace (Hasher & Zacks, 1988; Zacks & Hasher, 2006).

Working memory and focused, deliberate attention

It is possible to refer to keeping attention focused on mental contents for several seconds as retaining information in mind for several seconds. There are numerous similarities between WM and selective, focused attention, including their neurological bases. Awh et al., 2000; Awh & Jonides, 2001; Gazzaley & Nobre, 2012; Ikkai & Curtis, 2011; LaBar et al., 1999; Nobre & Stokes, 2011 are examples of studies that show how the prefrontal parietal system, which supports working memory and allows selective tuning out irrelevant thoughts while remaining focused on information held in mind, overlaps significantly with this system. According to Stedron et al. (2005), developmental advancements in WM can assist advancements in selective attention. People are quicker to notice and respond to stimuli in an area they are trying to hold in their working memory (WM), and their memory accuracy decreases if they are pushed to focus their attention away from that area (Awh & Jonides 2001; Kuo et al., 2012; Wais et al., 2010).

Typical psychological test to evaluate working memory

Forward-digit span tests (repeat items in the order you heard them) are a measure of short-term memory rather than working memory because they just require holding information in mind. Backward-digit span (saying the items backward in reverse order) approaches becoming a WM task. Requesting that subjects reorganize the items they have heard is a great WM test. It could be repeating the numbers they just heard (6, 9, 4, 7) in numerical order (4, 6, 7, 9), or it could be repeating objects back reordered by size. The Automated Working Memory Assessment (AWMA) battery includes a computerized version of this and a backward digit span (Alloway, 2007; Alloway et al., 2009).

Development of working memory

The ability to remember information develops extremely early; newborns and young children can remember one or two things for a long time (Diamond, 1995). However, the ability to hold more things in mind or perform any type of mental manipulation (reordering mental representations of objects by size) takes much longer to develop and has a much longer developmental progression (Cowan et al., 2002, 2011; Crone et al., 2006; Davidson et al., 2006; Luciana et al., 2005). WM declines with age (Fiore et al., 2012; Fournet et al., 2012). Much of this appears to be related to deteriorating inhibitory control, which makes older persons more prone to proactive and retroactive interference, as well as distraction (Rutman et al., 2010; Zanto & Gazzaley, 2009). Improved capacity to suppress interferences appears to be crucial to age-related increases in WM in children (Hale et al., 1997), whereas reduced ability to inhibit interferences may be responsible for WM loss in older adults. The decline in working memory with aging (Rozas et al., 2008; Salthouse, 1992; Zimprich & Kurtz, 2013) and the improvement in working memory during development (Case et al., 1982; Fry & Hale, 2000) are also highly correlated.

1.1.3 Cognitive flexibility

Cognitive flexibility (the third basic EF) develops more later than the other two (Davidson et al., 2006; Garon et al., 2008). Being able to alter viewpoints spatially ("What would this look like if I viewed it from a different direction?") or interpersonally ("Let me see if I can see this from your point of view") is one component of cognitive flexibility. To switch viewpoints, we must inhibit (or deactivate) our prior perspective and load (or activate) a new perspective into WM. Cognitive flexibility, in this sense, necessitates and is built on inhibitory control and WM. Another aspect of cognitive flexibility is the ability to change the way of thinking about something. Cognitive flexibility also entails being adaptable enough to shift demands or priorities, admit mistakes, and take advantage of unforeseen possibilities.

Cognitive flexibility and creativity, task switching, and set-shifting all have a lot in common. The polar opposite of rigidity is cognitive flexibility.

Typical psychological test to evaluate cognitive flexibility

Design fluency, verbal fluency and category (or semantic) fluency are some of the tasks that use cognitive flexibility. A variety of task-switching and set-shifting tasks are frequently used to study cognitive flexibility. The Wisconsin Card Sorting Task (Stuss et al., 2000), one of the standard evaluations of prefrontal brain performance, is one of the best known of these. In this test, each card can be sorted according to its color, shape, or number. The participant's task is to use feedback to determine the proper sorting criterion and to quickly switch sorting rules if the experimenter indicates that the sorting criterion has changed. Two tasks are involved in most task-switching. These tasks could include identifying whether a stimulus is a vowel or a consonant, an even or an odd number, on the left or right, in the upper or lower quadrant, or one color or another, or a certain shape (Allport & Wylie, 2000). The majority of task-switching tasks require to push the right or left keys, with each key being assigned to a different aspect of work (left might be for a consonant or an even number and right might be for a vowel or an odd number). The majority of task-switching tasks use bivalent stimuli, meaning that the right response for one task is incorrect for the other. The most straightforward task-switching test has been created by Zelazo et al. (1996, 2003). The Dimensional Change Card Sort Test (DCCS) uses bivalent stimuli where the right reaction for one task is the wrong response for another. However, only one switch happens during the whole test. The cards should first be sorted according to one dimension (color or form), and then the other dimension. Three-year-olds are perfectly capable of sorting by either color or form, but they are unable to switch even if they are aware that the other dimension is now important and that they are familiar with the procedures for doing so. Errors appear to be the result of difficulty controlling or overcoming "attentional inertia" or the propensity to keep paying attention to something that was once important (Kirkham et al., 2003; Kloo & Perner, 2005).

The children become stopped in the earlier perspective on the stimulus. This inertial tendency is always present. This is reflected in young adults' greater reaction times when asked to transition to and react in accordance with a different dimension (Diamond & Kirkham, 2005; Monsell & Driver, 2000). Therefore, adults respond less quickly during trials in which the relevant dimension switches than during trials in which it does not (Allport & Wylie, 2000; Meiran, 1996; Rogers & Monsell, 1995). Numerous other tasks use similar inertial tendencies, such as ambiguous figures, where a drawing may be interpreted in different ways, depending on how you look at it. Three-year-olds are incapable of changing their initial point of view or sorting dimensions, even after being informed of the choices in an ambiguous figure (Gopnik & Rosati, 2001). Most kids can see both figures in an ambiguous figure by the time they are 4 1/2 to 5 years old, and they can also change the sorting dimensions on the DCCS assignment (Diamond, 2002). However, children can't switch flexibly on a trial-by-trial until they are 7 to 9 years old (Davidson et al., 2006; Gupta et al., 2009). Adults can complete a block of one task and a block of the other easily. Adults can get into the habit of performing something over a block of trials, even if one of the tasks asks to go against prepotent propensity. Adults have no difficulty in answering over a block of trials on the side that a stimulus occurs on (Davidson et al., 2006; Lu & Proctor, 1995). Even if it is counterintuitive or goes against their initial inclination, it is not that demanding for adults to continue doing what they have been doing; over time, it requires little top-down management. Switching back and forth between mental sets is much more challenging. It is simpler to consistently block a dominating response than it is to do so sometimes. One of the hardest EFs to master is cognitive flexibility, which involves fighting inertial impulses to switch between different mental sets or methods of processing information.

Development of cognitive flexibility

A very simple switch consists in maintaining focus on the same dimension (the same stimulation perspective) while flipping the stimuli-response maps. This is referred to as an intradimensional shift, commutation across dimensions, or inversion (Roberts et al., 1988). For instance, it might push left for the circle and right for the triangle in Task 1, but it would press right for the circle and left for the triangle in Task 2. Kids who are 2 and a half years old can do these tasks successfully (Brooks et al., 2003; Perner & Lang, 2002). The ability to change how you respond (as in inversion tasks) develops before the ability to alter how you think about stimuli or alter which aspect of stimuli you pay attention to. Task switching improves during a child's development and declines with age (Cepeda et al., 2001; Kray, 2006). The gap between older individuals' speed on mixed blocks versus single task blocks is significantly bigger than that of younger adults because older adults slow down on a mixed block. When given mixed blocks versus single-task blocks, children have substantially greater variances in their speed (like older adults) and accuracy (unlike older adults) than do young adults (Cepeda et al., 2001; Cohen et al., 2001). Children and older adults tend to use executive functions (EF) in response to environmental demands (in a reactive manner), while older children and younger adults tend to be more planners and anticipators (in a proactive manner) Czernochowski et al., 2010; Karayanidis et al., 2011; Munakata et al., 2012).

1.1.4 Higher-order executive functions

According to Ferrer et al. (2009), fluid intelligence is the capacity to reason, solve problems, and recognize relationships or patterns among objects. It makes use of both inductive and deductive logic. It entails being able to deduce the underlying abstract relations of analogies. It is the same as the EFs' subcomponents of reasoning and problem-solving. According to Conway et al. (2003), Duncan et al. (2008), Kane & Engle (2002), and Roca et al. (2010), assessments of fluid intelligence and independent measures of EFs have a strong correlation.

1.2 Beneficial effects of executive functions on health

EFs are necessary for mental and physical well-being, academic and personal achievement, as well as cognitive, social, and psychological growth.

1.2.1 Executive functions and behavior related to health

Any behavior that includes overcoming prepotent reactions and is goal-directed involves EFs. So, examples of health-related behaviors that depend on EFs for successful execution include losing weight, quitting using drugs or alcohol, exercising, and adhering to prescribed medical procedures. Indeed, models of health behavior contain cognitive factors that can be considered EFs. To change a habitual behavior, for instance, a behavioral intention must be sustained over time until the behavior is changed, a skill that requires intact EFs. Behavioral intentions also play a significant role in models of health behavior. Recent studies do, in fact, point to the possibility that individual differences in EFs may modify the relationship between behavioral intention and behavioral performance, such as in the case of food and exercise behavior (Hall, 2008). In their analysis of the literature on EFs and substance abuse, Blume and Marlatt (Blume, 2009) outline a mutually reinforcing relationship: Executive functioning deficits make people more prone to poor self-regulation, which includes having trouble controlling substance use. Excessive substance use can promote EFs deficits. Furthermore, it appears that a low level of EFs hinders effective substance abuse intervention. As the authors point out, choosing the best therapeutic options may need to consider the degree of EF impairment. Furthermore, descriptions of people who are unsuccessful in changing their substance use patterns may be a sign of EFs deficiencies. Although Blume and Marlatt's (Blume, 2009) focus is mainly on substance use, various health behaviors and health behavior modification have been discovered to share similarities with EFs. For instance, older people with lower EFs appear to have more trouble quitting smoking (Brega, 2008) and EFs related to motor control (judgment in motor planning) may help predict elderly fall injury (Liu-Ambrose, 2008).

1.2.2 Heart rate variability and executive functions

Heart rate variability (HRV), which measures vagal function, has been demonstrated to be negatively correlated with mortality, morbidity, and risk factors for heart disease and stroke (Thayer, 2007). Therefore, a decline in HRV may have a direct impact on both health and sickness. HRV has, however, also been linked to activity in several brain regions linked to EFs (Thayer, 2005; Thayer, 2009a). The anterior executive region, a group of brain regions, is linked to individual variations in the accomplishment of a variety of EF tasks. The link between HRV, a measure of activity in these brain structures, and several aspects of cognitive regulation, including EFs, has been thoroughly studied by Thayer et al. (2009b). They have demonstrated that individual variations in resting HRV are preferentially associated with executive function tasks including working memory and go/no-go tasks. They have looked at these associations in both healthy persons and patients with anxiety disorders and psychopathy. Higher levels of resting HRV were associated with greater performance on tasks involving inhibitory processes and executive functions across these diverse populations and contexts. Therefore, individual variations in HRV may be related to individual variations in EFs, and therapies that improve HRV may also improve EFs. Therefore, HRV may directly relate to health and health habits, but it may also have an impact on health through correlations with EFs.

1.2.3 Stress management and executive functions

The prefrontal cortex and the limbic system, which includes the amygdala, thalamus, and hypothalamus, are functionally connected, suggesting that EFs play a significant role in stress management. As a result, EFs are crucial to understanding the causes of disease and how it progresses, as well as how to manage stress in populations with a variety of diseases. The neurovisceral integration model significantly features prefrontal cortex (PFC) functioning (Thayer, 2009b). According to high-frequency heart rate variability (HF-HRV) (Lane, 2001), this area specifically supports stress self-regulatory action through parasympathetic activation in addition to its involvement in

EFs. Therefore, individual differences in EFs have implications for stress risk and resilience models (Williams, 2009).

1.2.4 Executive functions and health-related lifespan processes

Aging is linked to a decline in PFC neuronal structures and related declines in EFs, as described by Denburg and colleagues (2009). Changes in EFs brought by aging will have an impact on health in several ways, including through effects on medical decision-making. Therefore, identifying susceptible older persons is a key area of research for behavioral medicine. Denburg and colleagues investigated the relationship between age and performance on the Iowa Gambling Task (Bechara, 1994), an experimental cognitive task that measures decision-making, and the five-factor model of personality. Only in elderly persons do neuroticism and poor decision-making come into play. One explanation for these findings is that prolonged stress in people with high levels of neuroticism may have a bad effect on EFs that only becomes apparent as these people age because neuroticism is highly related to poor stress regulation (Williams, 2009). Kern et al. (2009) reported two variables assumed to reflect individual variations in Efs, the personality trait conscientiousness and job success, independently predicting death. It’s critical to emphasize that assessments of conscientiousness were made during childhood, whereas assessments of professional achievement were made in midlife. Poor professional performance predicted mortality only among those who were less conscientious, which highlights the significance of looking at lifespan trajectories as well as the interacting effects of EFs-related characteristics.

1.2.5 Executive functions and chronic illness management

A link between several chronic diseases and lower EFs is supported by prior research. Deficits in EFs, for instance, have been linked to conditions like HIV/AIDS (Stern, 1995), diabetes (Shillerstrom, 2005), lung illness (Parekh, 2005), hypertension (Waldstein, 1996), and vascular disease (Waldstein, 1996; Waldstein, 2003).

Numerous pathophysiological mechanisms, including dopamine disruption in the prefrontal circuits, hypoperfusion and inflammatory and hormonal processes that are caused by the disease process itself or medical treatment have all been linked to the association between EFs and chronic illness (Shillerstrom, 2005). It's significant to note that deficiencies in EF functioning have been associated with lower adherence to treatment plans (such as medication adherence in HIV) (Solomon, 2008). Nes et al. (2009) use self-regulation to investigate the relationship between chronic pain and EFs. The capacity to exert control over cognition, emotion, behavior, and physiology is generally described as self-regulation (Carver, 1998; Baumeister, 2004). A good theoretical framework for articulating executive functioning in behavior is provided by the broad concept of self-regulation (Posner, 2007). The resting HF-HRV reflects individual differences in selfregulation, often known as self-regulatory capacity (Thayer, 2009). Nes and colleagues point out that self-regulatory ability and executive functions are closely related and they are scarce resources therefore they can run out. Furthermore, EF network components are crucial for processing pain and emotion signals. Thus, the investigation of relationships among EFs, self-regulatory capacity, fatigue, and chronic health problem management is facilitated by chronic pain syndromes. The fundamental theoretical relationships described by Nes and colleagues can be applied to numerous other chronic diseases with recognized EF deficiencies.

1.2.6 Development considerations

Most studies on EFs and health point to a dynamic, reciprocal relationship over time: lower EFs increase the chance of developing health issues, which in turn causes further declines in EFs. For instance, variations in EFs between individuals make them more susceptible to both higher levels of stress and more unpleasant reactions to traumatic life events.

1.2.7 Intervention implications

The treatment of behavioral medicine is significantly influenced by executive functioning. As previously mentioned, people with EF deficits may have difficulties to respect complicated behavioral change regimens, especially in the absence of adequate structure and support. Individuals with lower EFs will find it difficult to change their health-related behaviors (such as their diet and weight loss goals) and adhere to their treatment plans (such as managing their diabetes). These problems also imply that behavioral medicine professionals could include EFs assessment or, where necessary, refer patients for neuropsychological testing. Whether EFs can be increased is an intriguing question. Exercise, for instance, has been linked to improvements in EFs (Colcombe, 2003), however it is unclear how this happens exactly. As mentioned in multiple publications, mindfulness meditation and related therapies have been linked to increased PFC activation (Davidon, 2003) and executive functioning (Tang, 2007). Additionally, potential therapies to enhance EF in young infants (Diamond, 2007) and older individuals (Erickson, 2006) have been made. Interventions for stress management that target vagal tone, including timed breathing and HRV biofeedback, may have an impact on EFs through vagal links to the PFC. Furthermore, enhancements in performance on particular EF workloads do not always result in enhancements in real-world performance. A challenge for future interventional research is to consider EFs as a significant outcome in daily life.

1.3 Executive functions in open and closed skills sport

All age groups have benefited from exercise and physical activity, which has been well-documented (Booth et al., 2012; Hills et al., 2015). In recent years, an increasing number of researchers have focused their attention on exploring the potential links between exercise and cognitive functions (Lin et al., 2018; Pedersen, 2019; Stern et al., 2019). Studies generally tend to suggest that the positive effects of exercise are larger and more obvious for executive functions (Kramer and Erickson, 2007; Chaddock et al., 2011), even though existing evidence has shown that physical fitness and exercise have important relationships with various aspects of cognitive functions (Kramer and Erickson, 2007; Aberg et al., 2009; Chaddock et al., 2011). For instance, improved executive functions and academic performance in children and adolescents have been linked to higher levels of physical fitness (Huang et al., 2015; Marques et al., 2018; Westfall et al., 2018). According to inhibition and cognitive flexibility tasks, physical exercise intervention programs can improve children’s executive function performances (Hillman et al., 2014). People who regularly practice physical activity have also shown shorter cognitive deterioration and a decreased risk of dementia (Middleton et al., 2010; Zotcheva et al., 2018). Physical exercise can enhance executive functions and spatial memory in older persons, according to strong evidence (Kramer et al., 1999; Erickson et al., 2011). Furthermore, according to some research, various forms of physical activity may have different effects on mental and cognitive health (Tsai et al., 2012; Tsai and Wang, 2015; Chekroud et al., 2018). However, there is still considerable debate as to which physical activities are most likely to enhance cognitive performance. Research suggests that the movement characteristics of the activities performed may be associated with the degree of improvements in cognitive functions through physical exercise (Guo et al., 2016; Chang et al., 2017; Cho et al., 2017). Motor skills can be categorized into open and closed skills based on how the environment affects them. While closed skills are carried out in a predictable and static context, open skills are performed in a dynamic and changing environment (Galligan, 2000). Open skill exercise (OSE) and closed skill exercise (CSE) are thus two categories under which exercise modes can be categorized (Di Russo et al., 2010; Dai et al., 2013; Tsai and Wang, 2015; Tsai et al., 2016, 2017). The unpredictable environment, active decision-making, and continuous adaptability required by OSEs (such as judo, basketball, tennis or boxing) require participants to change their responses to unexpected external inputs (Brady, 1995; Di Russo et al., 2010; Wang et al., 2013a). The majority of OSEs are perceptual and externally paced. In contrast, CSEs (such as running, swimming or cycling) are practiced in an environment that is more predictable and steady, and where movements are guided by predetermined patterns. Because there are fewer cognitive demands and decision-making needs, CSE skills are more likely to be self-paced (Brady, 1995; Di Russo et al., 2010; Wang et al., 2013a). Researchers have examined the relationships between OSE and CSE and cognitive functions among individuals in various age groups in this context. According to some studies (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a), OSE participants outperformed CSE participants in some areas of executive functions (such as inhibitory control and cognitive flexibility). Contrarily, several research claimed that there were no differences in the cognitive effects of OSE and CSE (Chang et al., 2017; Chueh et al., 2017; Becker et al., 2018). In a systematic review (Gu et al., 2019), the impact of OSE versus CSE on cognitive performance was reviewed rigorously. Overall, they looked at the results of 19 investigations and discovered that OSE had cognitive advantages above control conditions in 12 of 14 observational studies (86%) and 4 of 5 intervention trials (80%). Additionally, individuals in OSE groups performed better on various measures of cognitive functions compared to participants in CSE groups in seven of fourteen (50%) observational studies and three of five (60%) intervention trials. Although the current research tends to suggest that OSE may be more beneficial to some aspects of cognitive functions than CSE (visuospatial attention, problem-solving, audiovisual perception, inhibitory control, and cognitive flexibility), it is too soon to draw definitive conclusions about the relative effects of OSE and CSE on a domain of cognitive functions.

