Inhibitory control in schoolers: domain evaluation and analysis of the effects of exercise interventions

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Dra. María Milagro Ezquerro García-Noblejas

DECLARE:

That the Bachelor in Physical Education and Sport Sciences, and Master in Compulsory Secondary Education, Sandra Amatriain Fernández, has developed under their supervision the work entitled "Inhibitory control in schoolers: domain evaluation and analysis of the effects of exercise interventions". This work satisfies all the requirements for a dissertation to aim for the International PhD in the University of A Coruña.

A Coruña,

María Milagro Ezquerro García-Noblejas

A mis puntos fijos del universo.

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"And once the storm is over,

you won't remember how you made it through, how you managed to survive.

You won't even be sure whether the storm is really over.

But one thing is certain.

When you come out of the storm, you won't be the same person who walked in.

That's what this storm's all about."

Haruki Murakami

"Y una vez que la tormenta se ha acabado,

No recordarás cómo lo lograste, cómo te las arreglaste para sobrevivir.

Ni siquiera estarás seguro de si la tormenta ha terminado realmente.

Pero una cosa sí es segura.

Cuando salgas de esa tormenta, no serás la misma persona que entró en ella.

De eso se trata esta tormenta."

Haruki Murakami

"-What if I fall?

-Oh but my darling,

What if you fly?"

Erin Hanson

ABSTRACT

Inhibitory control (IC) is a central component of the Executive Functions (EFs) with a fundamental role organizing how various mental processes work together in light of goal-directed behaviors. This domain includes a family of related functions that govern inter-related processes and are determinant in several high impact disorders.

To clarify the presence of IC differences in typically developed schoolers, and its training possibilities with exercise interventions, three studies were performed.

The first study involved an evaluation of several IC and impulsivity components in a schoolers sample. Underlying common connections were found between IC components, but not between IC and impulsivity components. However, accuracy and reaction times appear to link the IC and impulsivity domains. Elevated differences between IC and impulsive tendencies were discovered among participants.

In the second study, a systematic review and meta-analysis on the effects of diverse longitudinal physical exercise interventions in the IC of children and adolescents were accomplished. Small but statistically non-significant effect sizes were found.

The third study included an acute intervention with three intervention groups to evaluate their effects on schoolers' IC. Each intervention had a specific design regarding IC demands and exercise components. The results did not show significant improvements or significative differences.

RESUMEN

El control inhibitorio (CI) es un componente central de las funciones ejecutivas (FE), que gobierna varios procesos mentales para generar comportamientos dirigidos a objetivos; es una familia de funciones que rigen procesos interrelacionados y son determinantes en varios trastornos.

Para aclarar la presencia de diferencias en el CI de escolares con desarrollo normal y sus posibilidades de entrenamiento con ejercicio, se realizaron tres estudios.

En el primero se evaluaron varios componentes del CI y del constructo impulsividad. Los resultados mostraron conexiones entre los componentes del CI, pero no entre los del CI e impulsividad. Se observaron diferencias notables en el CI y las tendencias impulsivas de los participantes. Precisión y tiempos de reacción parecen vincular dichos constructos.

En el segundo, se realizó una revisión sistemática con meta-análisis sobre los efectos de diversas intervenciones de ejercicio, con un diseño longitudinal, en el CI de niños y adolescentes. Se encontraron pequeños tamaños del efecto estadísticamente no significativos.

El tercer estudio incluyó una intervención aguda con tres grupos de intervención (cada uno específicamente diseñado en cuanto a demanda de CI y componente de ejercicio físico) para evaluar sus efectos en el CI de escolares. Los resultados obtenidos no mostraron mejoras o diferencias significativas.

RESUMO

O control inhibitorio (CI) é un compoñente central das funcións executivas (FE) cun papel fundamental no funcionamento de diversos procesos mentais para xerar condutas dirixidas a obxectivos; É unha familia de funcións que rexen procesos conectados e son determinantes en varios trastornos.

Para aclarar a presenza de diferenzas no CI de nenos con desenvolvemento normal e as súas posibilidades de adestramento con intervencións de exercicio, realizáronse tres estudos.

No primeiro avaliáronse varios compoñentes do CI e da impulsividade. Os resultados mostraron conexións entre os compoñentes do CI, pero non entre os do CI e impulsividade. Observáronse diferenzas notables no CI e as tendencias impulsivas dos participantes. A precisión e os tempos de reacción parecen ligar estes dominios.

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O terceiro estudo incluíu unha intervención aguda con tres grupos de intervención (deseñados cada un especificamente en termos da demanda do CI e compoñente de exercicio) para avaliar os seus efectos no CI de escolares. Os resultados obtidos non mostraron melloras ou diferenzas significativas.

PREFACE

The current document entitled *"Inhibitory control in schoolers: domain evaluation and analysis of the effects of exercise interventions"* contains experimental work performed between 2014 and 2019. The main base of the work was carried out at the Faculty of Sports Science and Physical Education of the University of A Coruña, Department of Sports Science, and at the Medical School Hamburg (MSH) during two research stays.