1.3.1 Age-specific cognitive benefits of OSE compared to CSE

The results of the systematic review (Gu et al., 2019) revealed that OSE may have cognitive advantages over CSE at different developmental stages. Except one observational study (Becker et al., 2018), only three studies compared the effects of OSE and CSE on cognitive functions in children (Crova et al., 2014; Schmidt et al., 2015; Becker et al., 2018). The two intervention studies showed that the OSE intervention led to a greater improvement in executive functions than CSE (Crova et al., 2014; Schmidt et al., 2015). According to earlier research (Chaddock et al., 2011;

Khan and Hillman, 2014), the benefits of physical activity were higher on executive functions than other components of cognitive performance. This is supported by Gu et al. (2019), which also reported the possibility that OSE may benefit executive function more than CSE. Executive functions and brain growth are likely facilitated by regular engagement in OSE (Best, 2010). In order to effectively promote executive functions, there are rising evidence that OSE should be incorporated into children's exercise intervention programs, possibly through physical education at school (Crova et al., 2014; Schmidt et al., 2015). Although the majority of the included studies showed that the two forms of exercise were better for young adults' cognitive functions than their sedentary counterparts, there isn't much evidence that OSE is better for this function than CSE because there aren't many long-term intervention studies. In four observational studies (Giglia et al., 2011; Wang et al., 2013a; Jacobson and Matthaeus, 2014; Yu et al., 2017), participants in the OSE group performed cognitively better than those in the CSE group. However, in the intervention study (Hung et al., 2018), the benefits of the intervention on the OSE as a whole were only marginally significant. OSE's (vs CSE's) cognitive effects on this age group are therefore unclear. According to some hypotheses, brain development and cognitive capacity reach their peak in adolescence; wich may explain the poor evidence for the superior favorable effects of OSE on cognitive performance (Casey et al., 2000). Therefore, OSE cannot have more positive effects on young people's cognitive functions. Additionally, Gu's review discovered that there were no current studies with participants in the intermediate age range (36 to 55 years). This age range may be taken into account for future research. In the older adults, evidence from six observational studies (Dai et al., 2013; Huang et al., 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Li et al., 2018) and two intervention studies (O'Brien et al., 2017; Tsai et al., 2017) consistently support a beneficial role of exercise on cognitive functions. In addition, two intervention studies (O'Brien et al., 2017; Tsai et al., 2017) and three observational studies (Dai et al., 2013; Tsai and Wang, 2015; Tsai et al., 2016) suggested that OSE may be more effective in this population for enhancing attention, audio-visual perception, or cognitive flexibility. Even while there may be higher cognitive benefits for OSE, it is important to keep in mind that CSE has positive effects in this population as well as others. Overall, the findings of Gu's systematic review suggest that OSE, as compared to CSE, may be more beneficial for various aspects of cognitive function, particularly in early infancy and later adulthood. The findings have important practical ramifications in addition to helping to define the differing cognitive impacts of the two training modalities. It is plausible to propose that OSE should be included in exercise promotion programs to combat the prevalence of physical inactivity and sedentary behavior, since it may optimize the cognitive advantages of exercise.

1.3.2 Potential mechanisms for OSE's better effects than CSE

The results of Gu's systematic review point to an advantage of OSE for improving some aspects of cognitive functions, perhaps especially in childhood and late adulthood because these two life stages either occur before the prefrontal lobe brain development that underlies executive functions (Casey et al., 2000) or are linked to an aging-related decline in cognitive functioning. Naturally, this is a hypothesis because it's still unknown what possible pathways might underlie OSE's greater effects than CSE. OSE has more cognitive demands and requirements than the CSE does, which may help to explain some of its greater benefits in Gu's systematic review. Participants must adapt to a constantly changing environment while practicing OSE. As a result, some aspects of cognitive function, such as visuospatial ability, information-processing speed, multitasking flexibility, and other executive functions like working memory and inhibitory control, are more cognitively demanding and require more practice (Di Russo et al., 2010; Tsai et al., 2016, 2017). While performing CSE, individuals are less likely to be exposed to multi-sensory stimuli than they would while performing OSE (Brady, 1995; Di Russo et al., 2010). In order to complete a difficult task or coordinate the body to carry out complex actions, CSE thus provides substantially less cognition guidance (Di Russo et al., 2010; Tsai et al., 2016, 2017). Overall, Gu reported that OSE was more likely than CSE to support the hypothesis that the cognitive demands and difficulties of complex movement may be a mechanism behind the positive effects of exercise on cognitive functions (Best, 2010). In terms of physiology, moderate-intensity running appears to have a shorter favorable impact on the neurotrophic system in the cerebellum (the generation of brain-derived neurotrophic factor (BDNF) and its receptor functioning) than more complex and sophisticated movements (Klintsova et al., 2004). According to Huang et al. (2014) and Poo (2001), BDNF is a key player in brain plasticity and is regarded as a biomarker of the cognitive advantages of exercise. One session of OSE caused a larger increase in serum BDNF compared to a CSE intervention, according to a recent study in young people (Hung et al., 2018). Therefore, OSE's stronger cognitive benefits may also be supported by the greater neurophysiological alterations that it causes. Based on observational and intervention studies, Gu compared the effects of OSE and CSE on cognitive performance. According to him, OSE is more effective than CSE at improving various elements of cognitive performance. More studies with follow-up are needed to further support the current findings because the majority of the existing research is observational and contains just a small number of intervention studies.

Chapter 2. Executive functions and training

EFs can be enhanced (Diamond & Lee, 2011; Klingberg, 2010). CogMedc computerized training (Bergman Nutley et al., 2011; Holmes et al., 2009; Klingberg et al., 2005; Thorell et al., 2009), a combination of computerized and interactive games (Mackey et al., 2011), task switching computerized training (Karbach & Kray, 2009), traditional martial arts (Lakes & Hoyt, 2004), and two add-ons to school curricula, Promoting AlternativeThinking Strategies (PATHS; Riggs et al., 2006) and the Chicago School Readiness Project (CSRP; Raver et al., 2008, 2011) are some activities able to improve EFs in children. The above mentioned studies used random assignment, a control group and pre and post-intervention measurements. They discovered convincing transfer to different objective measures of EFs on which the children had not been trained.

Studies that have examined the advantages for EFs of children of aerobics (Davis et al., 2011; Kamijo et al., 2011), mindfulness (Flook et al., 2010), yoga (Manjunath & Telles, 2001), Tools of the Mind early childhood curriculum (Diamond et al., 2007), and Montessori curriculum (Lillard & Else-Quest, 2006) have found promising results but lacked one or more of the above mentioned design elements. With adults, computerized training, particularly for WM, has frequently been the main focus. Recent analyses of this type with adults are cautiously positive, but they also reported significant design problems (Morrison & Chein, 2011; Shipstead et al., 2012).

Independently from the EFs program or intervention, the following concepts are applied:

1. Any EF intervention or program brings higher benefits to children (also those disadvantaged) with lower levels of EFs (Flook et al., 2010; Karbach & Kray, 2009; Lakes & Hoyt, 2004). Early EF training could therefore even the situation by lowering social differences in EFs, preventing social disparities in academic results and health (O’Shaughnessy et al., 2003).
2. Although there is evidence that EF training transfers, this transfer of computerized WM or reasoning training has been limited (for example, computer training on spatial

WM transfers to other measures of spatial WM but not to visual WM or other EFs subcomponents; Bergman Nutley et al., 2011).

The EFs benefit from task switching training (Karbach & Kray, 2009), traditional martial arts training (Lakes & Hoyt, 2004), and school curricula (Raver et al., 2011; Riggs et al., 2006) have been more extensive, possibly because these programs involve EFs more broadly.

For instance, training task switching (which involves all three main EFs) transferred to inhibition (Stroop interference), verbal and nonverbal WM and reasoning, as well as to an untrained task-switching task (Karbach & Kray, 2009).

3. If EF demands aren't gradually raised over time, there won't be many improvements (Bergman Nutley et al., 2011; Holmes et al., 2009; Klingberg et al., 2005). About this, there could be two reasons: (a) if the level of difficulty stays the same, participants will be bored and lose interest; (b) if you don't continually push yourself to improve, progress will stall.

4. Repeated practice is key. The time spent constantly training such skills will determine EF gains (Klingberg et al., 2005). School curricula shown to improve EFs training, embedding that in all activities (Diamond et al., 2007; Lillard & Else-Quest 2006; Riggs et al., 2006).

5. The most difficult EFs tasks and conditions are those where the biggest differences between intervention groups and control groups are reported. EFs can be raised at any stage of life, including in young children and old adults.

Improvements in physical fitness have been shown to significantly improve EFs in old people (Erickson & Kramer, 2009; Voss et al., 2011). A growing number of research on computerized EF training for old people has shown encouraging outcomes (Lovden et al., 2010; Richmond et al., 2011). Much of the research (although not all) on improving EFs in young adults has focused on computerized training (Morrison & Chein, 2011; Muraven, 2010; Shipstead et al., 2012).

Except for the volume of work and core EFs, no one has yet examined what separates people who profit from EF training from those who don't. There isn't much information about the ideal amount or frequency, whether and how long advantages can last.

These questions are important because even small enhancements in inhibitory control could change the distribution of outcomes in a salutary direction and result in significant enhancements in health, wealth and crime rate (Moffitt et al., 2011).

In summary, EFs are essential for many of the abilities necessary for success (creativity, adaptability, self-control, and discipline). The ability to mentally play with ideas, swiftly and flexibly adapt to changing situations, stop to evaluate next action, resist temptations, maintain focus and face new and unexpected challenges is made possible by EFs. It is possible, however, to suppress our inclinations and conditioned responses and keep in mind what we can't see.

2.1 Cognitive-motor training

A particular and innovative method of training EFs is cognitive-motor training (CMT). It has been confirmed that CMT, by combining physical and cognitive exercises, is more effective in enhancing both cognitive and motor performance than only physical training (Moreira et al., 2021). Depending on the dynamics of the exercises, CMTs can be of two types: simultaneous training (dual task), in which athletes execute both types of exercises simultaneously, and sequential training, in which athletes execute motor and cognitive exercises sequentially on the same time (Tait et al., 2017). About that, numerous studies have shown that this type of CMT is more effective than sequential training (Fissleret al., 2013; Frith & Loprinzi, 2017; Roig et al., 2012). Although experts disagree on the optimal type of exercise to adopt, cognitive-motor dual-task (CM-DT) training appears to be more effective for cognitive processes than only sequential training and physical training (Moreira et al., 2021).

By focusing on some skills that are transferable to competitive sports and enhancing general cognitive capacities, CMT tries to increase sport performance in athletes (Taatgen, 2013). The cognitive processes that CMT typically aims to improve include perception (Clark et al., 2020), attention, concentration, reasoning, creative thinking, memory, and decision-making (Moreira et al., 2021). However, proactive cognitive processes like inhibition and anticipation (Aron, 2011; Aron et al., 2004) have not yet been fully studied. These functions are essential for some sports, in particular for open-skill sports where athletes are constantly exposed to dynamically changing situations and must prepare the correct action at the right time (Di Russo et al., 2010). This is especially true for basketball and judo because these sports are characterized by highly intermittent actions and fast changes in movement type (Scanlan et al., 2014; Lo et al., 2019).

Basketball has been shown to have cognitive impacts on attentional and inhibitory control (Wang et al., 2013; Nakamoto & Mori, 2008) as well as action anticipation when players must provide the success of free throws (Aglioti et al., 2008).

It has also been proven that traditional martial arts (such as judo) training is one of the methods to make a positive impact on EFs in young children (Lo et al., 2019). Therefore, basketball and judo require a fundamental skill as anticipatory control, which comes from a mix of sensory inputs, search strategies, effective pattern recognition, awareness of situational probabilities, planning, problem-solving, and set-shifting (Williams et al., 2002; Lo et al., 2019).

2.2 Study of Lucia

In this regard, Lucia et al., (2021) and Badau et al., (2022) used sensorized light systems to improve the cognitive abilities of basketball players.

Specifically, in Lucia's study, the primary aim was to determine whether, in comparison to physical training alone, CM-DT training with innovative and interactive tools may enhance basketball players' sport performance.

2.2.1 Materials and Methods

Twenty-four young, male basketball players were chosen for the study (mean age = 16.6 years; SD = 1.1).

Athletes were randomly divided into two groups, each with 12 members: the experimental (EG) and the control (CG) group. The CG group was trained for five weeks, 7 times a week, 1 day for a basketball match (2 h) and 6 times a week for traditional basketball training with group basketball training (3 h) and 2 standard individual training sessions (30 min) consisting only physical and technical activities. The EG executed the same training program, but the 2 individual sessions of 30 min were performed with the CMT.

Each participant performed a basketball specific test before and after the training, as well as a cognitive task. One or two days before and after the intervention, pre and post-tests were administered (two days for basketball tests, and one day for cognitive tests).

Cognitive-Motor Training-Dual Task (CMT-DT)

To prevent any prepotent or distracting reactions during task performance, the intervention included CM-DT training that required the performance of physical and cognitive activities. This required strong inhibitory control and concentration. The goal of the task was to enhance both cognitive and functional abilities. Exercises were organized into brief routines to simultaneously enhance muscle strength, static and dynamic balance, and various cognitive functions. Participants completed task sequences by changing or reversing the acquired order to encourage the inhibition of automatic responses and stimulate working memory.

A led matrix makes up this system, which can show symbols (letters, numbers, and arrows) in various colors and produce sounds that can communicate with participants. Numerous cognitive exercises including attention, memory, discrimination, anticipation, and decision-making are available on these interactive sensors.

Six CM-DT exercises were given to the EG to complete during this training. These exercises called for specific basketball skills like agility, precision, and control in dribbling while also stimulating mental processes including anticipation, discrimination, working memory, and decision-making.

Cognitive task

The discrimination response task (DRT), or the Go/No-go paradigm, made up the cognitive task. For 250 ms, four visual stimuli were displayed at random with equal chance. Participants had to press the button as quickly as they could only when (two out of four) planned target stimuli shown on the screen, and they had to inhibit the motor response when non-target stimuli appeared. Speed and accuracy were equally encouraged by the experimenter.

Behavioral Data

Average response times (RTs) for successful trials were considered for all participants. The percentage of omissions (missing responses to target stimuli) and commission errors (incorrect reactions to non-target stimuli) was used to calculate accuracy.

This investigation examined the impact of cognitive-motor dual-task training on young basketball players' athletic and cognitive performance.

2.2.2 Conclusions

Results showed that in several of the analyzed variables, the experimental intervention was the only one that was successful or more effective than the traditional training.

Indeed, only the EG increased sport performance in all of the basketball tests.

Evidence suggesting that only cognitive-motor dual-task training increased performance in sport-specific tests in just five weeks may be related to the increased cognitive load required by the training, which stimulated cognitive functions essential for quick and accurate basketball dribbling, such as anticipation and selective and divided attention.

The dual process demanded by the experimental task can mostly stimulate higher cognitive functions as attention facilitating response accuracy, which is why the cognitive-motor dual-task training improved accuracy performance in the cognitive test more than the traditional one (Evans & Stanovich, 2013).

In particular, the EG made fewer commission errors than the CG after the intervention.

While other studies (Kayama et al., 2014; Marmeleira et al., 2009; Schwenk et al., 2010; De Bruinet al., 2013) used more general exercises of training aerobic capacity, strength, balance, and flexibility or walking, progressive resistance, and functional balance training along with general tasks stimulating executive functions, such as working memory, attention, or executive processing speed, the most important news of Lucia's study was the use of specific sports exercises along with cognitive training.

2.3 Study of Badau

Instead, in Badau's study, sensorized light systems were used to study reaction times.

According to Delmas et al. (2018) and Casamento-Moran et al. (2019), the reaction time to visual stimuli is defined as the period between the onset of the stimulus and the beginning of a response of any of the three types: motor, cognitive, and recognition. According to studies, the reaction time depends on the nature of the stimulus, duration of the stimulus application, the intensity of the stimulus, the afferent and efferent transmission rate of nervous influx, the processing time dependent on the complexity of the task, the size of the muscle group or segment that performs the task (Tarkka & Hautasaari, 2019; Trofimova et al., 2020; Lakhani et al., 2014; Badau et al., 2018). There are three types of reaction time. Simple motor reaction time (MSRT) is a motor response to kinesthetic, visual, auditory, or verbal stimuli.

Recognition reaction time (RTD) is based on the cognitive processes that select the most appropriate responses to complex stimuli. The response depends on the kind and nature of the stimulus. Cognitive reaction time (CRT) is the ability to decode, analyze, associate, and apply particular information to a stimulus relative to the situation and cognitive complexity.

Some studies used computer games to identify different types of reaction times.

To maximize physical and technical performance, exergames help to connect sports and cognitive training (Farrow et al., 2019; O'Leary et al., 2011; Soltani et al., 2016; Reynolds et al., 2014). Numerous studies have demonstrated the utility of exergames in sports activity, focusing on enhancing proprioception (Wüest et al., 2014; Altimira et al., 2017; Ferrão et al., 2012), physical fitness components (Berg & Moholdt, 2020; Martin-Niedecken et al., 2021; Soltani et al., 2017; Soltani et al., 2021; Viana et al., 2021), proprioception (Wüest et al., 2014; Altimira et al., 2017; Ferrão et al., 2012), and the effectiveness of particular motor and technical skills in individual sports (Chye et al., 2014; Mousavi et al., 2019; Di et al., 2012) as well as in sports games (Zhang et al., 2021; Zhao et al., 2020; Xu et al., 2021; Krause & Benavidez, 2014).

The primary aim of Badau's research was to develop an exergame program through the use of Fitlight technology in order to determine the effects on motor, recognition, and cognitive reaction times in junior players practicing team sports like basketball.

2.3.1 Materials and Methods

The research was structured in three phases: initial test (Ti), intervention (12 weeks with 3 training sessions, 30 min per session) and final test (Tf). In this cross-sectional study three tests were performed: Human Benchmark test for simple motor reaction time (MSRT); "Hit the Dots" for recognition reaction time (RRT); Part B of the Trail-making Test (TMT) (Badau et al., 2018) for cognitive reaction time (CRT) using. For this study 360 athletes (average age ± SD 13.60 ± 1.07; average sports experience ± SD 6.24 ± 0.92) are recruited. Only the experimental group in the study received the 12-week program, which was carried out three times a week for 30 minutes per training session. The program comprehended exergame exercises through Fitlight technology, cards with different encryption (letters, figures, numbers), which made it easier to create a set of 24 exercises to enhance the ability to react to visual stimuli. Fitlight technology has been used in several studies to demonstrate how it may enhance cognitive functions and reaction times, both of which are useful in open-skill sports. The experimental exergame program consisted of three subprograms: eight exercises to improve the motor reaction time; eight exercises to improve the recognition reaction time and eight exercises for the cognitive reaction time. Two exercises from each of the three subprograms were performed for each training session. All experimental groups of athletes practicing team sports (like basketball) received the same application of the exergames program.

2.3.2 Conclusions

The authors of this study believe that exergames improve the ability to respond to visual stimuli because of the results they found on the impact of the experimental program on three different types of reaction times.

The study's findings improve understanding of how to measure reaction times to visual stimuli related to each of the three computer game tests and the experimental program through the use of Fitlight technology. The efficacy of the experimental program implemented by exergames using Fitlight technology, which focused on improving three categories of reaction times in junior athletes in team sports, was demonstrated in all tests of this study conducted through standardized computer games. Significant progress was made between the initial and final tests in favor of the latter. Because they offer a variety of practice, organization, and attractiveness options, exergame programs designed to enhance reaction times can be modified and integrated into recreational, preventative and athletic activities for a range of age groups (Ciocan, 2014; Ciocan, 2021; Ewert et al., 2001; Vaghetti et al., 2018; Moholdt et al., 2017). The study's findings make it easier to apply the exergames program to different open-skill sports and age groups. This study's findings demonstrated that junior athletes practicing team sports, like basketball, had notable improvements in their motor, recognition, and cognitive reaction times as a result of the exergame program through the use of Fitlight. Significant improvements were observed between the first and the last testing, as well as between the male and female players, according to the study.

When the study's results were analyzed for all kinds of reaction times, it was discovered that female players advanced further than comparable male players who were also part of the study.

2.4 Study of Lo

Very little research has been done currently on how judo training affects young athletes' EFs. However, previous research concentrated on how martial arts affected inhibition but not on set-shifting. Lo's study investigated the impact of judo training on the capacity to set-shift through the use of a spatial task-switching test that required participants to switch between left-right and up-down spatial dimensions. The research of Lo involved two protocols. The first protocol looked at how long-term judo training affected the ability to set-shifting.

The second protocol looked into the connection between set-shifting and judo training.

2.4.1 Materials and Methods

The identical spatial task-switching test was used in both protocols 1 and 2 to evaluate set-shifting capacity.

A grid with four squares has been displayed to the participants. An arrow that could point both horizontally and vertically was located in the center of the grid. At random, a sign appeared in any one of the four spaces. Participants were asked to switch between responding to the horizontal and vertical dimensions. When a horizontal arrow separated the four squares into the left and right blocks, the horizontal dimension became significant. The four squares were split into high and low blocks by the vertical dimension represented by the vertical arrow. The participants had to press a certain key on the keyboard if the sign appeared in the lower panel of the vertical dimension or the left panel of the horizontal dimension, while they had to press another key if the sign appeared in the upper panel of the vertical dimension or the right panel of the horizontal dimension.

Protocol 1

A secondary school was used to recruit the judo athletes and control group, who were all between the ages of 12 and 16. The first one required to have trained in judo for at least four years and to attend three or more training sessions each week. Regarding the control group, schoolchildren who had never engaged in martial arts training were recruited. Each participant only attended one session of data recording.

The E-prime 2.0 program was used to provide the spatial task-switching test (Psychology Software Tools, Inc., Pittsburgh, PA, USA).

Protocol 2

A secondary school was used to recruit the judo athletes and control group, who were all between the ages of 12 and 16. They must never have practiced judo.