The first research stay at the MSH was supported by a grant from the University of A Coruña through the Inditex-UDC Grant Program (2017). The second stay was partly supported by the Erasmus Program for Doctoral Students of the University of A Coruña (2018).

Besides an extended literature review of the topic, the current document includes three original studies that were carried out as a part of the research work.

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Chapter 1: **Introduction**

We, as humans, are social beings. We establish relations with others and create our social circles (relationships, family, job colleagues, friends, sports teams, etc.) with whom we share common interests. However, most probably we never ask ourselves how we can be able to connect with others, why some people are good in socializing and others are not, or why some relationships are lasting, and some are doomed to fail.

We are also quite adept to routines; that is why we obtain the name “creatures of habit” by Diamond (2013). We have our “rhythm of life,” our daily schedules where we have the feeling that we have everything under control. We think we can control our beliefs, our thoughts, and our behaviors. The simple idea of change scare us. But the truth is that we are already in constant change, our body, our mind and the environment. With all of these transformations around and inside of us, can we always control our behavior? If so, how can we do it?

The reality is that our behavior is under the control of environmental stimuli more than we can even imagine (Diamond, 2013). What happens with our impulses, our wishes, and our inner voice? Are all of them always aligned with the established norms of our society? Where is the line between what we want to do and what we finally do?

Even our planned and automatized responses have to be inhibited in our everyday life. While driving, for example, when a car unexpectedly appears in our way; when walking on the street and suddenly someone wants to take the same direction; when we wait for the rest of the people to start eating together; or while running in the mountains and obstacles have to be avoided. In the physical exercise and sports field, these processes appear in a variety of situations, e.g., when it is necessary to reschedule trajectories to elude the opponents, to change the course of our activities under the changing game circumstances, or to vary an immediate response depending on the opponent's actions.

All of these mentioned situations are possible thanks to a series of processes at a neurological base. These processes can be more or less complicated, and more or less automatic, but higher cerebral structures would always be involved.

As C. D. Chambers et al. (2006) as well as Wang et al. (2013) affirmed, these structures would help us to plan, execute, and update our behavior in response to an environment in continuous change. These structures are known as executive functions (EFs), and one of the main components of these high-level structures is inhibitory control (IC), the central topic of this work.

IC is, by definition, related to the capacity of controlling prepotent responses and interferences. To create a picture in our real-life setting, let us think of what happens when unexpected events occur. In most of the cases, we have to cancel our intended actions. In all of these situations, we are inhibiting and updating behavioral, motor, or cognitive activities due to the circumstances. Without this ability to inhibit and to update our responses, most of the daily circumstances would not be possible, e.g., engaging in the social day by day interactions, driving a car, or practicing sports. In general, IC allows us to not succumb to our most primal impulses and our automatic responses.

While thinking of the term "inhibitory control," the first idea that can appear in our minds may be connected with the capacity to control ourselves and to avoid doing the things we should not do. This idea is not misguided, as Diamond (2013, p. 2) affirmed, "*inhibitory control makes it possible for us to change and for us to choose how we react and how we behave rather than being unthinking creatures of habit.*"

The psychologist William James, in his book entitled *The principles of psychology* James (1890, p. 583), described inhibition as *"not an occasional accident; it is an essential and unremitting element of our cerebral life."* The definition was given while explaining the muscular contractions and the simultaneous processes that make possible the inhibition (and end) of this contraction. However, this affirmation is the base of the nature of inhibitory control.

The current introductory chapter will present the term "inhibitory control" and its relevance within the executive functions construct.

1.1. Inhibitory control: a conceptual approach

Inhibitory control is widely defined as a central component of the EFs (Browne et al., 2016; Bugos & DeMarie, 2017; Diamond, 2013; Liu, Zhu, Ziegler, & Shi, 2015) which plays a significant role in determining how various mental processes work together in light of goal-directed behaviors (Cohen-Gilbert & Thomas, 2013; Diamond, 2013).

The successful performance of a specific task, the capacity of having a particular behavior in a specific environment, or the capability to think before giving the first answer that comes to our mind are, among others, circumstances that are possible thanks to the restriction of automatic processes (Bugos & DeMarie, 2017; Cohen-Gilbert & Thomas, 2013; Diamond, 2013; Dowsett & Livesey, 2000).

It is generally accepted that IC governs the attention, the behavior, the thoughts, and even the emotions in order to invalidate a robust internal predisposition or external temptation (Diamond, 2013). This capacity is characteristic for humans and gives us, among other advantages, the ability to socialize (Guillén, 2017).

The specific processes ruled by IC include the ability to inhibit dominant, autonomic, or prepotent response in favor of a different response or the absence of it (Alesi, Bianco, Luppina, Palma, & Pepi, 2016; Wu et al., 2011) as well as the ability to resist interferences, distractions, or habits to maintain the focus on the primary objective when the situation requires it (Hillman et al., 2014; Nigg, 2000; Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015). Therefore, IC is understood as a family of related functions with individual differences that govern different but interrelated processes (Friedman & Miyake, 2004).