Participants could choose to take part in the experimental group (who practiced judo) or in the control group (who had not received judo training).

Intervention

For eight weeks, participants in the intervention group trained in judo three times a week. Twenty minutes of falling (throw down, push down, and hook down) and forty minutes of Randori (twenty minutes of ground judo fighting and twenty minutes of standing judo fighting) comprised the judo practice session.

The spatial tasks-witching test was administered to each subject both before and after the intervention.

2.4.2 Conclusions

Protocol 1

A total of 26 subjects were recruited to participate in protocol 1. Twelve subjects (9 males and 3 females) were recruited for the judo group. For the control group, 14 subjects (11 males and 3 girls) with similar ages were recruited. Every participant engaged in the physical education program each week.

Protocol 2

A total of 29 subjects were recruited to participate in protocol 2. Fourteen subjects (11 males and 3 females) were recruited for the experimental group. For the control group, 15 subjects (11 males and 4 girls) with similar ages were recruited. Every participant engaged in the physical education program each week.

The first protocol showed that schoolchildren with regular judo training were better at set-shifting than controls, and the second protocol showed that set shifting in schoolchildren may be enhanced by judo training. The current study is among the first to examine the impact of Judo training on schoolchildren’s set-shifting ability.
It is hypothesized that those who engage in open-skilled sports, where they must anticipate a dynamic environment, have superior EFs than those who engage in closed-skilled sports in a stable setting (Wang et al., 2013; Yu et al., 2017; Diamond, 2015). This concept is supported by Yu et al. (2017) in their examination of how open and closed skills improve EFs in a cued task-switching paradigm. It compared task switching between young subjects who played close-skill sports and those who played open-skill sports. The findings showed that, in a cued task-switching paradigm, open-skill athletes outperformed closed-skill athletes in task-switching, as seen by the reduced response time difference. This result corroborates findings from protocol 1 of Lo’s investigation, which showed that the judo training group had considerably lower switch trial mistake rates than the control group. Judo is an open-skill sport where athletes must respond to opponent strategies with particular and intense motor activities to obtain a benefit in a constantly changing environment (Franchini et al., 2014). Judokas must therefore continually predict what their opponent will do next and be ready to switch quickly from one action to the next to outwit him (Wang et al., 2013; Yu et al., 2017). Judo’s cognitive demands on athletes to adapt to a dynamic environment should improve EFs (Wang et al., 2013; Zhang et al., 2015). The outcomes of protocol 2 offered more proof in favor of the relationship between set-shifting and judo training. This was demonstrated by the judo group’s switch trial error rates were lower than those of the control group. The impact of judo training on EFs may be further supported by the observation of greater improvements in error rates for the judo group from start to post-intervention when compared to the control group.

The results obtained from protocol 2 are in line with Lakes & Hoyt (2004). The cognitive self-regulation skills of 207 schoolchildren who trained in martial arts for three months were evaluated by Lakes & Hoyt. Results showed that the martial arts training group had higher improvements in cognitive self-regulation after the intervention than the control group, indicating that martial arts training may be effective for self-regulation. The results of Lo's study suggested that set-shifting capacity could potentially be enhanced by judo training. Therefore, the results of this study provide proof that schoolchildren's set-shifting may be improved by judo training.

2.5 Theoretical framework and aims of the studies

Although it is known that physical exercise and sports practice are considered activities that may enhance EFs, it is not yet clear the relation between EFs and motor training. In particular, future research should examine which EFs are enhanced by a specific cognitive-motor training (CMT) and the duration of these enhancements in order to better understand the possible impacts of increased EFs on various sports, possibly with a motor activity to better stimulate EFs activation.

In addition, although it is known that athletes who play open-skill sports have higher EFs than athletes who play closed-skill sports, most scientific literature has focused on team sports.

Therefore, future studies should be focused on combat sports and in particular on how judo training could affect young athletes' EFs.

Therefore, this thesis aimed to verify whether cognitive-motor massed training using Fitlight™ induces improvements in EFs and physical fitness in young athletes practicing open-skill sports (specifically basketball and judo) compared to a non-intervention group.

The development of sensorized light systems, such as Fitlight™, to study their effects on EF development in order to improve sport practice with cognitive-motor training achieved great importance, especially in open-skill sports, such as basketball and judo.

These sensors, which can also be worn, consent to conduct training in real conditions and without influencing the movements of athletes.

Moreover, they can engage with users during physical training, offering engaging and difficult activities that increase task performance satisfaction. A great variety of motor exercises have been developed to activate cognitive functions (such as attention, working memory, inhibition, and cognitive flexibility) as a result of this feature (Lucia et al., 2021).

There are few studies on the use of cognitive-motor training using Fitlight^{TM} in basketball and none in combat sports, particularly judo.

Thus, the aims of Study 1 were: 1) to verify whether the Fitlight training system^{TM}, used to cognitively enrich a massed basketball training program, can improve young athletes' EFs (specifically, response inhibition, working memory, and cognitive flexibility) and motor performance (specifically, agility and aerobic capacity) in order to evaluate the effects of a massed CMT program on EFs and motor performance;

2) to verify if CMT induced changes in the rate of perceived effort and enjoyment of training in the experimental group compared to a non-intervention group.

Additionally, the high levels of cognitive and physical demands, such as those for planning, problem-solving, and shifting, may support the growth of EFs by promoting neuroplasticity related growth factors like brain-derived neurotrophic factor (BDNF) (Cho, 2017; Voss, 2010). Since, to our knowledge, there are no studies, or in any case a very limited number, regarding the increase in BDNF in relation to cognitive-motor training, we decided to investigate this relation in Study 2.

Therefore, the aims of Study 2 were: 1) to determine whether a 5-week CMT program using Fitlight improved EFs in young adults élite judo athletes when compared to a non-intervention group, 2) whether CMT had an impact on BDNF and IgA levels in the experimental group when compared to the non-intervention group, 3) whether the CMT changed physical fitness in the experimental group, 4) to verify if CMT induced changes on enjoyment of training in the experimental group compared to a non-intervention group, 5) to verify if CMT induced greater fatigue in the experimental group compared to the non-intervention group, 6) to verify if the CMT induced changes in psychobiosocial states in the experimental group, 7) to determine whether CMT results were related to athletes’ performance in competition.

Chapter 3. Study 1 “Acute Effects of Fitlight Training on Cognitive-Motor Processes in Young Basketball Players”

3.1 Introduction

Working memory, inhibition (including selective attention), and cognitive flexibility (including mental flexibility and creativity) are all parts of the family of cognitive processes known as executive functions (EFs). These capabilities, referred to as fundamental EFs, are necessary for the growth of high-order EFs including problem-solving, reasoning, and planning (Diamond, 2013).

These processes share the same cerebral region as some motor circuits, such as motor planning or the execution of difficult motor tasks, from a neurophysiological perspective, which is the prefrontal cortex (Diamond, 2000). Physical exercise is one of the activities that, when combined with the right stimuli, may enhance EFs, according to research (Diamond, 2012; Kolovelonis & Goudas, 2022). Since sports practice typically involves both physical and cognitive participation, the development of EFs, particularly in children and adolescents, may be linked to playing sports (Contreras-Osorio et al., 2022, 2021).

The development of EFs is age-related and grows as the athlete grows, according to recent literature (Beavan et al., 2019). Age-related effects on some EFs metrics, such as response accuracy, are still up for discussion (Beavan et al., 2019; Heilmann et al., 2022a).

In a recent meta-analysis, Contreras-Osorio and colleagues (Contreras-Osorio et al., 2021) examined various sports programs that might have an impact on students’ executive functions. Compared to individual sports, the authors discovered that team sports that are enhanced with cognitively stimulating activities can enhance EF engagement (Contreras-Osorio et al., 2021). In agreement with them, Waelle and colleagues (Waelle et al., 2021) came to the same conclusion that kids who play team sports exhibit higher levels of EFs development than kids who play other self-paced sports. According to a recent systematic study on the varied effects of open- and closed-skill exercises on EFs development, open-skill exercises improved EFs in both children and adults more effectively than closed-skill exercises (Gu et al., 2019).

Numerous factors and stimuli should be taken into account when practicing open-skill sports, which can increase the cognitive involvement of EFs (such as working memory or stimulus inhibition) (Contreras-Osorio et al., 2022, 2021). Indeed, both the motor and cognitive areas benefit greatly from the complexity of the open-skill athletic setting (Diamond, 2015; Formenti et al., 2021). Having a higher level of EFs has also been linked to an athlete’s better performance in many open-skill sports, including basketball, volleyball, table tennis, soccer, and tennis (Trecroci et al., 2021; Elferink-Gemser et al., 2018; Huijgen et al., 2015; Ishihara et al., 2018,2020; Wang et al., 2020). This is in line with research that suggests that open-skill sports practice can induce EF development. However, Heilmann et al. (2022b) recently noted how the greater EF engagement seems to be more connected to the cognitive demands of a sport than to the simple distinction between open- and closed-skill exercises (Heilmann et al., 2022b). Basketball is a high-demand, open-skill activity that stimulates and simultaneously necessitates EF activation in match activities. Basketball players need to discern between relevant and irrelevant stimuli fast (1-2 s) (Scanlan et al., 2014). Correct response capacity needs inhibitory control of contradictory information, critical focus, and selective attention (Chiu et al., 2020). Therefore, an improvement in EF levels in basketball players may result in better decision-making during sport-related tasks. Indeed, decision-making is required in matches when quick action changes happen in a restricted time (Heisler et al., 2023). Since making the correct decision necessitates information search and processing, the decision strategies and EFs accessible will determine this process (Raab, 2012). Theoretically, to generate answer possibilities during the game and improve the initial options, which are most likely to be chosen in action replies (Johnson & Raab, 2003), better working memory is required. Athletes may focus on fewer, higher-quality options as a result of having a high level of inhibitory control since it can block option formation (Hepler & Feltz, 2012). Athletes are therefore more likely to have success in decision-making tactics if they can swiftly provide high-quality possibilities and suppress low-quality replies. The degree of cognitive flexibility also affects the capacity to quickly switch between response possibilities and adapt to novel circumstances (Diamond, 2013). Based on this theoretical understanding and in accordance with recent findings (Heisler et al., 2023), we can infer that strengthening core EFs may improve decision-making processes and consequently, athletes' performance in open-skill sports. Recent research has used sensorized light systems, such as the Fitlight trainer, to study their effects on EF development in order to enhance basketball practice with cognitive-motor training (CMT) (Lucia et al., 2021; Badau et al., 2022). These tools can engage with users during physical training, offering engaging and difficult activities that increase task performance satisfaction. A great variety of motor exercises have been developed to activate cognitive functions (such as attention, working memory, inhibition, and cognitive flexibility) (Lucia et al., 2021). The effectiveness of CMT training regimens on athletic performance and cognition as compared to training focused just on motor exercises was proven by Lucia and colleagues (Lucia et al., 2021). However, they expanded the literature by demonstrating that these effects might be explained by improved anticipatory brain processing in the prefrontal cortex. Additionally, it has been demonstrated that the Fitlight training system^{TM} (2011) stimulates EF engagement throughout various sporting activities, optimizing athletes' human reaction times. In particular, Badau et al. (2022) discovered that these athletes reported faster reaction times in computerized tests after completing a 12-week program of workouts using Fitlight technology (three times per week; 30 min per training session).

This study examined whether the Fitlight training system^{TM}, used to cognitively enrich a massed basketball training program, can improve EFs (specifically, response inhibition, working memory, and cognitive flexibility) and motor performance (agility and aerobic capacity) in young athletes in order to assess the effects of a massed CMT program on EFs and motor performance. In addition, during basketball practice, the rate of perceived effort and enjoyment was assessed using Fitlight technology to learn more about athletes’ perceptions of CMT. Adolescence is a critical time for the development of both the brain and the body, and the EFs enhancement during this age may have a significant role in future improvements in open-skill sports performance.

3.2 Materials and Methods

3.2.1 Participants and Study Design

It was a randomized interventional research. The sample size for this study consisted of 58 male basketball players (mean ± SD, age: 15 ± 1.5 years; weight: 64.1 ± 13.6 kg; height: 173.8 ± 10 cm; sitting height: 88.1 ± 6.4 cm). The participants in the Interregional Basket Championships U17-U15, organized by the Federazione Italiana Pallacanestro (FIP), were chosen from three different Italian basket clubs (U.S.D. Pallacanestro Urbania (n: 26), Metauro Basket Academy (n: 18), and C.S. 93 Basket Vadese (n: 5)). Each study participant gave consent to participate. A self-administered rating scale for a pubertal development questionnaire utilized in earlier published studies (Perroni et al., 2014; Carskadon & Acebo, 1993) was used to assess pubertal development. The mid-pubertal stage was the most prevalent pubertal development stage among the players.

All the subjects were randomly assigned to two experimental groups: the control group (CTRL) and the Fitlight group (FITL). Athletes from the same experimental group trained together in the same basketball gym during the intervention period, regardless of club affiliation. After the intervention, nine players (four from the U.S.D. Pallacanestro Urbania and five from the Metauro Basket Academy, respectively) were excluded from the study due to injuries, COVID-19 vaccines and diseases. In total, 49 athletes, 24 from the control group (CTRL) and 25 from the Fitlight-trained group (FITL) completed the training period. Players had to be in good physical and mental health, free from any conditions that would interfere with the study. Additional requirements for inclusion included (a) being a man; (b) participating in basketball training and competition for at least five years before the project, demonstrating good temporal continuity (at least 75 minutes of basketball training, three times a week); and (c) being available each day to move for training for the experimental groups.

The exclusion criteria were used: any ailment, illness, or therapy that could endanger volunteers' safety when exercising; taking medication, drug or nutritional supplements; smoking or consuming alcohol.

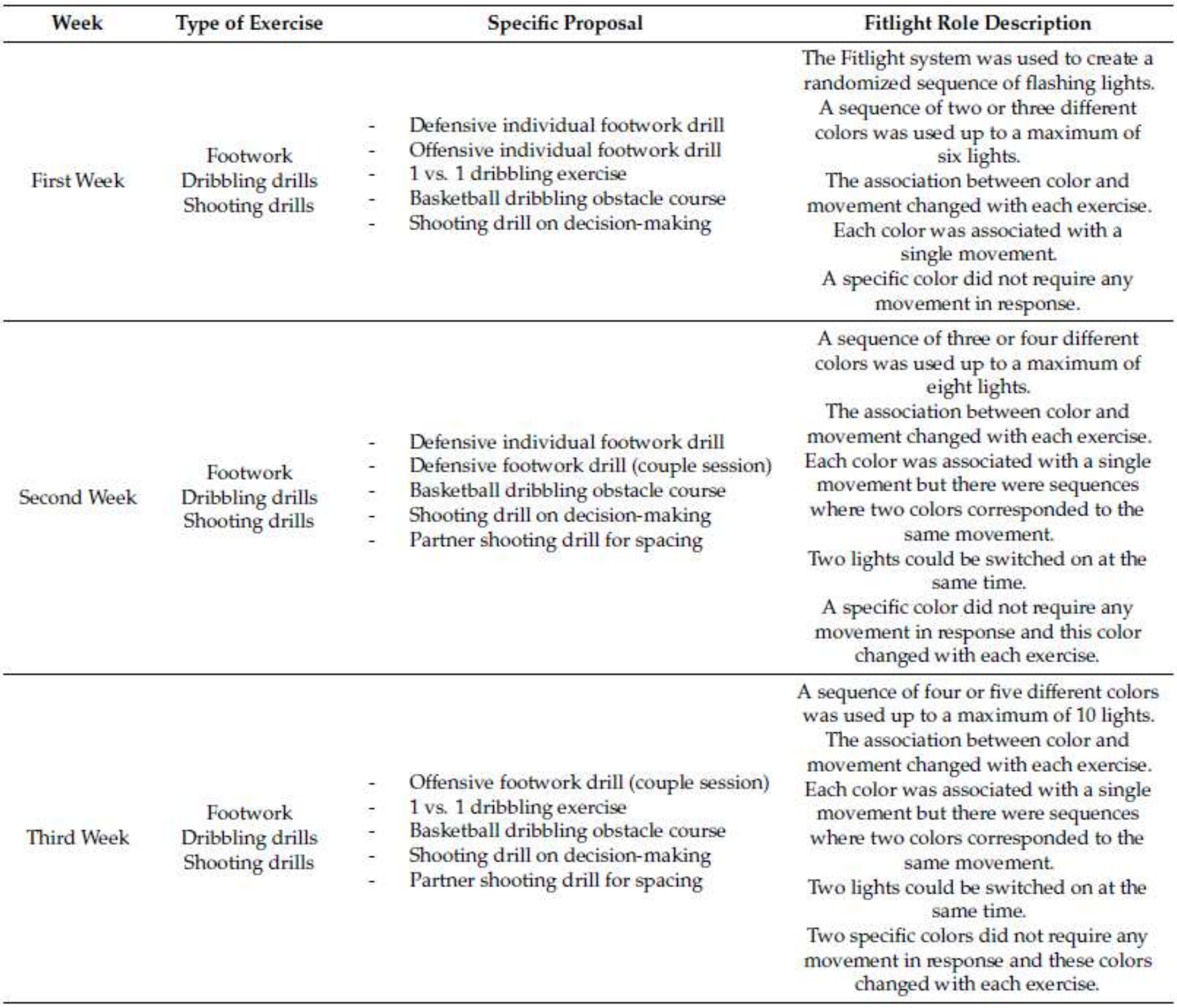
The Institutional Review Board of the University of eCampus (registered number: 02/2021) reviewed and approved this study in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards, as well as the institutional and/or national research committee's ethical standards.

The participants and their parents gave informed and written consent to participate in the study after receiving a written information document.

3.2.2 Experimental Procedures

The research was conducted during the preseason. All volunteers had trained for the study for three weeks, following two weeks of specialized training to prevent injuries and enable better adaptation to the impending load increase. Both groups trained five days a week (Monday through Friday) over the three weeks, taking two days off (Saturday and Sunday). There was usually one training session every day, from 4:00 to 6:00 p.m. Except for the Fitlight training sessions, which were only used in the FITL group while the CTRL group engaged in pair or group shooting practice sessions, the identical training material and methodology were used across all experimental groups. The Fitlight training system was employed in particular to influence decision-making, hand-eye coordination, and peripheral awareness during drills for footwork, shooting, and dribbling (Table 1).

Table 1: Details of the Fitlight training program



Week	Type of Exercise	Specific Proposal	Fitlight Role Description
First Week	Footwork Dribbling drills Shooting drills	- Defensive individual footwork drill - Offensive individual footwork drill - 1 vs. 1 dribbling exercise - Basketball dribbling obstacle course - Shooting drill on decision-making	The Fitlight system was used to create a randomized sequence of flashing lights. A sequence of two or three different colors was used up to a maximum of six lights. The association between color and movement changed with each exercise. Each color was associated with a single movement. A specific color did not require any movement in response.
Second Week	Footwork Dribbling drills Shooting drills	- Defensive individual footwork drill - Defensive footwork drill (couple session) - Basketball dribbling obstacle course - Shooting drill on decision-making - Partner shooting drill for spacing	A sequence of three or four different colors was used up to a maximum of eight lights. The association between color and movement changed with each exercise. Each color was associated with a single movement but there were sequences where two colors corresponded to the same movement. Two lights could be switched on at the same time. A specific color did not require any movement in response and this color changed with each exercise.
Third Week	Footwork Dribbling drills Shooting drills	- Offensive footwork drill (couple session) - 1 vs. 1 dribbling exercise - Basketball dribbling obstacle course - Shooting drill on decision-making - Partner shooting drill for spacing	A sequence of four or five different colors was used up to a maximum of 10 lights. The association between color and movement changed with each exercise. Each color was associated with a single movement but there were sequences where two colors corresponded to the same movement. Two lights could be switched on at the same time. Two specific colors did not require any movement in response and these colors changed with each exercise.

However, while the content of shooting sessions was comparable, the most important goals were to improve shooting skill and mental toughness. Each session lasted 25 minutes and was carried out after the warm-up period at the start of each workout. In accordance with the program shown in Figure 1, all subjects underwent the following tests.