IC is known to promote success in thinking and learning processes (Benson, Sabbagh, Carlson, & Zelazo, 2012), physical and mental health, cognitive development, academic success, social competence, and psychological functioning, among other benefits (Blair & Razza, 2007; Browne et al., 2016; Carlson & Moses, 2001; X. Chen, Chen, Li, & Wang, 2009). IC is also suspected of contributing to intelligence (Carlson & Moses, 2001; Lee, Lo, Li, Sung, & Juan, 2015).

According to Barkley (1997), IC is essential for the proper functioning of the EFs, and a deficit in this domain might lead to a cascade effect in the rest of the EFs. This theory situates IC as an essential key not just for the development of cognitive flexibility or working memory (both EFs that will be explained in the following section), but also for the regulation of all of the already mentioned underlying processes that encompass IC like attention, behavior, thoughts, and emotions.

Therefore, the lack of inhibitory control leaves us at the mercy of our internal impulses, our automatic responses, and the environmental stimuli, which will drive us in a specific way (Diamond, 2013). Without inhibitory control, our answers are immediate and lack any prior reflection process. Our past experiences are not taken into account and, consequently, it is easy to commit the same mistakes over and over again. This process of immediately acting and giving answers might cause trouble in our daily life, especially in situations where a specific way of behaving is already established. An immediate reward is usually selected over a long term one, even when the last option is better (in quality or amount). This is due to the effort that the maintenance of a long-term goal produces. Somehow, a lack of IC instigates us to behave, to think, and to respond, "without filter," with all of the included consequences of this fact.

1.2. Inhibitory control: a component of the executive functions

EFs are considered high order interactive cognitive functions (Filippetti & Richaud de Minzi, 2012), also known as general-purpose control mechanisms (Miyake et al., 2000). EFs have an indispensable role in the management of emotions, attention, and memory (Guillén, 2017), and in the regulation of purposeful and goal-directed behaviors (Banich, 2009; Lezak, Howieson, Loring, Hannay, & Fischer, 2004; Pennington & Ozonoff, 1996). These functions are mostly conceptualized as a multidimensional construct (Baggetta & Alexander, 2016) that allows us to have the necessary cognitive and behavioral control to be able to plan and make appropriate decisions (Barkley, 2001; Guillén, 2017).

Furthermore, EFs address novelty, override automatic actions, and help to appropriately respond to the context, among other linked functions (Banich, 2009; A. G. Chen, Yan, Yin, Pan, & Chang, 2014; Verburgh, Konigs, Scherder, & Oosterlaan, 2013; P. D. Zelazo, Craik, & Booth, 2004). Consequently, EFs are related to success in several areas of life like academic performance, physical health, economic conditions, as well as personal and social relationships, among others (Baggetta & Alexander, 2016; Diamond, 2013; Latzman, Elkovitch, Young, & Clark, 2010; Moffitt et al., 2011).

To understand the structure of EFs, Guillén (2017) suggested to think of a managing system that controls all of the information of our brain. This managing system would facilitate efficient performance in tasks with different requirements based on all of the available information. EFs will help us not to be distracted from our objectives, especially when they are new or require greater complexity (Guillén, 2017).

Most researchers suggest the existence of three main EFs: inhibitory control, working memory, and cognitive flexibility (Alesi et al., 2016; Diamond, 2013). Nevertheless, the terms used to name these three components varied along with the literature, which sometimes complicates their understanding. The term executive function(s) itself is frequently replaced by “cognitive control” (J. D. Cohen, 2017; Drollette et al., 2014). Several authors have criticized the lack of agreement on the terminology and definitions and the need for a universal language to describe and explain its psychological and theoretical mechanisms (Baggetta & Alexander, 2016).

Besides inhibitory control, the other two most studied EFs components are working memory and cognitive flexibility. Working memory (WM) is the ability to maintain information in mind and to be able to mentally work with this information even when it is no longer physically present (Diamond, 2013). WM is operating when we have to rapidly add or delete relevant and irrelevant information based on the demands of the task or the environment (Baggetta & Alexander, 2016; Diamond, 2013; Miyake et al., 2000). This term is frequently interchanged with updating (Miyake et al., 2000). However, updating (actualizing the information) is only one of the specific capacities that WM includes (Baggetta & Alexander, 2016). According to Diamond (2013), there are two kinds of WM depending on its content: verbal and non-verbal. In any case, both kinds of WM are essential to hold in mind past information to connect it with present situations, which allows the generation of adequate responses according to the circumstances. Nevertheless, Diamond (2013) also highlights that WM should not be confused with short-term memory because the latter includes the capacity of holding information in mind, while WM adds the possibility of manipulating this information to our benefit.