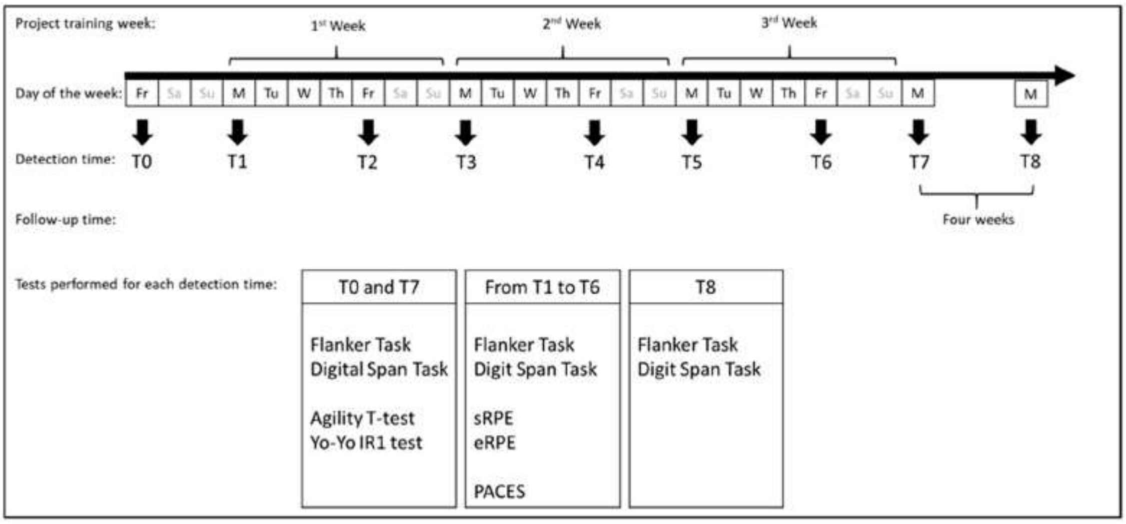


Figure 1: Timetable for the experimental procedures

3.2.3 Measurements

Agility T-Test

The participants' running efficiency was assessed for agility using the agility T-test (Stewart et al., 2014; Chang et al., 2020). Four cones were set up in a T form for the test. In a straight line, three cones were positioned 5 meters apart. The starting cone was positioned 10 meters distant and extended perpendicularly to the center cone. Participants were instructed to run as quickly as they could forward, laterally, and backward between the cones, accelerating to touch each cone base. The performance time was assessed using a dual infrared reflex photoelectric cells system (Polifemo, Microgate, Udine, Italy).

Yo-Yo Intermittent Recovery 1 (Yo-Yo IR1) Test

The ability to engage in intermittent exercise to stimulate maximal activation of the aerobic system was evaluated using the Yo-Yo IR1 test (Nyakayiru et al., 2017). Repeated 2 x 20 m sprint between a starting, turning, and finishing line at an escalating speed indicated by audible bleeps from an audio system made up the test. Subjects had a 10-second active recovery period between each sprint, moving back and forth in a 2 m line behind the start/finish line that was marked with cones. A warning was issued if a subject didn't cross the finish line before the bleep. The test was completed when a subject failed to reach the finish line twice before the beep. The final distance covered was recorded and served as the test result.

Physical Activity Enjoyment Scale (PACES)

Using the PACES survey, enjoyment was quantified. This modified version, created by Motl et al. (2021), had 16 items, 9 of which were positive and 7 of which were negative, with responses on a Likert scale from 1 (“I disagree a lot”) to 5 (“I agree a lot”). All questions concerned feelings about physical activity enjoyment indicating face validity of the questionnaire. Negatively worded items were recorded for the overall scale in order to align with the positively worded scale. The average of the sum of items was then determined.

Borg’s CR-10 Scale

The Borg’s CR-10 scale was used to measure exercise and session ratings of perceived exertion (eRPE and sRPE) (Egan et al., 2006). In the FITL and CTRL groups, respectively, eRPE referred to the perceived effort associated with the Fitlight training or shooting sessions, whereas sRPE referred to the entire training session. Standard instructions and anchoring procedures were presented throughout the familiarization session to assess RPE during the workout sessions. A rating of 0 indicated no effort (rest) and a rating of 10 indicated maximum effort and the most demanding activity completed.

Flanker/Reverse Flanker Task

The Flanker/Reverse Flanker task was performed using a computer (Diamond et al., 2007; Hooper et al., 2022). A set of five fish (blue or pink) was displayed in each of the three successive blocks that made up this test. In the first, all the fish were blue and participants had to indicate the right direction of the central stimulus by selectively reacting and ignoring the side stimuli (Eriksen and Eriksen, 1974).

If the central stimulus was pointing right or left, participants were instructed to push the key on the far right or far left. The second block presented a Reverse Flanker condition, the five fish were pink, and the rule was to press the key corresponding to lateral fish, ignoring the central stimulus.

The blue and pink fish were alternated randomly in block 3 (mixed), while adhering to previous rules. As a result, the test required attentional control, reorienting attention, suppressing prepotent responses, and memorizing both rules (Diamond, 2013; Diamond et al., 2007; Hogan et al., 2018). The assessments evaluated working memory, inhibitory control, and cognitive flexibility, which are the fundamental EFs.

In the first two blocks, the participants completed 22 trials (16 congruent and 6 incongruent), and in the third block, they completed 44 trials (32 congruent and 12 incongruent), for a total of 88 trials. The volunteers received visual feedback during the practice trials that preceded each block (first and second block: 4 trials; third block: 8 trials). These practice trials were not included in the analysis.

Only the third block was used for the analysis. Both the average response time (RT) and the percentage of correctly answered questions (accuracy) were examined. All trials with RT < 250 ms were deemed invalid for these analyses because the players were unable to perceive the stimulus and sufficiently suppress a response before the stimulus was processed. After these trials were disregarded, the percentage of correct responses on valid responses from block 3 was determined. All trials in which the RT exceeded the upper or lower threshold of ± 2 standard deviations were excluded to calculate the mean RT from block 3.

More information regarding the task can be found by Hooper et al. (2022).

Digit Span Task

The Forward-Digit Span and the Backward-Digit Span tasks made up the Digit Span task employed in this study. Short-term memory was measured in the first test, while Working memory was tested in the second (Diamond, 2013).

The participants had to enter a set of digits on a computer keyboard in a certain order after reading them on a screen at a rhythm of one digit per second. They received a longer list if they wrote the words in the right sequence. Up until the individual failed consecutively two attempts of the same digit span length, the number of digits increased by one. The length of the longest list a participant could remember represented his digit span. Participants in the Forward-Digit Span were instructed to repeat the items in the order that they had read them. On the other hand, participants in the Backward-Digit Span had to write the digits backward (Samuel et al., 2017).

The highest number of digits successfully obtained was the span score.

We also estimated the rate of correct score (RCS), which is equal to the span divided by the average RT (de Paula et al., 2016), and the average response time (RT).

3.2.4 Statistical Analysis

The Shapiro-Wilk test was used to study the distribution of each variable. As a descriptive statistical method, mean and standard deviation were employed. We employed two-way repeated measures ANOVAs. Mauchly's test was employed to test the sphericity assumption, and the Greenhouse-Geisser correction was applied when it was infringed. Furthermore, the F1-LD-F1-model of the ANOVA-type statistics for non-parametric longitudinal data analysis from the nparLD R package was utilized when the two-way repeated measures ANOVA assumptions were infringed. When necessary, Bonferroni post hoc analyses were done. The effect size was determined using partial eta-squared (ηp^2) and divided into three categories: small, between 0.01 and 0.09; medium, between 0.09 and 0.25; and large, greater than 0.25. All analyses were carried out in RStudio Version 1.1.463 for Windows, an integrated programming environment for R, with a significance level set at $\alpha < 5\%$.

3.3 Results

3.3.1 Executive Functions

Overall, the EFs test showed progressive improvement in both groups. The EFs test between the FITL and CTRL, as well as the interaction between the groups and time, did not, however, reveal any significant differences.

Flanker/Reverse Flanker Task

The measured outcomes in both groups significantly improved with time (from T0 to T8) on the Flanker/Reverse Flanker task. With a medium effect size, the accuracy of the responses (Figure 2A) considerably improved with time in both groups [F(5.22, 246) = 7.50; $p < 0.001$; $\eta p^2 = 0.14$]. There were no significant differences between the groups [F(1, 47) = 0.04; $p = 0.842$; $\eta p^2 < 0.01$] or between the groups and their interaction with time [F(5.22, 246) = 1.09; $p = 0.369$; $\eta p^2 = 0.02$]. Additionally, both groups' response times (Figure 2B) considerably decreased over time [F(8,376) = 43.08; $p < 0.001$; $\eta p^2 = 0.48$], with a big effect size. There were no significant differences between the groups [F(1, 47) = 0.07; $p = 0.786$; $\eta p^2 < 0.01$] or between the groups and their interaction with time [F(8, 376) = 1.12; $p = 0.345$; $\eta p^2 = 0.02$].

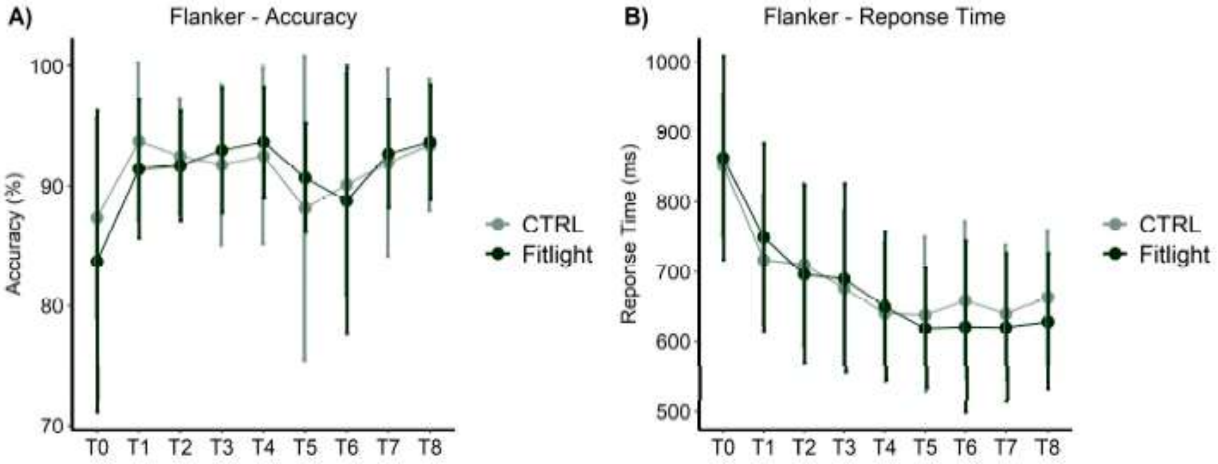


Figure 2: Results of Flanker/Reverse Flanker task over time and between groups in all conditions. (A) Flanker/Reverse Flanker task accuracy; (B) Flanker/Reverse Flanker task response time

Forward and Backward Digit Span

Both groups significantly improved their span scores (Figure 3A, D) in forwards [$F = 2.97$; $p = 0.004$; $\eta p^2 = 0.05$] and backwards [$F = 4.60$; $p < 0.001$; $\eta p^2 = 0.09$] over time in the Forward and Backward Digit Span working memory test (Figure 3). Additionally, both groups significantly enhance the time to respond to correctly remembered answers in forward (Figure 3B, E) [$F(8, 376) = 3.70$; $p < 0.001$; $\eta p^2 = 0.07$] and backwards [$F(5.9,278) = 2.70$; $p = 0.015$; $\eta p^2 = 0.05$] over time. There were no significant differences between the groups and in the interaction between the groups and time, in both span and response time. Furthermore, both groups significantly increased the rate of correct scores in the first time measures for both forwards and backwards [$F(6.1, 286) = 12.6$; $p < 0.001$; $\eta p^2 = 0.21$] and [$F(5.1,238) = 9.90$; $p < 0.001$; $\eta p^2 = 0.17$] (Figure 3C, F). A significant interaction between the groups and time was also revealed by the analysis of the rate of accurate scores [$F(6.1, 286) = 2.9$; $p = 0.008$; $\eta p^2 = 0.06$] in the Forward-Digit Span. Compared to the CTRL group, the FITL group reported a higher rate of correct score throughout the training sessions.

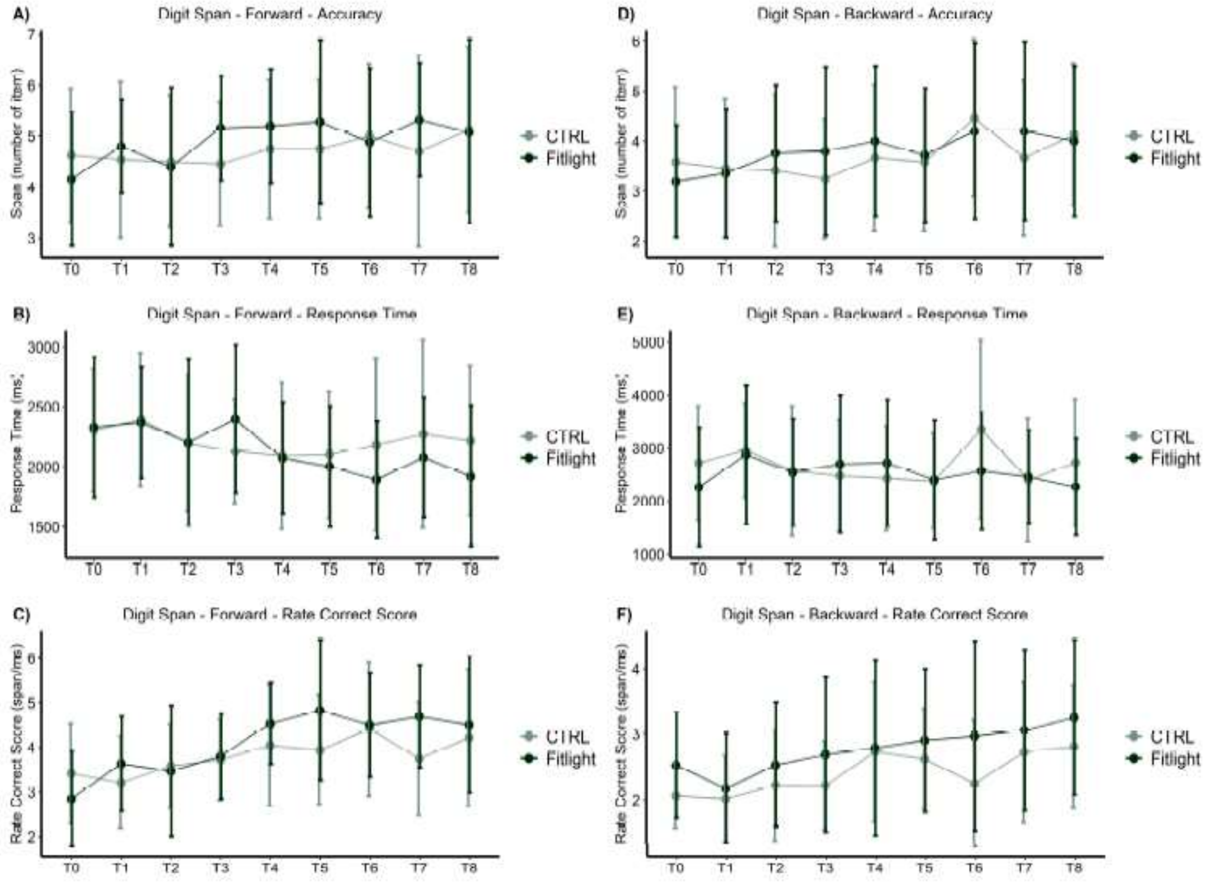


Figure 3: Results of Digit Span over time and between groups in all conditions: (a) span in Forward-Digit Span; (b) response time in Forward-Digit Span; (c) rate of correct scores in Forward-Digit Span; (d) span in Backward-Digit Span; (e) response time in Backward-Digit Span; (f) rate of correct scores in Backward-Digit Span

3.3.2 Perceived Effort

A significant difference in the interaction between the groups and time was revealed by the study of the eRPE from T1 to T6 [F = 2.86; p = 4.69; ηp² = 0.03]. A significant (p = 0.01) greater perceived effort was found in the FITL group (Figure 4A). No significant differences in the groups [F = 1.64; p = 0.200; ηp² = 0.02] and in the time [F = 1.00; p = 0.412; ηp² = 0.02] were discovered (Figure 4A). Additionally, the analysis of the sRPE (Figure 4B) from T1 to T6 revealed a significant difference in time (F = 4.16; p = 0.002; ηp² = 0.08) and in the interaction of groups and time (F = 5.50; p < 0.001; ηp² = 0.10). Particularly, when compared to the CTRL group, the FITL group had a greater perceived effort throughout the entire training sessions [F = 1.64; p = 0.200; ηp² = 0.3]. No significant differences between the groups were discovered.

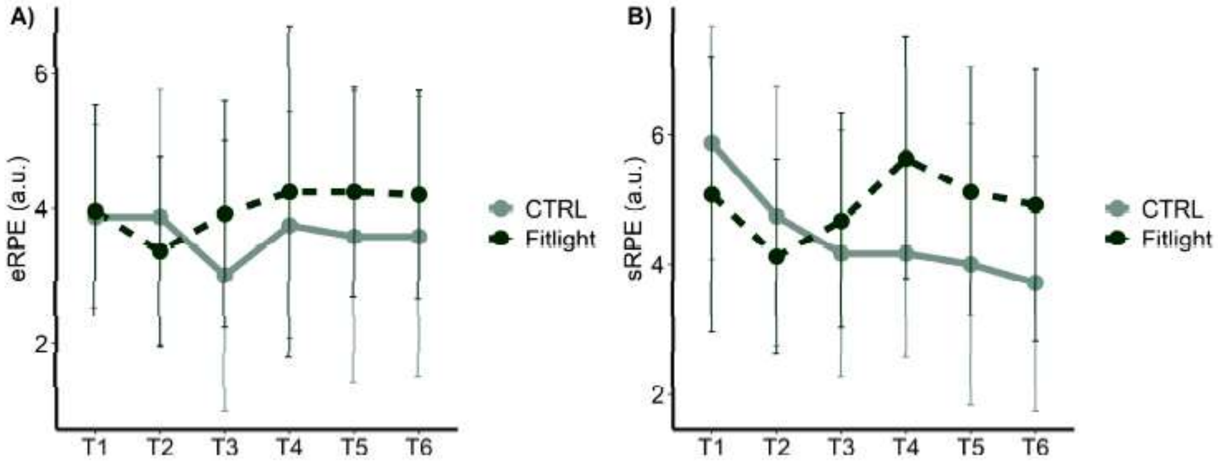


Figure 4: Results of Rate of perceived exertion (RPE) over time and between groups in all conditions: (A) exercise ratings of perceived exertion in arbitrary units; (B) session ratings of perceived exertion in arbitrary units

3.3.3 Session Enjoyment

The evaluation of athletes' satisfaction (PACES) during training, as shown in Figure 5, reported no significant differences in the groups [F(1,47) = 0.07; p = 0.797; ηp² < 0.01], time [F(2.2,103.34) = 1.04; p = 0.361; ηp² = 0.01], and interaction between the groups and the time [F(2.2,103.34) = 0.614; p = 0.558; ηp² < 0.01].

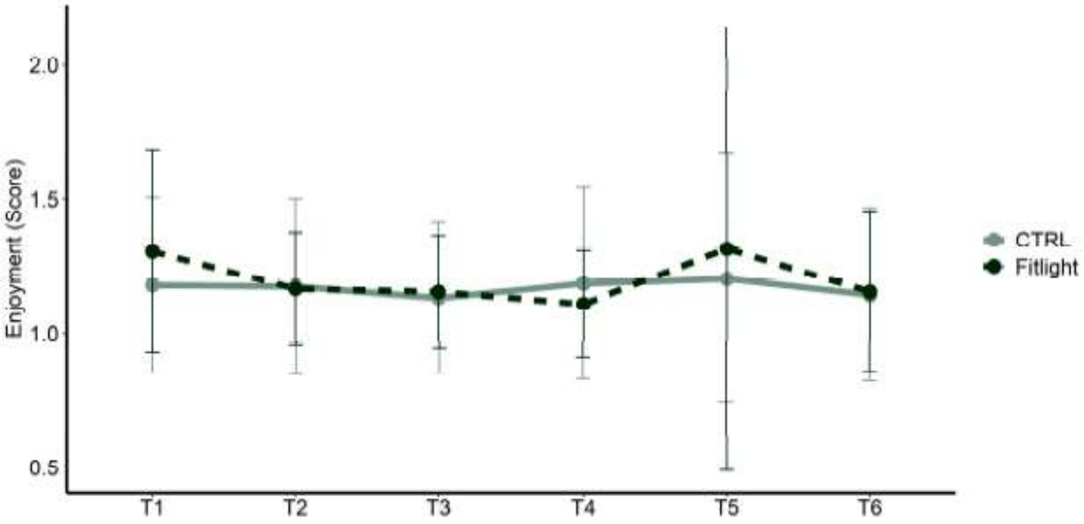


Figure 5: Results of Enjoyment scores over time and between groups in all conditions

3.3.4 Fitness Tests

Following a period of mass basketball practice, both groups' results on the fitness tests significantly improved.

The time required to complete the agility test (Figure 6A) significantly decreased with time, indicating an increase in agility in both groups [$F(1,47) = 11.098$; $p = 0.002$; $\eta p^2 = 0.19$]. There were no significant differences between the groups [$F(1,47) = 0.02$; $p = 0.882$; $\eta p^2 < 0.01$] or between the groups and their interaction with time [$F(1,47) = 0.058$; $p = 0.810$; $\eta p^2 < 0.01$].