Cognitive flexibility (CF) is also known as mental flexibility, shifting, set-shifting, or switching (Baggetta & Alexander, 2016; Best, Miller, & Naglieri, 2011; Diamond, 2013; Garon, Bryson, & Smith, 2008; Miyake et al., 2000). CF involves the capacity of changing perspectives at a spatial, relational, and thoughts level (Diamond, 2013). This ability can be seen when we intentionally go back and move forward between tasks, mental information, or purposes. Its base is the capacity of being able to change the course of action if necessary, avoiding being stuck on ineffective strategies (Baggetta & Alexander, 2016; Best et al., 2011; Friedman et al., 2006; Friedman et al., 2008). According to several authors (Davidson, Amso, Anderson, & Diamond, 2006; Diamond, 2013; Garon et al., 2008), this EF is settled thanks to IC and WM, and is developed in a later stage.

These three main EFs (inhibitory control, working memory, and cognitive flexibility) result in higher-order EF like reasoning, problem-solving, and planning (Diamond, 2013; Guillén, 2017).

Chapter 2: Theoretical framework

2.1. The historical inhibitory control term development

The use of the inhibitory control or inhibition term has undergone an increase in recent years, but it is not a new term. Some philosophical theories already, a long time ago, and in their aim of reflecting on the essence, properties, causes, and effects of natural phenomenon presented the idea of what is currently understood as inhibition. Plato's allegory of the human soul, for example (where the charioteer driving two horses with different characters has to be able to control them in order to drive the chariot properly) can be seen, according to Bari and Robbins (2013), as a metaphor of the inhibitory processes that were still unexplained in that moment.

However, not until the beginning of the 19th century (coinciding with the recognition of science as a profession) was the concept of inhibition introduced in the scientific literature (Bari & Robbins, 2013; Macmillan, 1996). Its appearance came from the moral-philosophical theories of Plato and Aristoteles that situate inhibition as a mechanism from the intellect to control our passions by which the "will" do not succumb to impulses (R. Smith, 1992). Researchers from different fields like physiology, neurology, and psychology, addressed the possible role of inhibitory processes in the brain and cognitive functioning (Clark, 1996).

The first use of the term in the literature, tried to explain concepts reaching from simple spinal reflexes to abstract psychological processes (Bari & Robbins, 2013), and IC received different meanings depending on the study perspective: mechanisms to govern behavior, circuits between brain regions, neural firing, or enzymes, among others (Aron, 2007).

One example of its use is the already mentioned definition of inhibition that was given by James (1890, p. 583) to explain the simultaneous inhibitory processes that accompany a muscular construction in order to end it, that defined inhibition as: *"not an occasional accident; it is an essential and unremitting element of our cerebral life"*.

The concept of inhibition was shortly adopted by the psychiatry field to describe some characteristic behaviors from particular mental disorders (Bari & Robbins, 2013). Nonetheless, J. D. Cohen (2017) suggested that the associations of inhibition with executive function and the frontal lobes exist since the Phineas Gage case, reported by Harlow (1868), and several neurological studies like the performed by Adie and Critchley (1927) and Brain and Curran (1931), that tried to identify specific reflexes of the infantile age that reappear in adults with damage in the frontal lobes.

There were, however, different theories about the level of the implication that inhibition has in the executive functions. Some authors (Bachorowski & Newman, 1985; Barkley, 1997; Dempster & Corkill, 1999) mentioned the fundamental role of inhibition in unifying EFs. However, most of the theories are based on the premise that inhibition is separable from other executive functions, but that all of the EFs share common joining factors (Bari & Robbins, 2013; Miyake & Friedman, 2012; Miyake et al., 2000).

Another difficulty is that several terms have been used over the years to explain the same or closely related processes. These circumstances have caused problems to understand the real nature of inhibitory control and have made it difficult to differentiate it from non-related processes.

Blair and Razza (2007) adopted the term “effortful control” previously used by Rothbart and Ahadi (1994) in their study of self-regulation in children, and defined it as the ability to voluntarily inhibit a dominant response in favor of a subdominant response, which corresponds with a recognized ability that belongs to the IC construct. In a different line, Diamond (2010) referred to effortful control as an aspect of temperament with a genetic predisposition, which situates effortful control as an individual tendency towards inhibition. In a recent review of several related terms carried out by Nigg (2017), effortful control is defined as a dispositional trait-level that represents the tendency to be able to employ top-down (deliberate) control to self-regulate. Consequently, effortful control might be understood as a predisposition to implement deliberate control abilities under the umbrella term of self-regulation.

Self-regulation should neither be confused with inhibitory control. Diamond (2010), affirmed that self-regulation overlaps to some extent with IC (as a central component of the EFs) because both, self-regulation and EFs, encompasses the control of our emotions. However, the difference between these terms seems to rely on the relevance that emotions received in the respective origin of the terms. While the study of EFs was from the beginning, more focused on the inhibition of thoughts, perceptions, and actions; in self-regulation research, emotions always received a relevant position to explain both learning and goal achievement process (Diamond, 2010).

However, the line between these terms is undoubtedly fragile. While emotional development includes changes in emotion expression, understanding, and regulation, the emotion regulation process is, according to authors like Carlson and Wang (2007), especially expected to be related to EF. Besides, the connection between cognition and emotion has been confirmed from a neuroscientific perspective that proposes that both work together in the information processing and action accomplishing (Carlson & Wang, 2007).

Therefore, it can be assumed that self-regulation and EFs are highly connected and that IC has a principal role not just in the control of thoughts, perceptions, and actions but also in the emotional inhibition, to achieve a specific objective. In fact, Diamond (2012) situated IC as an essential aspect of self-regulation that allows us to control emotions and to be able to avoid inappropriate behaviors. Davisson and Hoyle (2017), as well as Miyake et al. (2000), also affirmed that EFs contribute to processes involved in self-regulation.

Independently of its relationship with EFs, self-regulation is an intrinsic kind of regulation (carried out of and by oneself), that includes both top-down processes (subjectively deliberate, slow, sequential, require working memory, and are capacity-limited) and bottom-up processes (automatic, stimulus driven, rapid, and without the requirement of mental capacity) as aspects of the same continuum that should not be considered as absolute categories Nigg (2017).

Another related term is self-control. Self-control is known as an auto-regulatory psychological strategy that includes a conscious personal decision to proceed, or to continue, in a different way than it is dictated by the internal synergies of the person (impulses, behavioral patterns, wishes) or situations (rules, requests stablished by others) (Davisson & Hoyle, 2017).

Self-control and self-regulation were also used indistinctly. As it was affirmed by Nigg (2017), the cause of the problems might have emerged due to the combination of emotion and self-regulation (in emotionally challenging tasks) and cognition with control (in cognitively challenging tasks). However, according to Davisson and Hoyle (2017), self-regulation involves more general and numerous processes than just a specific strategy, while self-control is an strategy that involves, among other processes, inhibitory control to inhibit inner impulses and behave in a specific way according to the circumstances, and to achieve different goals of behavior (to initiate a goal-consistent behavior, to be able to continue with this behavior over a period of time, and to stop a non-goal-directed behavior, among others).

Diamond (2013), from a different perspective, situated self-control as one aspect of the inhibitory control (and not vice-versa) that involves the control of behavior, cognition, and emotions intending to resist temptations and not acting impulsively. In another line, Fujita (2011), affirmed that several researchers defined self-control as a preference for more substantial delayed rewards over smaller immediate rewards. The lack of capacity for delaying a reward is known as one of the main components of the impulsivity construct that will be addressed in the following sections due to its connection to inhibition problems. However, this author also affirmed that self-control might include any deliberate action that promotes long-term adaptations. Nigg (2017), explained that several definitions of the term implicitly simplified self-control to the top-down aspects of self-regulation.

In summary, the thin line between terms is a reality of the field. The study of IC (and EFs in general) from different areas of research, different perspectives and several disciplines (physiology, psychology, neurology, etc.) might be the cause of this situation. However, despite of the terminology problems, the term inhibitory control has been more outlined with time. Besides, on the basis of its role to explain the neuronal synapses, might lay the foundations to understand the connection between the "neuronal" nature of IC and its "behavioral" reality. Nevertheless, more research is needed to clarify the connection between cognitive and behavioral inhibition.

2.2. Inhibitory control at a neural level

From a biological perspective, several authors (Bear, Connors, & Paradiso, 2007; Dustman, Emmerson, & Shearer, 1996; Kandel, Schwartz, Thomas, Siegelbaum, & Hudspeth, 2013) agree that the brain is the principal organ of the central nervous system. This organ is capable of establishing communications not just with our body’s internal environment but with the external too. These communications are possible thanks to the synaptic connections of the billions of neurons that it contains.

The synapses are the regions where communication occurs between two neurons or between a neuron and a target cell. A synapse is, therefore, the union or connection between these neurons/cells (Bear et al., 2007). In a muscular contraction, for example, the synapses occurs between a motor neuron and a muscular fiber. Synapses allow the information to be filtered and integrated, and during the learning process, some of their structures and functions are modified. These changes allow some signals to be transmitted and others to be blocked from this moment on.

Dustman et al. (1996), as well as Bear et al. (2007), explained that synapses occur between pre-synaptic (situated before the synapse) and post-synaptic neurons (situated after the synapse). Two types of synapses exist: electrical and chemical. The second kind makes it possible for a nerve impulse to be conducted. This conduction is feasible thanks to the release of a neurotransmitter in the pre-synaptic neuron. The post-synaptic neuron will receive this chemical information, and a post-synaptic potential will be produced as a result. However, not all of the post-synaptic potentials are the same. A neurotransmitter can cause two different effects on post-synaptic membranes: excitation or inhibition. The first possibility (excitation) will lower the cell membrane thresholds and will, therefore, increase the chance of cell activation. The second option (inhibition) will increase membrane thresholds and will consequently decrease the chance of cell activation. The final activation of the cell will depend on the spatial and temporal summation of all of the excitatory and inhibitory effects it receives.