Both groups significantly increased their final scores over time in the Yo-Yo IR1 assessments (Figure 6B) [$F(1,47) = 22.47$; $p < 0.001$; $\eta p^2 = 0.32$]. Additionally, the Fitlight group outperformed the CTRL group in the Yo-Yo IR1 tests [$F(1,47) = 7.23$; $p = 0.010$; $\eta p^2 = 0.13$]. There was also a significant difference in the interaction between the groups and time [$F(1,47) = 5.09$; $p = 0.029$; $\eta p^2 = 0.10$] with the Fitlight group outperforming the CTRL group at T7.

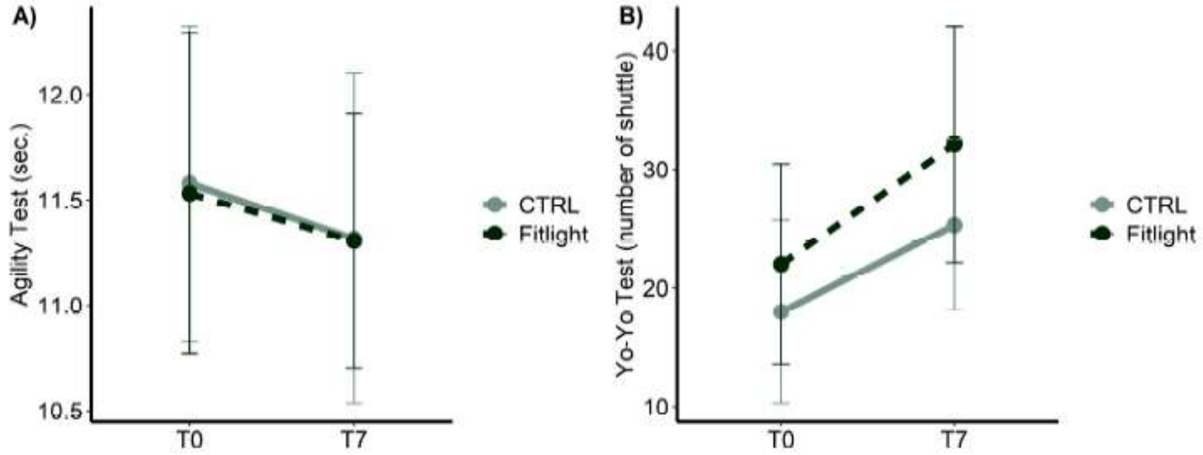


Figure 6: Results of Fitness test over time and between groups in all conditions. (A) agility test; (B) yo-yo test

3.4 Discussion

In this study, before and after a massed training period, we examined the impact of CMT on cognitive and physical factors in basketball players also measuring their perceptions of effort and enjoyment. The most important discovery was that three weeks of massed basketball training (BT) significantly increased the EFs of players, regardless of the type of training they received (basketball drills vs. Fitlight training). Even though they employed different study methods, these findings are coherent with prior papers that examined the effects of BT on EFs. For example, Xu and colleagues (2022) comparing children (6 to 8 years old) with low and high week BT workload, found that participation in BT (more than twice per week) was positively associated with an improvement in EFs. Additionally, Wang and colleagues (2020) discovered that, compared to a control group (keeping usual daily activities), 12 weeks of mini-BT (five days per week) had a positive impact on EF development in children aged 6 to 12 with autism spectrum disorder. Thus, in line with earlier research (Contreras-osorio et al., 2021; Waelle et al., 2021; Diamond & Ling, 2016; Koch & Krenn, 2021), our findings add to the body of knowledge that supports the causal relationship between open-skill sports and cognitive development in childhood. While there were no significant differences between the groups on the EF tasks, both groups significantly improved over time (from T0 to T8). Additionally, we noted a significant impact on the rate of correct scores in the Forward-Digit Span, a measure of working memory processing speed, in the interaction between the groups and time. This finding implies that a Fitlight intervention could enhance working memory in addition to basketball training (Diamond, 2013). The results must be interpreted cautiously, given the other parameters did not differ between the groups. Generally, the findings of prior studies on transfers between various domains have been conflicting (Fransen, 2022) (for example, Fitlight with a basketball training intervention to EFs). For example, Badau and colleagues (2022) used the Fitlight technology to train athletes for three months in open-skill sports (basketball, handball, and volleyball) and discovered that the athletes' cognitive reaction time, which is a parameter used to measure cognitive flexibility, had significantly improved after the training period. Additionally, they discovered after a period of CMT that in basketball (Diamond, 2013) and open-skill sports (Badau et al., 2022) players' cognitive tests and athletic performance significantly improved.

The different intervention times, which in our study consisted of 3 weeks of mass Fitlight training, five times per week, while Badau and colleagues' (2022) program used a 12-week program three times per week, could be the cause of the disparate results. Despite having a similar overall training load, distributed cognitive training may be a prerequisite for achieving appreciable EF increases during sports practice. This may be why our 3-week program was unable to produce significant cognitive improvements. Theofilou and colleagues (2022) found no significant enhancement in cognitive outcomes in adolescent soccer players after 6 months of training intervention with a visual stimulus program, which is in line with our findings. Therefore, more research is required to determine the possible advantages of Fitlight training for EFs in open-skill sports. In particular, to comprehend the ideal volume and frequency for cognitive improvement, it may be pertinent to examine alternative distributions of cognitive training treatments (massed vs distributive). Additionally, we discovered that throughout three weeks of intervention, the FITL-trained group had higher sRPE (the perceived effort for the duration of the entire daily session). The same outcomes were observed when the eRPE (perceived effort only during the Fitlight session or shooting session) was evaluated. This final finding makes us believe that the varied intervention type is most likely the cause for the increased perceived effort throughout the entire training session. The greater sRPE and eRPE results likely reflect the fact that the FITL group training required more cognitive work. Because of this, even though both interventions similarly enhance EFs, our results could imply that adding Fitlight training to a basketball session could increase the training effort by increasing the cognitive demands as evidenced by both sRPE and eRPE compared to the execution of basketball exercises.

According to recent research, a greater perceived effort is the best predictor of mental weariness in sports (Van Cutsem et al., 2017). RPE's role in the relationship between mental exhaustion and sport-specific performance, however, is still unclear (Habay et al., 2021a). Although extensive literature suggests that mental fatigue caused by cognitive demands can impair sport performance (Habay et al., 2021a; Habay et al., 2021b; Van Cutsem et al., 2017), including basketball technical and cognitive performance (Cao et al., 2022; Faro et al., 2022), more recent research have suggested that athletes can improve their tactical performance while already experiencing pre-induced mental fatigue by improving their action selection and attentive focus (Silva et al., 2023).

Future studies should therefore examine whether the mental exhaustion caused by Fitlight training improves performance in a particular sport. Since enjoyment and motivation (Jung et al., 2021) are favorably linked to improved EFs in childhood (Ishihara et al., 2017), they may also have an impact on training progress in sports practice. In our research, we discovered that PACES did not reveal any differences in the negative effects of the two different training programs (Fitlight vs basketball drill sessions) between the groups. This information implies that the increased effort, probably caused by Fitlight training, had no impact on the satisfaction of training sessions, taking into account the findings of the sRPE and eRPE research.

In terms of the study of the fitness tests, it was discovered that the 3 weeks of massed training significantly improved the agility and Yo-Yo IR1 scores. However, there were no significant differences across the groups. The intervention's focus on improving cognitive and technical abilities rather than metabolic training may help to explain the outcomes about the Yo-Yo IR1 test, a test that measures metabolic performance. On the other hand, we hypothesized differences between the groups in the agility tests, consistent with earlier research that showed increased values in repeated sprints following the Fitlight training intervention in young soccer players (Theofilou et al., 2022). However, the authors utilized a 6-month intervention period with daily cognitive training sessions of 15 minutes. As a result, if agility were compared to the length of our program, a longer intervention period might be required to see significant enhancement. This research has several restrictions. Since the study's participants were exclusively male athletes, gender variations in CMT and EFs could not have been examined. It's possible that the duration of the massed intervention was too brief to find any potential variations in EF improvement in response to CMT. However, the intervention was designed to be completed over 3 weeks to accommodate seasonal sports commitments.

Furthermore, it's hard to project ecological protocols that might analyze and describe how the improvement in EFs affects sports performance during match actions and contests, even if validated motor and cognitive tests were employed to evaluate the progress of athletes.

3.5 Conclusions

In conclusion, we discovered that a 3-week basketball training program enhanced the cognitive and physical performance of young basketball players. However, in addition to this program, CMT using the Fitlight training method enhanced perceived effort without lowering enjoyment. Fitlight training may therefore be a helpful strategy to enhance mental effort without reducing athletes' motivation during basketball practice. Fitlights^{TM} and other sensorized light systems may improve training variability management (such as colors of light and stimulus start time). Additionally, it enables the creation of customized training plans, allowing coaches to oversee small teams of athletes at the same time and customize their training. As a result, these tools can help CMT development and execution, promote EFs, and enhance the strategic decision-making of an athlete. Given the findings of this study, a massed cognitive-motor program lasting just three weeks would appear to be unable to further enhance EFs development in young basketball players. To date, it is still unclear how long an intervention should last before CMT training can significantly improve EFs. According to the current literature, 8 to 12 weeks of CMT appear to be able to improve EFs (Badau et al., 2022; Benzing & Schmidt, 2019) and a distributed program appears to be a prerequisite for EFs development in open-skill sports. This should be taken into account by coaches when creating seasonal training plans. The connections between EFs and physical training still raise many requests without answers. Future studies should look at which EFs are improved by a particular CMT, a possible motor task to better promote EF activation, as well as how long these enhancements stay. To better understand the potential effects of a high level of EFs on various sports practices, it will be important in this framework to fill the gap between EF development and sport performance.

Chapter 4. Study 2 “Effects of Fitlight training on cognitive-motor performance in élite judo athletes”

4.1 Introduction

Executive functions (EFs), a group of cognitive processes that includes inhibition (including selective attention), working memory, and cognitive flexibility (including creativity and mental flexibility), are essential for many daily tasks from early childhood through later stages of life. These abilities, often defined as basic EFs, are essential for the development of higher-order EFs including planning, reasoning, and problem-solving (Diamond, 2013). Researchers have identified physical activity (PA) and sport practice (SP) as two activities that, when integrated with the appropriate inputs, may improve EFs (Diamond, 2012; Kolovelonis, 2022). In fact, since SP frequently involves both physical and cognitive participation, playing sports may have a positive impact on EF development, particularly in children and adolescents (Contreras-Osorio, 2022; Contreras-Osorio, 2021). Recent studies have shown that EF development is age-related and rises in accordance with growth (Beavan, 2019) until the young adult stage (Stuss, 1992). On the other hand, there is still debate over the impact of aging on some EFs parameters, such as response accuracy (Beavan, 2019; Heilmann, 2022a).

According to earlier research, the type of SP, such as open- or closed-skills sports, can have a several impact on how EFs develop (Wang, 2013; Heilmann, 2022b). When playing open-skill sports, which can enhance the cognitive involvement of EFs (such as working memory or stimulus inhibition) (Contreras-Osorio, 2022; Contreras-Osorio, 2021), numerous elements and stimuli should be taken into consideration. Gu et al. (2019) evaluated the effects of open and closed-skill activities on EFs development in a systematic review and discovered that open-skill activities had larger benefits on EFs improvement in both children and adults. The complexity of the open-skill sports environment, according to earlier studies, has a significant positive impact on both the motor and cognitive domains (Diamond, 2015; Formenti, 2021).

The relationship between open-skill sports and EFs is strongly supported by research in both team sports like football, basketball, or volleyball (Vestberg, 2017; Huijgen, 2015; Alves, 2013; Policastro, 2018) as well as individual sports like tennis (Ishihara, 2017) or combat sports like judo, karate, and taekwondo (Lo, 2019; Alesi, 2014; Lakes, 2013; Lakes, 2004). According to all of the above mentioned studies, practicing open-skill sports can promote EFs development.

The stronger EF involvement, according to Heilmann et al. (2022b), appears to be more closely related to the cognitive demands of a specific sport than to the clear distinction between open- and closed-skill exercises. Participants in open-skill sports like martial arts must be able to react quickly in a dynamic environment (Wang, 2013; Yu, 2017). Indeed, the primary judo techniques of grappling and throwing contribute to the alteration of conditions and environments (Lo, 2019).

Additionally, the high levels of cognitive and physical demands, such as those for planning, problem-solving, and shifting, may support the growth of EFs by promoting neuroplasticity related growth factors like brain-derived neurotrophic factor (BDNF) (Cho, 2017; Voss, 2010). Earlier research didn’t just focus on set-shifting but also looked at how martial arts affected inhibition. Only a small number of studies, mostly focusing on young and amateur athletes, examined the effect of judo training on EFs. The next step is to discover whether Judo training enhances EFs in élite athletes as well as in adolescents and young adults (Lo, 2019).

Numerous studies have employed sensorized light systems, such as Fitlight^{TM}, as a form of cognitive-motor training (CMT) to enhance EFs (Lucia, 2021; Badau, 2022).

Reaction times of athletes are also optimized using the Fitlight training system^{TM}, which has been shown to enhance EF involvement during a variety of sport activities. In particular, these tools can interact with users by presenting them with entertaining and demanding activities during physical training sessions. Fitlights^{TM} may also help with training variability management (by controlling for example color of light and stimulus start time). Additionally, it makes it possible to create personalized training programs, giving coaches the possibility to manage groups of players at the same time and adjust their training. Therefore, these tools can support CMT development and execution, promote EFs, and improve the ability to make strategic decisions of an athlete. Numerous motor exercises have been developed as a result of the capacity to activate executive functions (working memory, inhibition, and cognitive flexibility) (Lucia, 2021). According to the above-mentioned study, CMT training methods enhanced sports performance and cognition more than training that only involved physical activities. Additionally, Badau et al. (2022) discovered that after a 12-week program of Fitlight training, open-skill athletes showed quicker reaction times in computerized evaluations.

To date, there are no studies available that used CMT with Fitlights to enhance EFs in martial arts, specifically in Judo.

The purpose of the current study was to determine if young adult athletes' EFs (specifically, response inhibition, working memory, and cognitive flexibility) and physical performance (isometric strength, resistance strength of the upper limbs, explosive-elastic strength of the lower limbs and specific fitness index) could be improved by the Fitlight training system^{TM}, which was used to cognitively enrich a massed judo training program. In addition, during judo practice, the rate of perceived exertion and enjoyment were assessed to investigate athletes' perceptions of CMT. The specific objectives of this study were: 1) to determine whether a 5-week cognitive-motor training (CMT) program with Fitlight^{TM} improved EFs in young adults élite judo athletes when compared to a non-intervention group, 2) whether CMT had an impact on BDNF and IgA levels in the experimental group when compared to the non-intervention group, 3) whether the CMT changed physical fitness in the experimental group, 4) to verify if CMT induced changes on the enjoyment of training in the experimental group compared to a non-intervention group, 5) to verify if CMT induced greater fatigue in the experimental group compared to the non-intervention group, 6) to verify if the CMT induced changes in psychobiosocial states in the experimental group, 7) to determine whether CMT results were related to athletes' performance in competition. As compared to the control group, we predicted that a CMT with Fitlight would bring an improvement of EFs, a trend to increase physical fitness, and higher levels of BDNF and IgA in the experimental group. In addition, we predicted that a CMT with Fitlight^{TM} would show an improvement in the enjoyment of training and perceived effort and a tendency to increase in the psychobiosocial states in the experimental group compared to the control group. Finally, a relation between CMT outcomes and athletes’ performance in competition was expected.

4.2 Materials and Methods

4.2.1 Participants and Study Design

Using a within-between subjects design, a priori analysis with G*Power revealed that 24 participants were capable of detecting a medium effect size (f = 0.25) with a coefficient of correlation of r = 0.6, 80% power and $\alpha = 0.05$. So, taking into account a possible drop-out percentage, 30 élite judoka were recruited from “Banzai Cortina” Judo Club (Rome, IT). Three athletes left the study in the middle of it because they were unable to maintain their training programs. Then, a randomized controlled interventional study was then carried out on 27 athletes (14 men and 13 women; age = 19.5 ± 2.0 years). All athletes were randomly assigned to two groups: the Fitlight-trained group (FG, n=14; 8 males and 6 females) who received the Fitlight training (FitT) in addition to the traditional training, while the control group (CG, n=13; 6 males and 7 females) was just engaged in the traditional training. Table 2 reported sample characteristics.

Table 2: Sample characteristics

	FG (mean, SD)	CG (mean, SD)	All participants (mean, SD)
Number	14	13	27
Males	8	6	14
Females	6	7	13
Age	20.1 ± 1.7	18.8 ± 2.1	19.5 ± 2.0
Weight (kg)	75.6 ± 14.6	68.5 ± 10.7	72.2 ± 13.1
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1
BMI (kg/m^2)	25.3 ± 2.5	24.3 ± 2.0	24.8 ± 2.3

The requirements for participation were as follows:

- having good physical and mental health and being free of any illnesses that might affect the research;

- having a brown or black belt;

- participating in judo competitions and training at the national or international level for at least eight years after the project;

- training consistently over a long period (four times a week for at least 90 minutes in judo in the previous five years);

- being between the ages of 17 and 24.

This study was reviewed and approved by the University of eCampus Institutional Review Board in compliance with the 1964 Helsinki Declaration and any subsequent changes or comparable ethical standards (registered number: 02/2021).

Before taking part in the study, every participant or their parents, if the athletes were minors, provided informed and written consent.

4.2.2 Experimental Procedures

The study was carried out before the World and European Championships (Guayaquil 2022 and Prague 2022), during the competitive phase of the season and before the start of any weight loss program. Measurements of executive functions were taken before and after the intervention as well as two months later (T0, T1, and T2), whereas measurements of physical fitness were taken only at T0 and T1. All participants in the study trained three times a week (one session per day) for a total of five weeks. Both groups carried out the same amount of work, however, the FITL group carried out Fitlight training sessions and the CTRL group practiced traditional judo. After the initial warm-up phase, which was shared by both groups, the following 25 minutes phase was divided as follows:

FG completed the FitT, which also included uchi-komi exercises (drills of techniques without projection), to affect stimuli discrimination, inhibition capacity and working memory (see Table 3). On the other hand, CG practiced traditional training, which included uchi-komi exercises (without fitlights) and technical-tactical situations to advance technical capacity.

Table 3: experimental training protocol. Positive: attack execution; negative: inhibition

Week	Workout	Type of training	Number of fitlight colors	Notes
1st	1st	non-specific sport	1	
	2nd	uchi-komi	1	
	3rd	uchi-komi	2	1 positive color and 1 negative
2nd	4th	non-specific sport	2	
	5th	uchi-komi	2	change color association
	6th	uchi-komi	2	change color association
3rd	7th	non-specific sport	3	2 positive colors and 1 negative
	8th	uchi-komi	3	
	9th	uchi-komi	3	change color association
4th	10th	uchi-komi	3	change color association
	11th	uchi-komi	4	2 positive colors and 2 negative
	12th	uchi-komi	4	change color association
5th	13th	uchi-komi	4	change color association
	14th	uchi-komi	4	change color association
	15th	uchi-komi	4	change color association

4.2.3 Measurements

Anthropometric measurements

The following participants' anthropometric measurements were assessed: body-weight, height, Body Mass Index (BMI) and body composition.

Using a scale and a stadiometer, the participants' weight and height were calculated to the nearest 0.1 kg and 0.1 cm, respectively. Body composition was measured by the bioelectrical impedance method (BIA AKERN 101 Anniversary, Pontassieve, FI, Italy) (Figure 7).

Figure 7: BIA AKERN 101 Anniversary, Pontassieve, Italia

Physical fitness assessment

Dynamic judogi chin-up

The initial recommendations made by Franchini et al. (2011) were followed for this test and it was employed to assess strength endurance. The participants were told to execute as many correct repetitions as they could while extending and flexing their elbows until the chin was above the hands holding the judogi (judo outfit).

When athletes stopped on their own or were unable to finish the explained exercise correctly, the test was declared over. They were not allowed to bend their backs or lift their knees to help with the activity while they were tested; they had to maintain complete knee extension (Figure 8). Finally, to relativize the work done by the participants during the test, body mass was multiplied by repetitions.

Isometric judogi chin-up

As previously mentioned, this test assessed strength endurance in accordance with the previous recommendations made by Franchini et al. (2011). The athletes were told to maintain the position for as long as they could with their elbows flexed and chin raised over the hands holding the judogi. A chronometer was used to measure the amount of time held. When athletes were unable to maintain the initial isometric position, the test was terminated. To start the test, they held the judogi with bent elbows. When the participants extended their elbows as a sign of fatigue, the test concluded and the chronometer was stopped. The athletes had to keep their knees completely extended and were not allowed to flex their trunks or lift their knees in order to maintain the isometric position for a longer period (Figure 8). To relativize participants' performance, body mass was multiplied by the duration of the test.

Figure 8: Dynamic and Isometric chin-up

Countermovement jump (CMJ)

By countermovement jump with an optical detecting device made up of a transmitting and a receiving bar (Optojump, Microgate, Udine, Italy), the explosive strength of the lower limbs was assessed. After a brief warm-up, the participant was positioned between the two bars with his hands on his hips in a standing position (Figure 9). After that, he quickly executed a push-up on his legs and then jumped as high as he could. A specific software recorded the best (highest) of the three outcomes in centimeters during three attempts with a gap of 10 seconds between them (Glatthorn et al., 2011).