This explanation of inhibition at a neural level is relevant because as it was affirmed by Dustman et al. (1996), every behavior we have, from the simplest to the most complex, is the result of these electrochemical changes in our neuronal systems. The evidence of inhibitory synapses gave a neurobiological base to understand choice behavior (Ursin, 2005), as it was expected by Morgan (1891, p. 461) in his celebrated sentence: "*When physiologists have solved the problem of inhibition, they will be in a position to consider that of volition.*"

Some years ago, it was not easy to extrapolate synaptic inhibition to more complex processes. The inhibitory interactions between different brain areas, as well as the concept of inhibition at a behavioral level (where more variables are implied), were still unclear (Ursin, 1976). However, the demonstration of the role of inhibitory synapses, and the location of some specific brain areas with an inhibitory function on behavior, clarified these connections and gave inhibition the relevance it deserved.

With time, the brain areas where inhibition processes occur were better established, and their relevance for learning recognized. Besides, the plasticity of the brain was also accepted (Ursin, 2005). Nowadays, thanks to the evolution of neuroimaging techniques, the activation of different brain areas has been seen while executing different tasks. These studies provided the base to confirm that specific regions of the brain are involved in different behaviors, and therefore, the behavior was understood as the visible result of the electrical activity of our nervous system (Kandel et al., 2013).

However, the concept of inhibition itself is complicated, and according to MacLeod, Dodd, Sheard, Wilson, and Bibi (2003), it should not be assumed that the cognitive level of inhibition is originated directly from the neural level, because they belong to different levels of analysis. The neural level is related to automatic inhibition (going from simple reflexes to more sophisticated phenomena) and the voluntary inhibition level is the kind of inhibition we talk about related to the EFs (Bari & Robbins, 2013), and includes a more deliberate and controlled process (Miyake et al., 2000). In the current work, the focus was made on the latter.

2.3. Inhibitory control components

One of the most widely used definitions of IC is the already mentioned one given by Diamond (2013). This definition situates IC as a governor capacity for attention, behavior, thoughts, and emotions, that allows us to invalidate a strong internal predisposition or external temptation according to the circumstances. All of these processes are regulated by several neuropsychological mechanisms. This fact gives a multifactorial nature to IC and situates the construct as a family of related functions (Friedman & Miyake, 2004; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004).

The exact number of components that constitute the IC construct and the distinct boundaries that delimit the different mechanisms involved in it are still unclear. However, the current scientific literature gives an approximation thanks to the different studies that were carried out in the last years. The different perspectives of research that approached this domain made it possible to have it more bounded and better defined despite the need for more research.

Barkley (1997) used the term "behavioral inhibition" and included at least three interrelated processes on it: inhibition of a prepotent response, inhibition of an ongoing response, and interference control. Diamond (2013), meanwhile, established that IC is composed by response inhibition (closely related to self-control that includes resisting temptations and resisting acting impulsively) and interference control (that can be divided into selective attention and cognitive inhibition). Brocki, Nyberg, Thorell, and Bohlin (2007) also differed between two different types of interference control: within a task, and outside a task.

Bari and Robbins (2013) tried to organize this overwhelming atmosphere of terms presenting an intuitive diagram with a possible explanation for the division of the IC construct between cognitive and behavioral inhibition. These authors understand the first as the capacity to stop or override a mental process, entirely or in part, with or without intention, and the latter as the inhibition of manifest behavior.

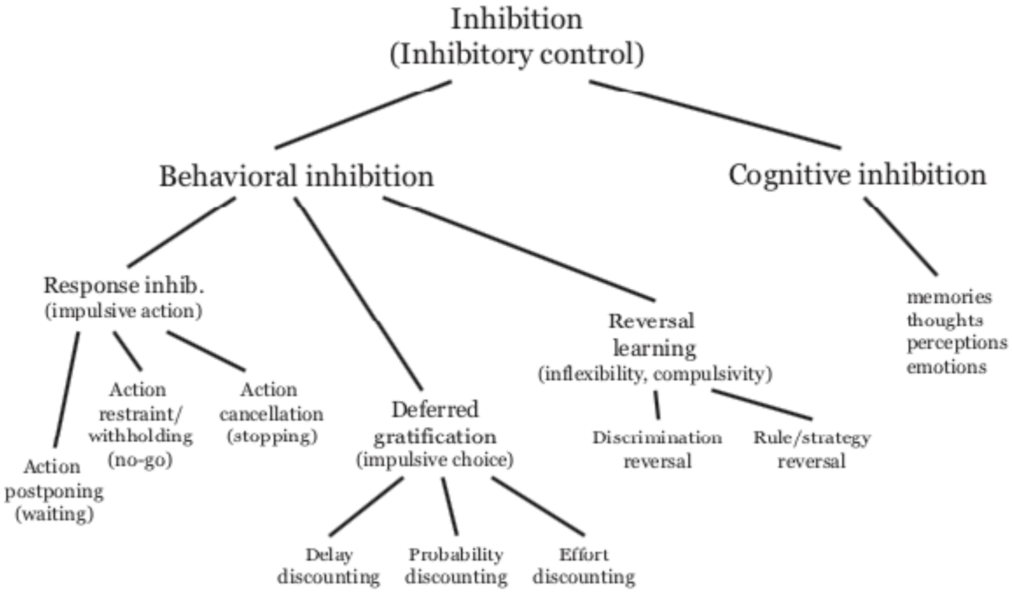


Figure 1. *Diagram of the possible subdivision between behavioral and cognitive inhibition. Adapted from Bari and Robbins (2013).*

As it can be seen in Figure 1, those authors sub-divided behavioral inhibition in three components: response inhibition, deferred gratification, and reversal learning. Response inhibition is based on the ability to wait, withhold, and stop the action in paradigms measuring impulsive action. Deferred gratification is associated with paradigms measuring impulsive choice, and also diverges in three sub-components: delay discounting, probability discounting, and effort discounting. All of the sub-components are related to the ability to inhibit the urge to obtain an immediate reward to obtain more substantial rewards. Reversal learning paradigms are more related to the study of cognitive flexibility and compulsive behavior due to the unexpected changes in stimulus/reward contingencies they entail. However, these authors affirmed that the relationship between inhibition of mental processes and physical responses is still not clear.

In any case, the sub-components might vary depending on the conception adopted to understand and to assess the domain. As has already been mentioned, neurons can inhibit each other (neural inhibition), actions can be avoided, or even started and then stopped (response inhibition), and mental processes or representations can be inhibited (cognitive inhibition) (MacLeod, 2007).

In the current document, inhibitory control was assessed under a simplified behavioral prism, including the most well-known components, and focused in a stimulus-response analysis. Under this perspective, and after a stimulus presentation, the response (or lack of response), the speed, and the response accuracy indicated different results related to the inhibitory control capacity.

Most of the latest literature on IC established the study of response inhibition and interference control as two undoubtedly components of inhibitory control (Liu et al., 2015; Maraver, Bajo, & Gomez-Ariza, 2016; Zhao, Chen, Fu, & Maes, 2015; Zhao, Chen, & Maes, 2018). Some others, like Thorell, Lindqvist, Bergman Nutley, Bohlin, and Klingberg (2009, p. 108), detailed that the “three most fundamental forms of inhibition” are inhibition of a prepotent motor response, stopping of an ongoing response, and interference control. However, in most of the cases, response inhibition also includes the “stopping of an ongoing response” as a component of response inhibition, like in the study of Liu et al. (2015).

Consequently, the ability to avoid dominant, automatic, or prepotent responses (response inhibition) (Bari & Robbins, 2013; Egger, Conzelmann, & Schmidt, 2018; Miyake et al., 2000; Wu et al., 2011; Zhao et al., 2015), and the ability to control interferences (interference control) (Bari & Robbins, 2013; Nigg, 2000; Zhao et al., 2015; Zhao et al., 2018) were the two sub-components of IC selected to be studied in the current document.

2.4. Specific cerebral regions involved in inhibitory control

The nervous system is one of the smallest but more complicated systems of our body (Bear et al., 2007; Kandel et al., 2013). This structure consists of an intricate net of billions of neurons and can be divided into two main parts: the central nervous system (CNS; formed by the brain and spinal cord) and the peripheral nervous system (PNS; including nerves, ganglia, enteric plexuses, and sensory receptors). The organization of its components makes it possible for the nervous system to accomplish its three essential functions: sensitive, integrative, and motoric.

Bear et al. (2007), as well as Kandel et al. (2013), explained that the brain includes the following structures: medulla oblongata, pons, cerebellum, midbrain, diencephalon, and cerebrum. This division is shown in the Appendix (Figure A1). The cerebrum is known as the “headquarters of intelligence.” It consists of an external cerebral cortex and an inner region of cerebral white matter with gray matter centers. A ring of structures situated on the inner edge of the cerebrum is called the limbic system. This system is also known as “emotional cerebrum” due to its fundamental role in a wide range of emotions, among other processes like memory and the sense of smell.

The cerebral cortex is an area of grey matter, 2 to 4 millimeters thick, that contains billions of neurons arranged in layers. Its highly convoluted disposition, with sulci and gyri, permits a more significant amount of cortical tissue to be accommodated inside our skulls, which allows hosting millions of neurons in a brain of relatively small size, increasing the brain's ability to process information (Bear et al., 2007; Kandel et al., 2013; Shipp, 2007).

Deep sulci are called fissures. The most profound fissure (longitudinal fissure) divides the cerebrum into two parts (left and right) called brain hemispheres. The corpus callosum connects these two hemispheres. Each cerebral hemisphere is subdivided into several lobes. The lobes are named according to the bones that cover them: frontal, parietal, temporal, and occipital (Bear et al., 2007; Kandel et al., 2013).