Figure 9: CMJ

Handgrip test

According to the recommendations of Guidetti et al. (2002), the maximum voluntary isometric grip strength of the hand was determined using a digital dynamometer with an adjustable grip (CAMRY EH101, Senssun Weighing Apparatus Group Ltd, Guangdong, China) (Figure 10). The participant had to use one hand to grip the dynamometer while standing. When the test has conducted the arm and hand holding the dynamometer should never come into touch with the body and the elbow was fully extended. The participants had to apply as much force as they could to the dynamometer without moving their arm. The best of the two outcomes from the two trials which were completed using the right and left hands, respectively, is reported in kilograms.

Figure 10: Handgrip

Special judo fitness test

The Special Judo Fitness Test (SJFT) was carried out in accordance with Sterkowicz's initial recommendations (1995). The SJFT is composed of three times (A, 15 sec; B, 30 sec; and C, 30 sec), each separated by 10-sec intervals. The tested athlete throws two partners, at a distance of 6 m from each other, as many times as he can utilizing the ippon-seoi-nage technique, during each period (Figure 11). All participants who will be taking part in the test should have comparable height and body mass features. A heart rate monitor (RS 400, Polar Electro™, Kempele, Finland) was used to measure the athletes' heart rates immediately following and one minute after the conclusion of the test. The SJFT index was then determined using the formula reported in following Figure 12.

$$\text{SJFT Index} = \frac{\text{Final HR (bpm)} + \text{HR 1 min (bpm)}}{\text{Throws in total (N)}}$$

Figure 11: SJFT index

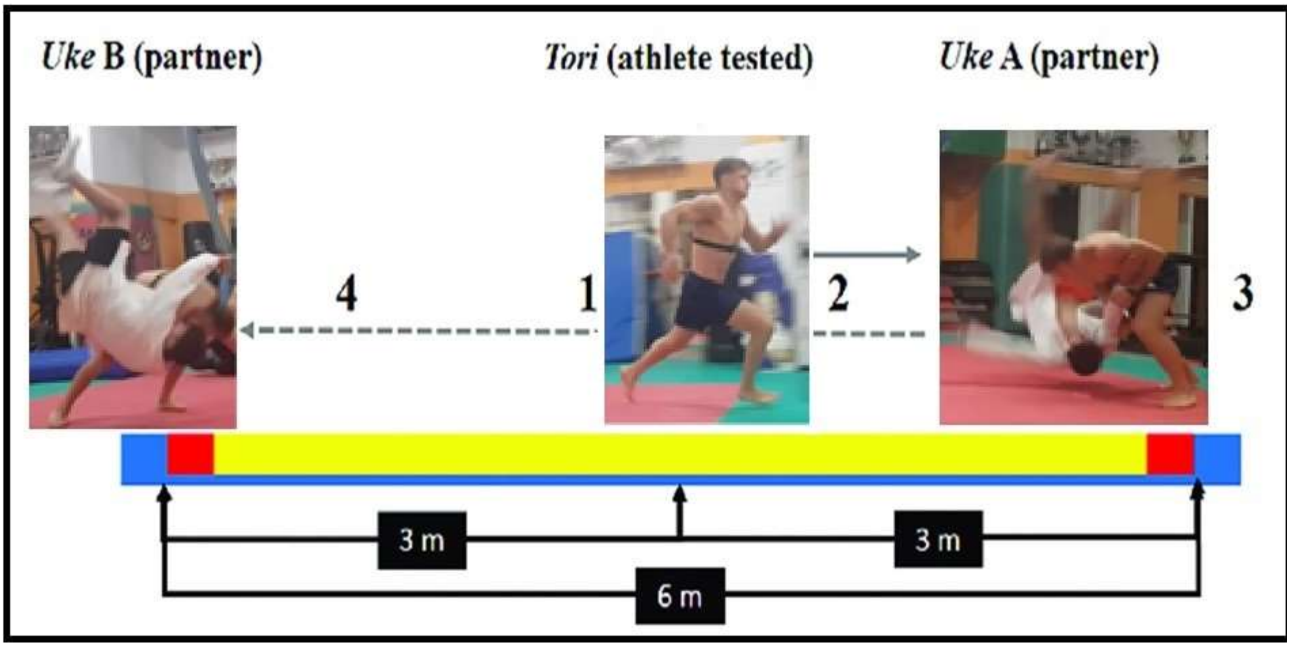


Figure 12: SJFT performed by Mattia Miceli (European Champion)

Salivary measurements

Saliva analysis was used to examine BDNF and IgA levels. Devices for ultrapure polypropylene sampling (SaliCaps) with less than 5% absorption were employed. The athletes were instructed to wait 30 minutes after eating, drinking, or chewing gum before providing a saliva sample because it would affect the results. Any blood-contaminated saliva samples from bleeding gums or oral cavity lesions were eliminated (Kivlighan et al., 2004). Samples were frozen and thawed before analysis to reduce viscosity and make the solution simpler to pipette and aliquot as required (Schultheiss et al., 2009). Before and after the initial experimental training for both groups as well as before and after the final experimental training, saliva samples were collected.

EFs assessment

Flanker/Reverse Flanker Task

Computers were used to complete the Flanker/Reverse Flanker task (Diamond et al., 2007; Hooper et al., 2022) (Figure 13). Each of the three succeeding blocks that made up this test presented a group of five fish, blue or pink. All fish in the first block were blue, and athletes had to choose their responses carefully while neglecting lateral fish to point in the right direction of the central fish. The athletes were instructed to press the letter “L” if the central fish was turned to the left and the letter “A” if it was turned to the right. The five fish in the second block (Reverse Flanker) were pink, and the rule was to push the key that was equivalent to the fish on the outside while ignoring the others. In block 3, the blue and pink fish were alternated at random while still following the fish’s color rules. As a result, the test demanded the ability to control attention, inhibiting overbearing responses, refocus attention, and recall both rules (Diamond, 2013; Diamond et al., 2007; Hogan et al., 2018). After that, the basic EFs (working memory, inhibitory control, and cognitive flexibility) were assessed. The athletes completed 88 trials in total, with 22 trials (16 congruent and 6 incongruent) in the first two blocks and 44 trials (32 congruent and 12 incongruent) in the third block. During the practice trials that preceded each block (four trials for the first and second blocks and eight trials for the third block), the athletes received visual feedback. These trial simulations were left out of the analysis. The percentage of correct answers (accuracy) and the mean response time (RT) for the right answers were calculated.

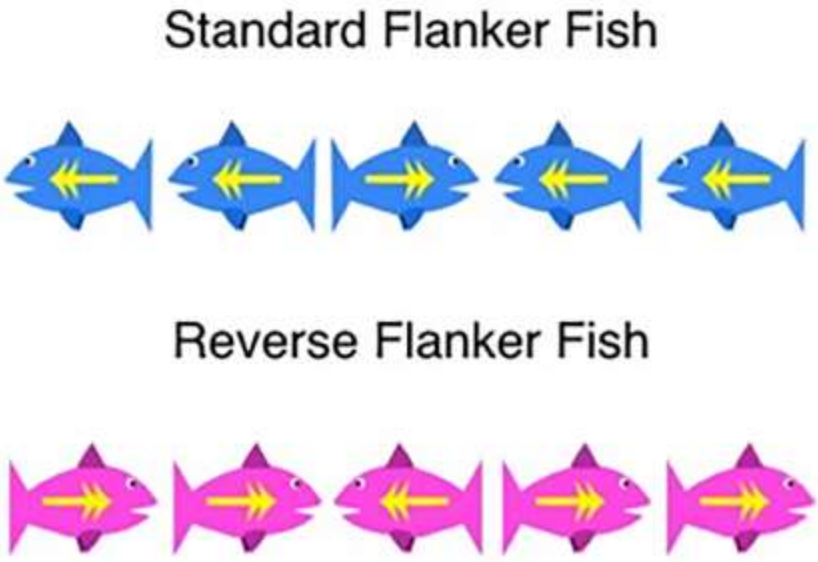
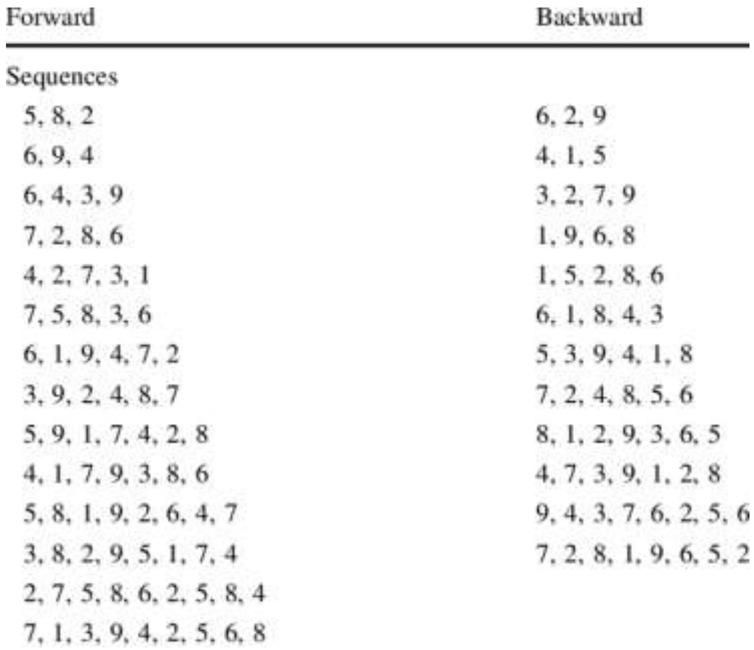


Figure 13: Flanker test

Digit Span Task

The Digit Span task used in this study consisted of the Forward-Digit Span and the Backward-Digit Span tasks (Figure 14). The first one assessed short-term memory and the second one tested working memory (Diamond, 2013). The athletes had to enter a series of digits in a specific order on a computer keyboard after reading them on a screen at a rate of one digit per second. If they entered the numbers in the correct order, they were given a longer list. Up until the athlete missed two consecutive trials of the same digit span length, the number of digits increased by one. The length of the longest list that a participant could recall corresponded to the digit span. The items were to be recited again by participants in the Forward-Digit Span in the same sequence that they had been read. The Backward-Digit Span, on the other hand, required participants to enter the digits backwards (Samuel et al., 2017). The span score had the most digits that could be successfully achieved. Additionally, the rate of correct score (RCS), which is determined by dividing the number of correct responses by the average response time (RT in ms), has been calculated (De Paula et al., 2016).



Forward	Backward
Sequences	
5, 8, 2	6, 2, 9
6, 9, 4	4, 1, 5
6, 4, 3, 9	3, 2, 7, 9
7, 2, 8, 6	1, 9, 6, 8
4, 2, 7, 3, 1	1, 5, 2, 8, 6
7, 5, 8, 3, 6	6, 1, 8, 4, 3
6, 1, 9, 4, 7, 2	5, 3, 9, 4, 1, 8
3, 9, 2, 4, 8, 7	7, 2, 4, 8, 5, 6
5, 9, 1, 7, 4, 2, 8	8, 1, 2, 9, 3, 6, 5
4, 1, 7, 9, 3, 8, 6	4, 7, 3, 9, 1, 2, 8
5, 8, 1, 9, 2, 6, 4, 7	9, 4, 3, 7, 6, 2, 5, 6
3, 8, 2, 9, 5, 1, 7, 4	7, 2, 8, 1, 9, 6, 5, 2
2, 7, 5, 8, 6, 2, 5, 8, 4	
7, 1, 3, 9, 4, 2, 5, 6, 8	

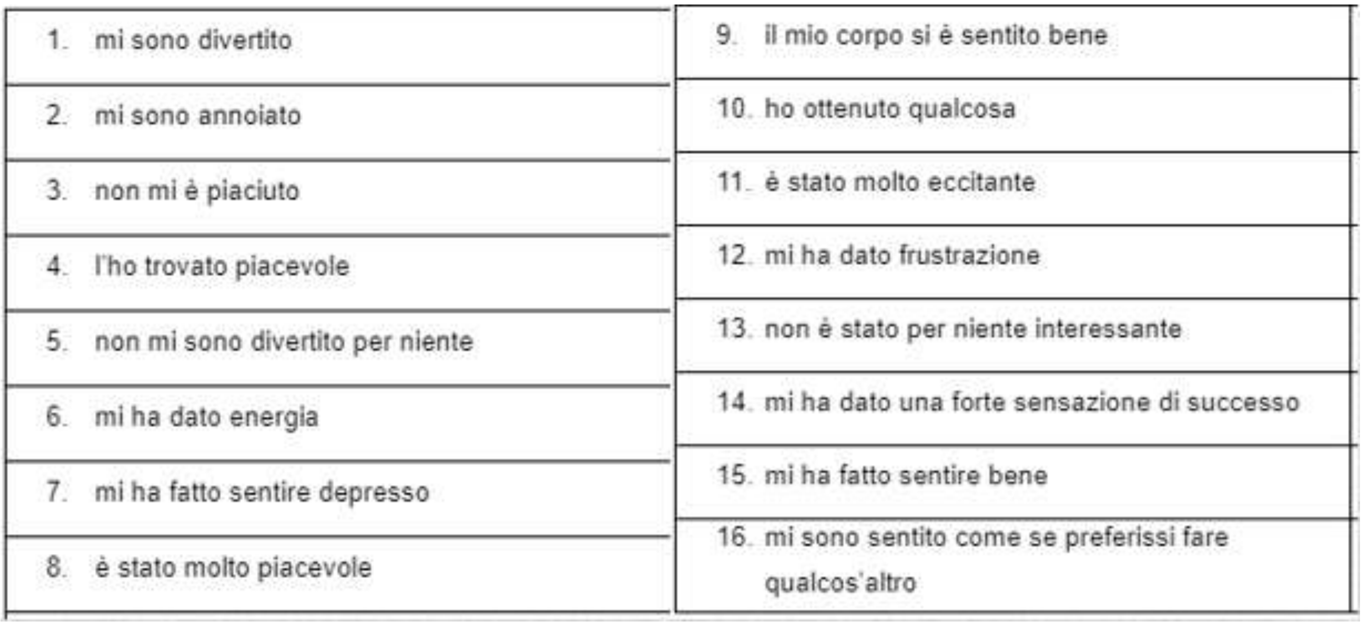
Figure 14: Digit span test

Questionnaires

Physical Activity Enjoyment Scale (PACES)

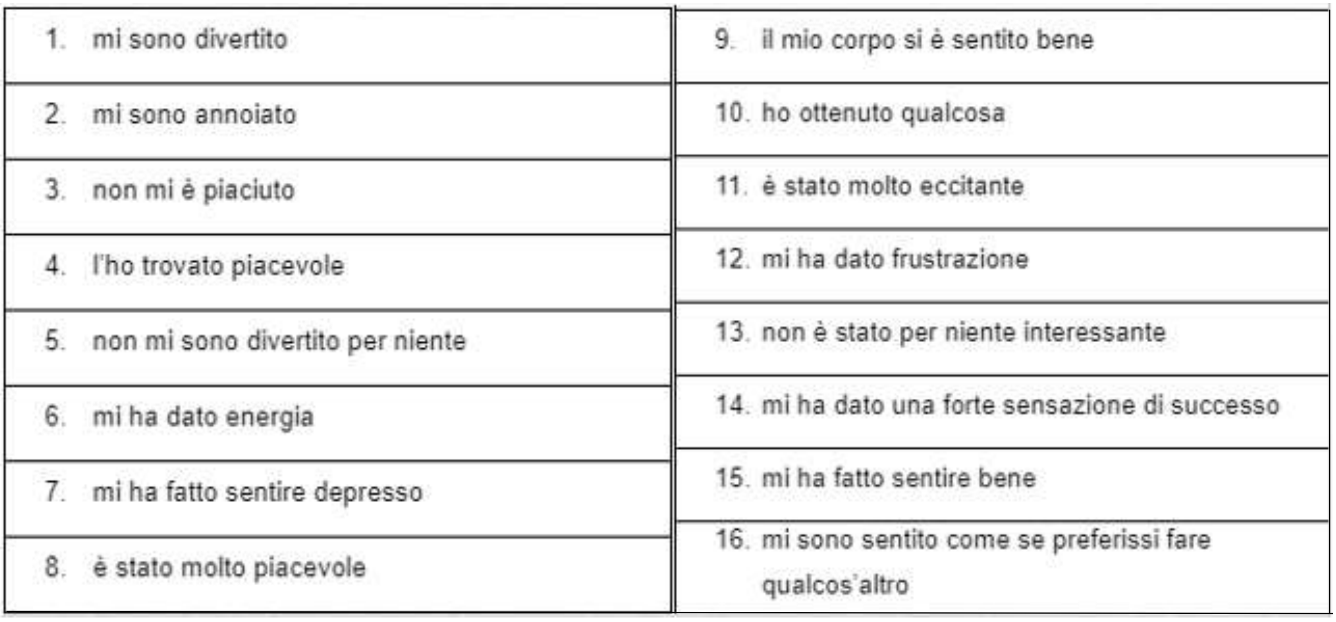
To quantify the enjoyment, two types of PACES questionnaire were administered: a generic one (Figure 15), referring to how the athletes feel every time they engage in physical activity (performed three times across the study) and a specific one (Figure 16), relating to each workout for both groups.

This modified version, created by Motl et al. (2001), had 16 items (nine positive and seven negative items) with responses on a Likert scale with a maximum of five points (one signifying “I disagree a lot” and five signifying “I agree a lot”). All of the questions asked about “how much you enjoyed exercising”. Negative items were recorded for the overall scale in order to align with the positive scale. Also in this case there are two outcomes: the average of the positive and negative items.



1. mi sono divertito	9. il mio corpo si è sentito bene
2. mi sono annoiato	10. ho ottenuto qualcosa
3. non mi è piaciuto	11. è stato molto eccitante
4. l'ho trovato piacevole	12. mi ha dato frustrazione
5. non mi sono divertito per niente	13. non è stato per niente interessante
6. mi ha dato energia	14. mi ha dato una forte sensazione di successo
7. mi ha fatto sentire depresso	15. mi ha fatto sentire bene
8. è stato molto piacevole	16. mi sono sentito come se preferissi fare qualcos'altro

Figure 15: Generic PACES

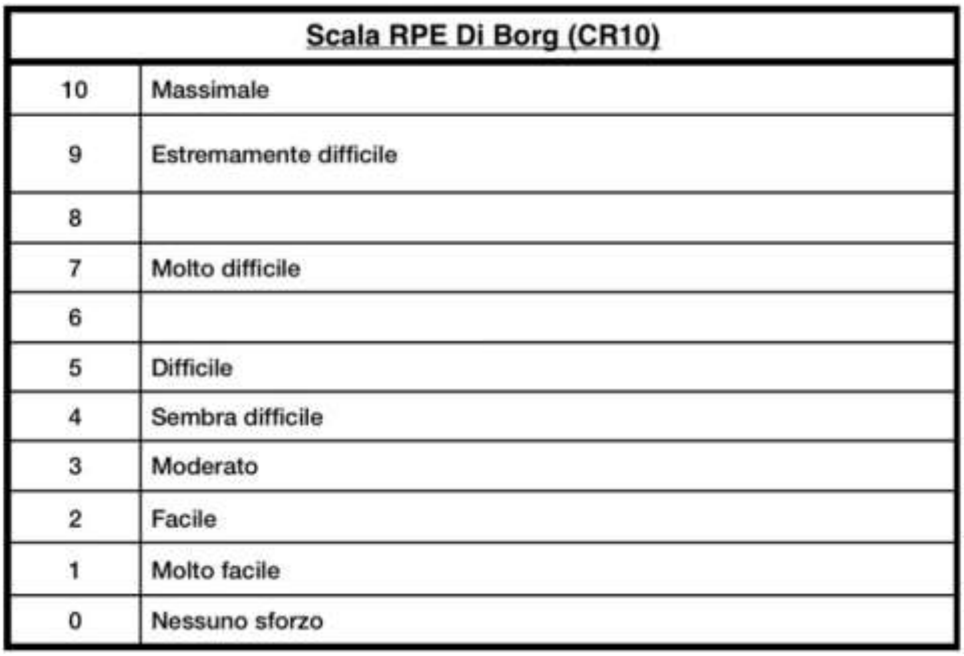


1. mi sono divertito	9. il mio corpo si è sentito bene
2. mi sono annoiato	10. ho ottenuto qualcosa
3. non mi è piaciuto	11. è stato molto eccitante
4. l'ho trovato piacevole	12. mi ha dato frustrazione
5. non mi sono divertito per niente	13. non è stato per niente interessante
6. mi ha dato energia	14. mi ha dato una forte sensazione di successo
7. mi ha fatto sentire depresso	15. mi ha fatto sentire bene
8. è stato molto piacevole	16. mi sono sentito come se preferissi fare qualcos'altro

Figure 16: Specific PACES

Borg's CR-10 Scale

The Borg's CR-10 scale was used to measure exercise ratings of perceived exertion (eRPE) (Egan et al., 2006). eRPE was used to describe the perceived exertion associated with Fitlight training or traditional training in the FG or CG groups, respectively. Standard instructions were presented throughout the familiarization session in order to evaluate RPE during the exercise sessions. A rating of 0 indicated no effort (rest), a rating of 10 indicated maximum effort and denoted the most demanding activity completed (Figure 17).



Scala RPE Di Borg (CR10)	
10	Massimale
9	Estremamente difficile
8	
7	Molto difficile
6	
5	Difficile
4	Sembra difficile
3	Moderato
2	Facile
1	Molto facile
0	Nessuno sforzo

Figure 17: Borg's scale

Psychobiosocial states (SPBS)

Psychobiosocial states were measured using the Psychobiosocial States Scale (SPBS). The Individualized Emotion Profiling created by Ruiz et al. (2016) was the basis for the PBS-S scale.

The scale consists of 20 rows with 3–4 descriptors per row measuring eight performance state modalities (emotional, cognitive, motivational, volitional, bodily-somatic, motor-behavioral, operational, and communicative). An item was made up of a row of synonym descriptions. Each modality is evaluated using two rows of items, one of which is functional for performance and the other of which is dysfunctional. Six rows of functional (+) and dysfunctional (-) questions measuring positive, anxiety-related, and anger-related emotions make up the emotional modality assessment. Athletes first choose one word to describe how they are feeling right now in connection to their performance (Figure 18). The intensity is then rated on a scale from 0 (=not at all) to 4 (=very much). So there are two outcomes: the average of the positive and negative items.

1. Entusiasta, fiducioso, tranquillo, felice, gioioso	0	1	2	3	4
2. Combattivo, grintoso, aggressivo	0	1	2	3	4
3. Movimento attivo, coordinato, dinamico, fluido	0	1	2	3	4
4. Distratto, deconcentrato, dubbioso, confuso	0	1	2	3	4
5. Prestazione efficace, abile, sicura, costante	0	1	2	3	4
6. Chiuso, riservato, non socievole, isolato	0	1	2	3	4
7. Nervoso, irrequieto, scontento, insoddisfatto	0	1	2	3	4
8. Fisicamente vigoroso, pieno di energia, carico	0	1	2	3	4
9. Movimento debole, goffo, scoordinato, fiacco	0	1	2	3	4
10. Vigile, concentrato, attento	0	1	2	3	4
11. Demotivato, disinteressato, disimpegnato	0	1	2	3	4
12. Allegro, compiaciuto, appagato, soddisfatto	0	1	2	3	4
13. Prestazione inefficace, scadente, incerta, instabile	0	1	2	3	4
14. Comunicativo, espansivo, socievole, cooperativo	0	1	2	3	4
15. Risoluto, determinato, tenace, perseverante, deciso	0	1	2	3	4
16. Preoccupato, angosciato, scoraggiato, turbato	0	1	2	3	4
17. Motivato, coinvolto, interessato	0	1	2	3	4
18. Fisicamente teso, nervoso, affaticato, esausto	0	1	2	3	4
19. Furioso, risentito, rabbioso, astioso, irritato, infastidito	0	1	2	3	4
20. Indeciso, incerto, esitante, rinunciatario, incostante	0	1	2	3	4

Figure 18: SPBS

4.2.4 Statistical analysis

Outliers and the normal distribution of the data were initially screened. When the assumption of normality was broken, a logarithmic transformation was used. A series of 2x3 repeated measures analysis of variance (RM-ANOVA) were conducted with Group (2 levels: Experimental, Control) as the between-subject factor and Time (3 levels: T0, T1, T2) as the within-subject factor in order to examine the effects of the intervention on cognitive (Flanker, Digit-Span) and psychological (generic PACES and SPBS) measures. A one-way multivariate analysis of variance (MANOVA) was conducted to test the hypothesis that there would be one or more mean differences between training (experimental and traditional one) and RPE and specific PACES scores. Additionally, a series of 2x2 RM-ANOVA was used to examine the potential effects of the intervention on fitness measures (such as handgrip, CMJ, absolute and relative DC, absolute and relative IC and SJFT), with Group (2 levels: Experimental, Control) serving as the between-subject factor and Time (2 levels: T0, T1) serving as the within-subject factor. The effects of the intervention on salivary measures (BDNF and IgA) were also examined using two different 2x2x2 RM-ANOVA, with Group (2 levels: Experimental, Control) serving as the between-subject factor and Time (2 levels: T0, T1) and Session (2 levels: pre-session, post-session) serving as the within-subject factors. Additionally, Chi² test was used to determine the relation between CMT results and players' competitive outcomes. Mauchly's test was used to determine the sphericity of the data and the Greenhouse-Geisser correction was used whenever the assumption was infringed. Effect sizes for significant interaction effects are expressed as partial eta squared (η^2p), with values of 0.01, 0.06, and 0.14 corresponding to small, medium, and large effects, respectively (Lakens, 2013; Cohen, 1988). Critical α was set at $p \leq 0.05$ for significance level and Tukey Honestly Significant Difference (HSD) correction was applied to all post hoc analyses. Jamovi (v. 2.3; The Jamovi Project, 2022) for Windows and R-Studio for R (v. 4.3) were used for the analyses.

4.3 Results

4.3.1 Executive Functions

Flanker/Reverse Flanker Task

A significant interaction (Time x Group) for Flanker accuracy performance was found by the mixed model ANOVA with Greenhouse-Geisser correction, F (1.44, 36.05) = 7.62, p= 0.004, η^2p= 0.234. Post hoc analyses reported that the accuracy of the experimental group at T1 was significantly different from the control group's accuracy (98.30% vs 92.05%, p=0.028), indicating that the experimental group was more accurate than the control group (Figure 19). Additionally, the experimental group at T2 was more accurate than the control group at T1 (97.73%, p=0.035) (Figure 19). There was no significant difference in reaction times (p= 0.280).

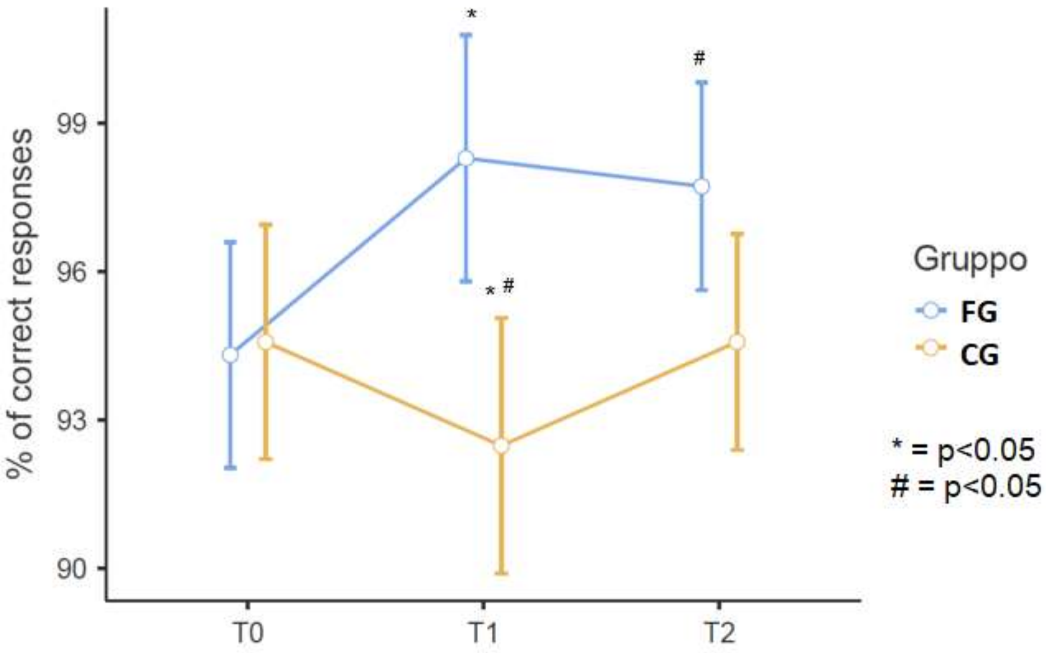


Figure 19: Accuracy in flanker test

Forward and Backward Digit Span

The RM-ANOVA with Greenhouse-Geisser correction revealed a significant interaction (Time x Group) for the Rate of Correct Score in the forward Digit Span, F (1.42, 35.42) = 8.588, p= 0.003, η^2p= 0.256. Post hoc analysis revealed no statistically significant difference between the two groups as measured at different periods after Tukey HSD correction (Figure 20). Furthermore, neither for Span (p= 0.157) nor for RTs (p= 0.352), significant interaction effects were found. In the backward version, the RM-ANOVA reported a significant interaction (Time x Group) for the Span, F (2, 50) = 4.147, p= 0.021, η^2p= 0.143. Post hoc analysis revealed a significant difference between T0 and T2 in the experimental group (3.571 vs 5.214, p 0.001) (Figure 21).

No significant interaction effects were found neither for RCS (p= 0.088) nor for RTs (p= 0.905).

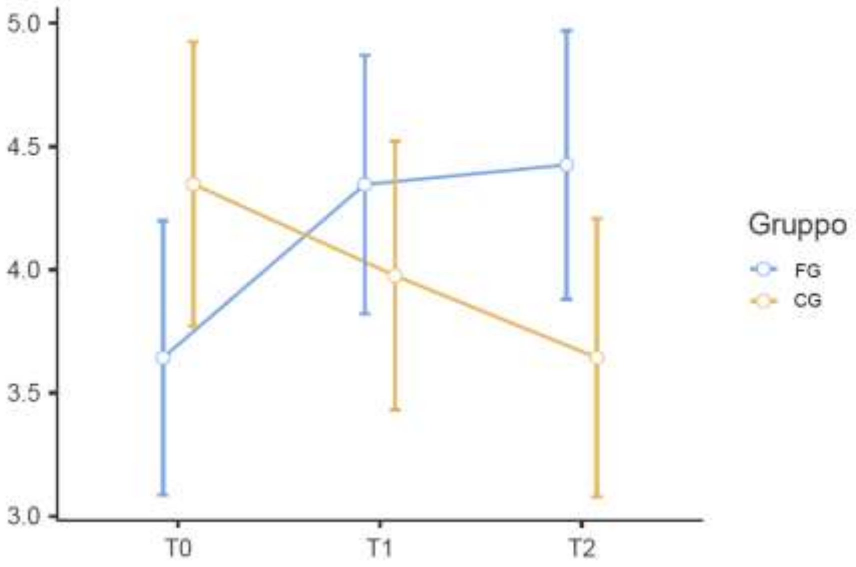


Figure 20: RCS in forward digit span test

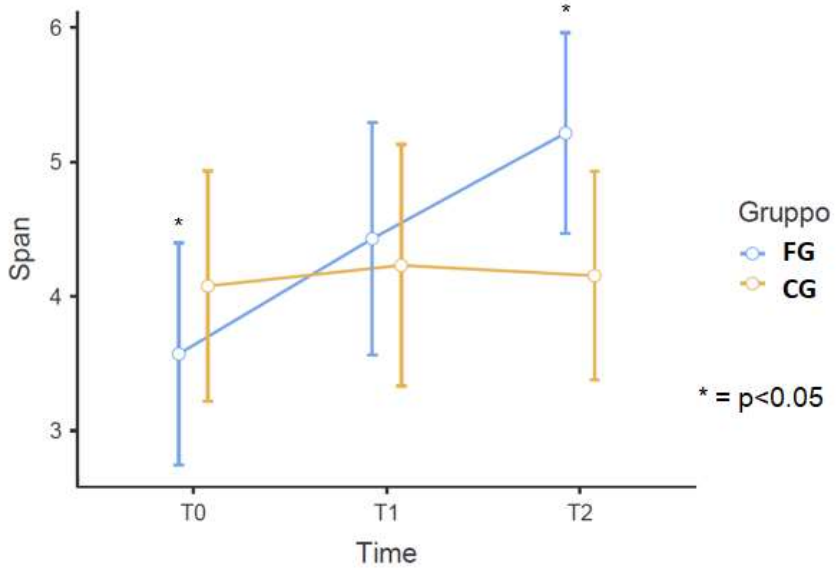


Figure 21: Span in backward digit span test

4.3.2 Fitness Test

Dynamic Chin-Up

The RM-ANOVA showed a significant interaction (Time x Group), F (1,25) = 7.070, p= 0.013, η^2p= 0.220 in terms of absolute values. Post hoc analysis revealed no statistically significant difference between the two groups at different measurement time points after Tukey HSD correction. The RM-ANOVA performed on the relative values of the dynamic chin-up revealed a significant interaction (Time x Group), F (1,25) = 8.280, p= 0.008, η²p= 0.249, similar to its absolute values. Post hoc analyses showed that participants in the experimental group significantly improved their performance (Figure 22) from T0 (M = 11.5) compared to T1 (M = 14.29) (p= 0.027).

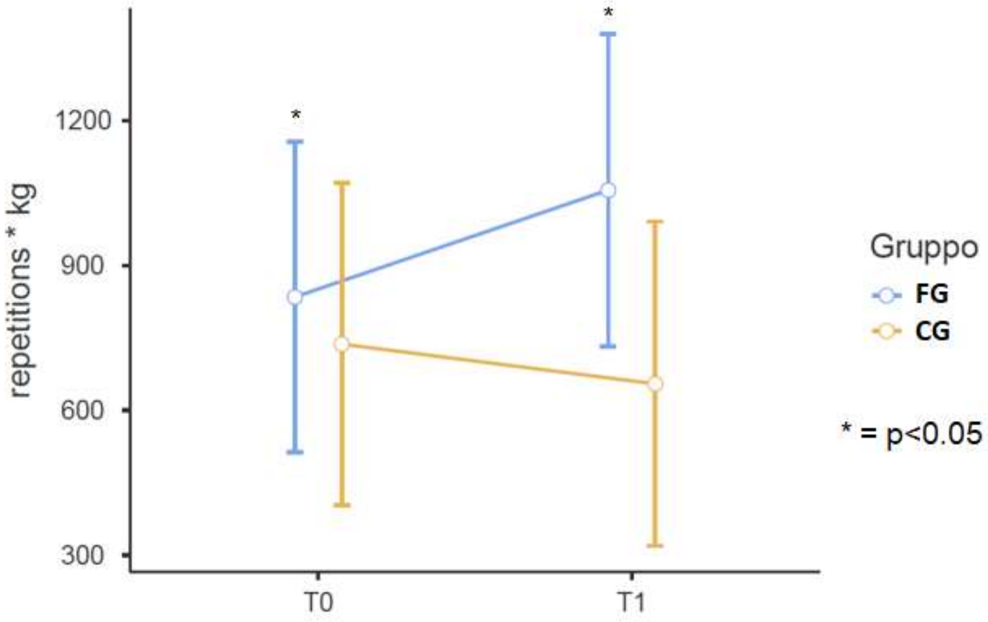


Figure 22: Dynamic chin up

Isometric Chin-Up

The RM-ANOVA showed a significant interaction (Time x Group), F (1,25) = 7.820, p= 0.010, η²p= 0.238 in terms of absolute values. Post hoc analysis with Tukey HSD correction showed no significant difference between the two groups. The RM-ANOVA performed on the relative values of the isometric chin-up showed a significant interaction (Time x Group), F (1,25) = 7.794, p= 0.010, η²p= 0.238. Tukey HSD corrected post hoc analyses showed no significant difference between the two groups at different measurement time points (Figure 23).

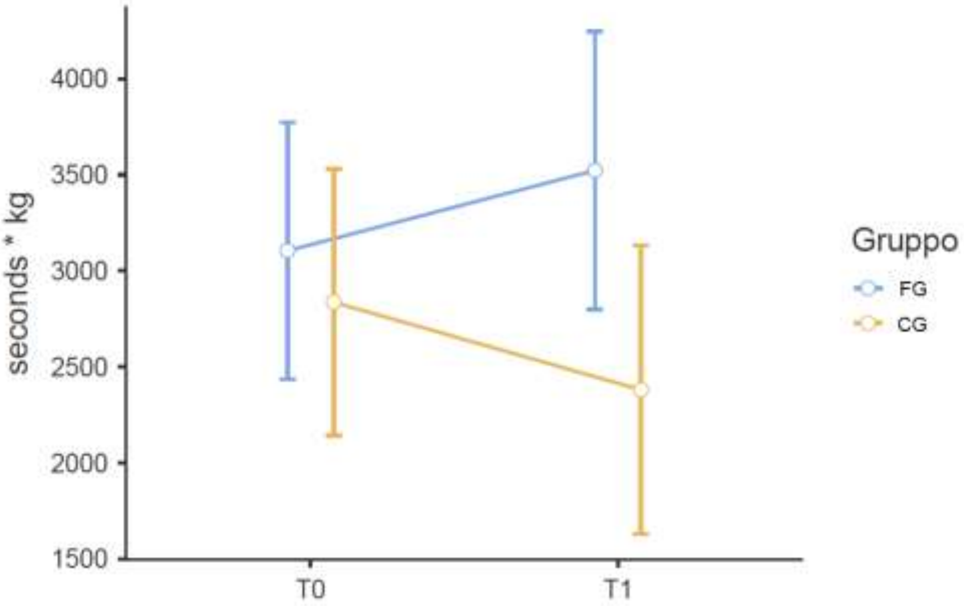


Figure 23: Isometric chin up

Counter Movement Jump

A significant interaction (Time x Group), F (1,25) = 11.520, p= 0.002, η²p= 0.315, was found using the RM-ANOVA. Tukey HSD corrected post hoc analyses that showed that participants in the experimental group significantly improved their performance (Figure 24) from T0 (M = 29.21) than at T1 (M = 31.49) (p= 0.05).

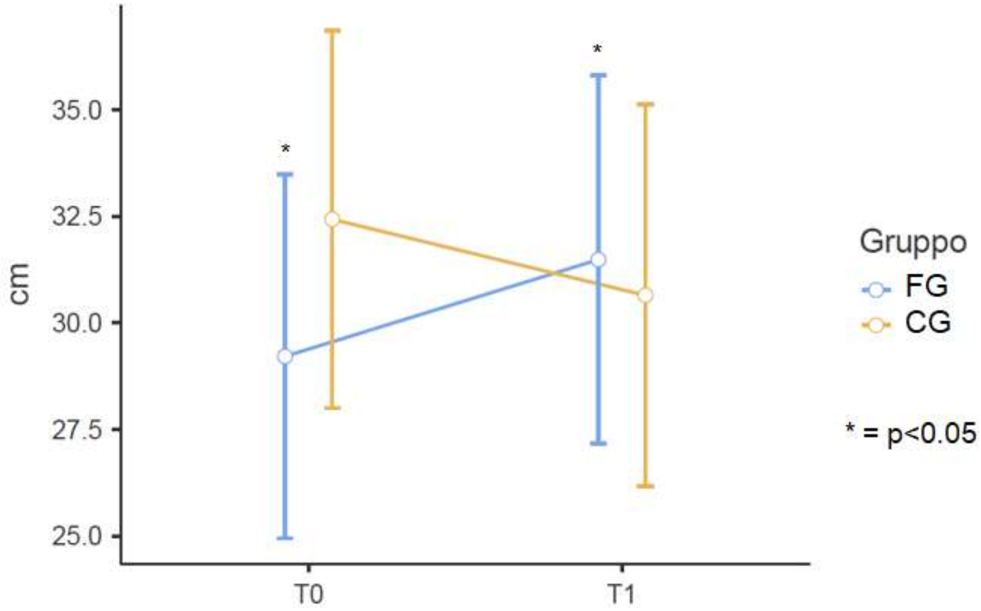


Figure 24: CMJ

Handgrip test

No significant interaction effect was found for the measure of HG (p > 0.05).

Special judo fitness test

No significant interaction effect was found for the measure of SJFT (p > 0.05).

4.3.3 Salivary analysis

The RM-ANOVA on BDNF (Figure 25) and IgA (Figure 26) measures did not show any significant interaction (all, p > 0.05).

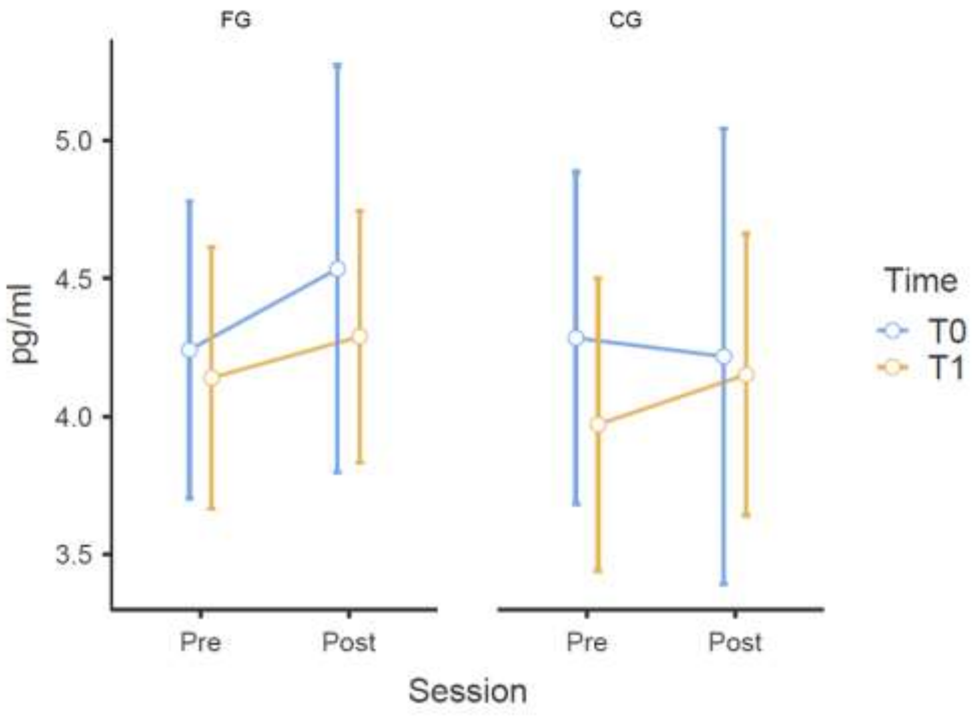


Figure 25: BDNF

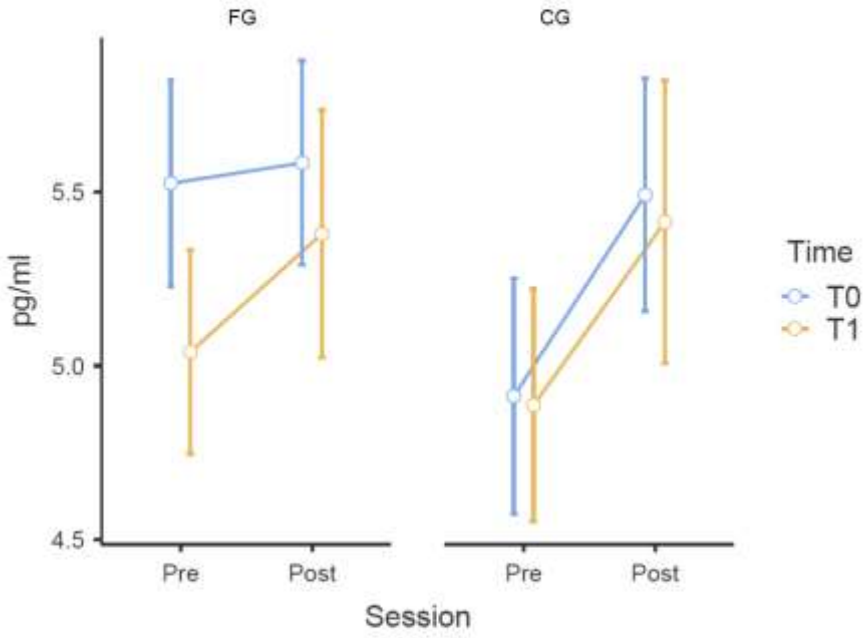


Figure 26: IgA

4.3.4 Questionnaires

Generic Physical Activity Enjoyment Scale (PACES)

The RM-ANOVA revealed a significant interaction (Time x Group) for the positive dimension of the generic PACES, F (2, 50) = 4.01, p = 0.024, $\eta^2p = 0.138$. Post hoc analyses indicated that the reports of positive affect in relation to physical activity at T1 were significantly higher for participants in the experimental group (M = 4.429) compared to the participants in the control group (M = 3.923) (p = 0.043), suggesting higher levels of enjoyment in relation to training after the intervention. Moreover, participants in the experimental group had higher scores at T0 (M = 4.468) and T1 than T2 (M = 4.119) (respectively, p = 0.035 and p = 0.013). Furthermore, the experimental group also reported higher scores at T0 compared to the ones of the control group at T1 (M = 3.923) (p = 0.043). No significant interactions were detected for the negative dimension of the generic PACES (p = 0.301).

Specific Physical Activity Enjoyment Scale (PACES) and Rating of Perceived Exertion (RPE)

The MANOVA showed a significant multivariate effect, F (3,23) = 3.709, Wilk's λ = 0.674, p = 0.026, $\eta^2p = 0.326$. Univariate analysis showed significant differences between groups for positive (p=0.004) (Figure 27) and negative PACES (p =0.042) (Figure 28). Therefore, experimental training has an effective influence on PACES variables.

Univariate analysis for RPE showed no significant difference between groups (p = 0.516) (Figure 29). Therefore, experimental training does not have an effective influence on RPE variables.

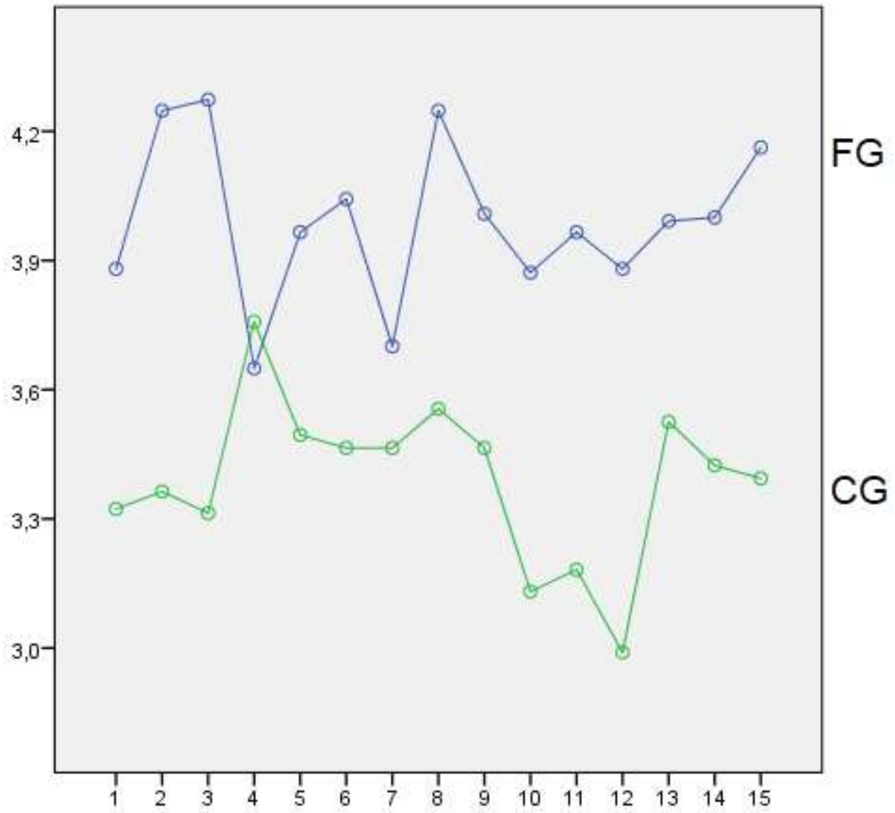


Figure 27: Specific PACES +

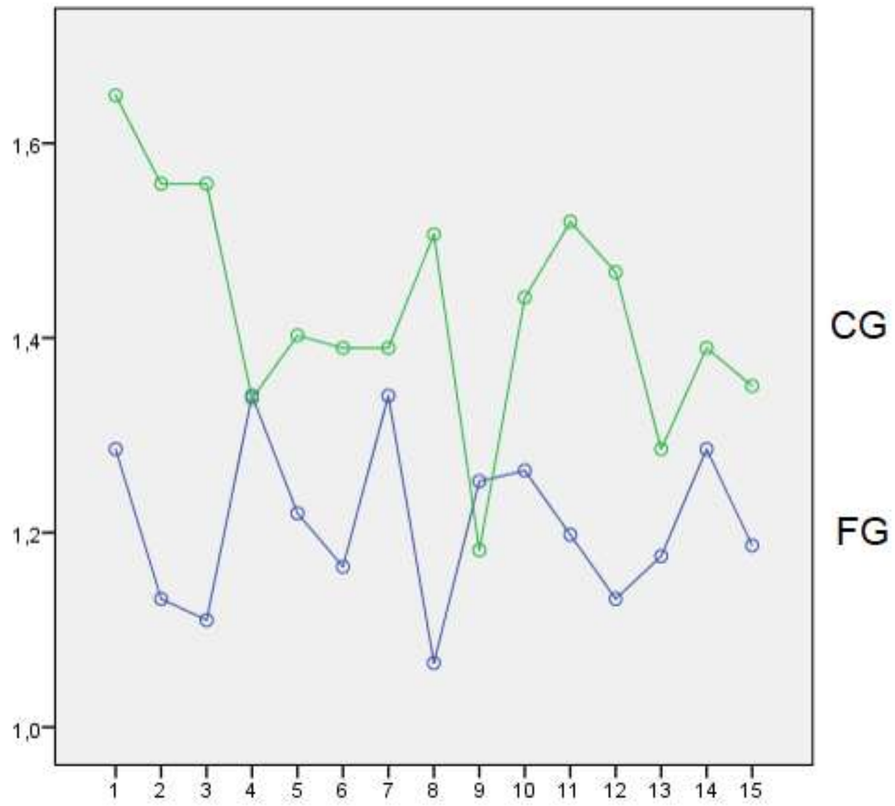


Figure 28: Specific PACES –

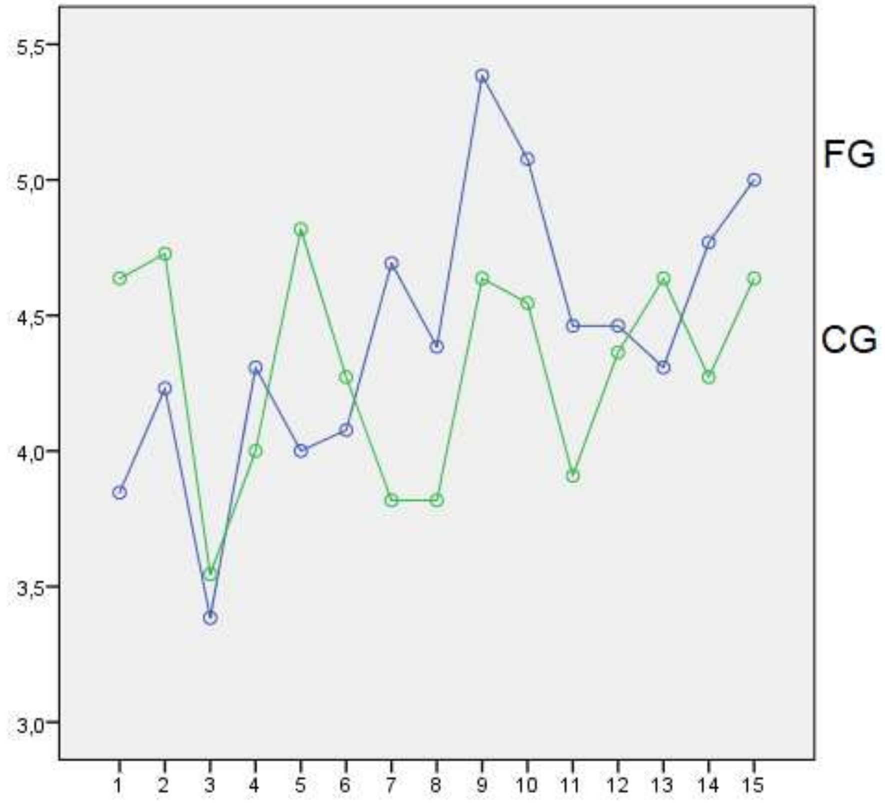


Figure 29: PRE

Socio-Psycho-Biological State (SPBS)

The RM-ANOVA revealed no significant interactions, neither for the positive ($p = 0.219$) nor for the negative states ($p = 0.669$).

4.3.5 CMT and competitive results

After the training sessions, the FG won 64.3% of competitive matches while the CG won 38.5% of them ($p < 0.01$).

4.4 Discussion

The current study examined the impact of CMT on cognitive and physical variables in élite judo athletes after a period of mass training, during which perceived effort and enjoyment were also measured. The main finding of this study was that five weeks of mass judo training increased the accuracy of answers for the flanker test and the span in the backward-digit span of athletes of the FITL which represents an indicator of working memory. Results also reported that this effect persisted for a further 8 weeks following the conclusion of the CMT.

These results are in line with our initial hypothesis. Additionally, the Fitlight-trained group reported enhancements through time (from T0 to T2) in the rate of correct score of forward digit span, which is a measure of working memory processing speed. As a result, these findings suggest that, as previously reported (Diamond, 2013), a Fitlight intervention in addition to traditional judo training may improve working memory. For the other EFs tasks, there were no additional significant differences between the groups. These results could be explained by two reasons: 1) as élite athletes, they already had high levels of EFs, as it was verified at T0; 2) the CMT could not continue more than 25 minutes because athletes were evaluated during a competitive period, which is, in any case, a comparable length of training as described by prior research (Silvestri et al., 2023; Badau et al., 2022).

These results need to be interpreted carefully because there were no differences in reaction times between the groups. Badau and colleagues (2022), who used Fitlight technology in open-skill sports training with adolescent athletes, reported that cognitive reaction time, a parameter used to measure cognitive flexibility, had improved after a 3-month intervention. They also discovered that players practicing open-skill sports, who received CMT, improved significantly in cognitive and physical tests. Therefore, the different results could be due to the dissimilar duration of the interventions; in our study, the intervention lasted five weeks and included mass Fitlight training three times per week, whereas Badau and colleagues (2022) used a distributed 12-week program. Distributed cognitive training may be necessary to achieve significant EF enhancements during sports practice, although having a similar overall training load. For this reason, our 5-week program was unable to produce significant cognitive enhancements, except the accuracy of answers in the flanker test and the span in the backward-digit span.

To establish the potential benefits of Fitlight training for EFs in elite athletes who practice in open-skill sports, more research is necessary. It may be important to investigate various distributions of cognitive training (massed versus distributive) in order to understand the appropriate volume and frequency for cognitive improvement. In addition, it was found that throughout the intervention, the FITL-trained group had greater RPE, although this difference was not significant. This finding leads us to believe that the perceived increased effort in the training sessions is most likely a result of the different typology of intervention. The higher cognitive effort required by the FITL group training is indeed reflected in the higher RPE scores. Because of this, even though both groups reported a similar increasing trend for RPE, our findings could imply that adding FITL to traditional judo training could improve the perceived effort by increasing the cognitive demands. According to recent research, a greater perceived effort is the best predictor of mental weariness in sports (Van Cutsem, 2017). RPE’s role in the relationship between mental exhaustion and sport-specific performance, however, is still unclear (Habay, 2021a). The idea that mental fatigue brought by cognitive demands can impair sport performance is supported by a sizable body of literature (Habay, 2021a; Habay, 2021b; Van Cutsem, 2019). However, recent research suggests that athletes can improve their tactical performance and action efficiency while experiencing pre-induced mental fatigue (Silva, 2023).

Future studies should therefore investigate if the mental demand brought by the FITL improves performance and in which specific sport.

The evolution of training in sports may also be influenced by enjoyment and motivation (Jung, 2021), as these factors are favorably correlated with enhanced EFs (Ishihara, 2017). In our study, specific PACES showed significant differences between the groups in terms of both positive and negative outcomes of the two different training programs (Fitlight vs. traditional judo training). Instead, generic PACES showed significant differences between the groups only in terms of positive outcomes. This information, combined with the RPE results, suggests that the Fitlight training induced, even if not statistically significant, an increase in effort that may impact how much one likes workouts.

Regarding physical fitness, there was a significant improvement in dynamic chin-up scores and CMJ following the 5-week massed training, as well as a perceptible improvement in isometric chin-up scores. However, there was no difference between the groups for the last. These results may be largely explained by the intervention's focus on enhancing cognitive abilities rather than physical fitness. Additionally, because they were élite athletes, the participants already started from a higher level of fitness performance.

Additionally, this study looked into how BDNF and IgA saliva levels in élite judo athletes were affected by traditional judo training and Fitlight training. BDNF levels have been studied in an increasing number of studies during both short and long-term exercise in both healthy subjects and those with chronic illnesses (Seifert, 2010; Rojas, 2006). Results indicated that both the level of PA and the status of training may have an impact on elevated blood BDNF. In our study, the absence of significant BDNF level differences is likely because saliva was used for collection rather than blood sampling.

Regarding the correlation between CMT outcomes and the competitive outcomes achieved by FG athletes following the intervention, it was found that there was a significant difference between FG and CG (64.3% vs. 38.5%) in terms of matches won.

This finding is important because all of the participants were élite athletes. Therefore, despite there is need for further studies, it appears that CMT with Fitlight™ might be seen as a further support to coaches during the training period.

This study has several strengths: 1) this is the first judo study to use fitlights. The sport-specific training sessions, in particular, were conducted in real conditions, proper open-skill sports, which are a regular part of the training for élite athletes; 2) in our study, both the experimental and control groups consisted only of élite athletes. In our study, the athletes trained for an average of 20 hours per week, which was uncommon in past studies.

There are also some limitations to this study. In fact, it is reasonable that the intervention's duration, despite massive, was likely too brief to induce any potential variations in EF enhancement in response to CMT. A distributed program appears to be necessary for EF development in open-skill sports and the available data indicates that 8 to 12 weeks of CMT can increase EFs (Badau, 2022; Benzing, 2019). However, as above mentioned, the athletes' seasonal sporting engagements necessitated a 5-week intervention. Moreover, although validated physical and cognitive assessments were used in the study, it is difficult to design ecological protocols that allow to analyze the improvement in EFs during match actions, without interfering with the context.

4.5 Conclusions

Elite judo athletes' cognitive ability, specifically their cognitive flexibility accuracy and working memory, as well as their physical performance, specifically their endurance strength and explosive strength, were improved by a 5-week judo-specific CMT using the Fitlight training approach. This protocol also improved athletes' enjoyment without reducing perceived effort. Fitlight training may therefore be a helpful strategy to stimulate cognitive effort without lowering athletes' motivation and enjoyment during judo practice. Elite judo athletes appear to be able to further improve some EFs tasks and physical fitness components with a CMT that lasts only 5 weeks. Coaches could take this information into account when projecting seasonal training programs. Many unsolved research questions are still raised by the relationship between EFs and motor training. Future research should look at which EFs are enhanced by a particular CMT to better understand the potential effects of higher EFs on different sports, possibly with a motor task to better trigger EFs activation, as well as the duration of these enhancements. Additionally, saliva sampling, a noninvasive alternative method that is easy to use, was employed to collect BDNF rather than blood sampling, the most reliable but invasive procedure that cannot always be performed. Unluckily, BDNF could not be accurately detected in saliva. Due to the potential limitations of commercial BDNF kits for noninvasive saliva measurements, the frequency and conditions of sampling are limited (Vrijen, 2017).

Chapter 5. Conclusion of the studies

5.1 General conclusion

The overall aim of this work was to verify whether a cognitive-motor massed training using Fitlight^{TM} induced improvements in EFs and physical fitness in young athletes practicing open-skill sports (specifically basketball and judo) compared to a non-intervention group.

The first study aimed to verify whether the Fitlight^{TM} training system could enhance basketball players’ EFs and motor performance, as well as, to verify if CMT induced changes in the rate of perceived effort and enjoyment of training in the experimental group compared to a non-intervention group.

The results showed that cognitive-motor training of only 3 weeks enhanced cognitive and fitness performance in both groups over time, without differences between the groups. However, CMT using the Fitlight training system, in addition to this program, enhanced the experimental group’s perceived effort without lowering their level of enjoyment.

Based on the findings of this study, it appears that a 3-week massed cognitive-motor program is not capable of further enhancing the development of EFs in young basketball players.

Therefore, future studies should be conducted for a longer period.

The second study is the first that investigated cognitive-motor training using Fitlight™ in judo.

The results showed that a 5-week judo-specific CMT improved EFs and motor performance in the experimental group. The additional Fitlight training increased the enjoyment without decreasing perceived effort. Furthermore, the experimental group obtained better competitive results than the non-intervention group.

Therefore, it seems that CMT with Fitlight™ could be considered an additional support to coaches during the training period.

In conclusion, this thesis adds important information to the existing scientific literature for the improvement of executive functions, through massed cognitive-motor training using Fitlight™, in open-skill sports, in particular in team sports (as basketball) and mostly in combat sports (as judo).

5.2 Limitation and future research

The studies of this thesis have some limitations that need to be considered:

Concerning Study 1, important limitations are: (1) because all of the study's subjects were male athletes, it was not possible to examine how gender differed in CMT and EFs; (2) the massed intervention's duration may be too brief to fully consider any potential variations in how EFs improved in response to CMT.

For these reasons, further research is needed to ascertain the influence of gender differences in CMT and EFs. In addition, CMT should be conducted for a longer period.

The limitations of Study 2 are (1) the duration of the intervention, though massive, was likely short to induce any potential variations in EFs improvement in response to CMT; (2) BDNF collection was made by saliva sampling, a non-invasive alternative and simple to use method, compared to blood sampling, which is most reliable but invasive and uneasy to be carried out in the on-court condition.

For these reasons, CMT should be conducted for a longer period and BDNF should be taken by blood sampling.

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