The whole composition of the cerebral cortex is specialized and hierarchized. Each one of the different regions has specific functions, allowing to process specific kinds of information: sensorial, motor, and associative. The sensory areas (mostly situated in the half posterior part of both cerebral hemispheres) receive sensitive information (related to our senses): touch, sight, smell, taste, and hearing. Meanwhile, the motor areas, mostly located in the frontal part of the hemispheres, control the generation, maintenance, and termination of voluntary and conscious movements by the voluntary contraction of one specific muscle or a specific group of muscles. The associative areas are located in the occipital, parietal, and temporal lobes and in front of the motor areas in the frontal lobe. None of these associative regions have a specific sensitive or motor function. However, as their name suggests, they are highly interconnected with other areas specifically involved in sensory and motor processing (Bear et al., 2007; Kandel et al., 2013). The principal motor and sensory areas of the cerebral cortex, are shown in the Appendix (Figure A2) for further information.

The prefrontal cortex (PFC), is one of these associative areas, located in a vast region situated in the anterior portion of the frontal lobe. The PFC is the newest area of the brain from an evolutionary point of view (Diamond & Ling, 2016), and the central component of the cortical structures that support executive functions activity (Badre, 2008; Browne et al., 2016; Diamond, 2012; Guillén, 2017). This area has a late development from a maturational point of view (Verburgh et al., 2013), and is the most vulnerable area of the brain (Diamond & Ling, 2016). According to Diamond and Ling (2016), stress, sadness, loneliness and lack of physical health negatively influence the function of the PFC, which has repercussions over all of the abilities this area controls, including the EFs.

The activation of prefrontal circuits is considered essential to accomplish tasks with specific objectives (Filippetti & Richaud de Minzi, 2012). However, the PFC is not the only region of the brain that is activated to allow the operating of EFs. The PFC has several reciprocal connections with other cortical and subcortical frontal regions to permit these processes (Aron, Behrens, Smith, Frank, & Poldrack, 2007; Badre, 2008; Filippetti & Richaud de Minzi, 2012).

In summary, the PFC is the "control tower" of inhibitory control, working memory and cognitive flexibility, and the base for higher-order processes. However, besides the PFC, other brain areas and structures are also involved in IC (Figure 2). Several cortical and subcortical brain regions conform circuits, that as it was affirmed by Forstmann and Alkemade (2017), display complex interactions which may inhibit each other. Furthermore, the specific requirements of a task would cause the activation of different cortical and subcortical brain regions (Bari & Robbins, 2013).

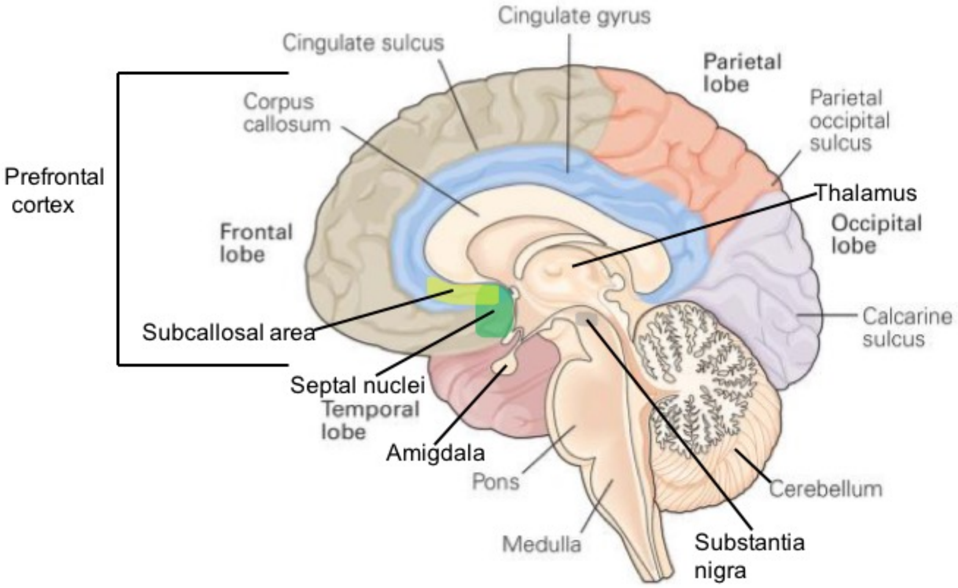


Figure 2. *Structures related to inhibitory control. Modified from Kandel et al. (2013).*

Over the years, many attempts have been made to clarify the cerebral structures responsible for inhibitory control. From the studies carried out by Kaada (1951) suggesting that the subcallosal area was necessary for response suppression, and McCleary (1961), who proposed the cingulate cortex as a response-facilitating / response-initiating area, the research on inhibitory control continued to develop. Some years later it was assumed that inhibition was not a unitary construct as expected (Ursin, 1976). It was concluded that inhibition as a single concept model was inadequate to explain the new findings related to lesions in the septal nuclei (Ursin, 2005).

The current knowledge of the topic assumes that inhibition is possible by the existence of several complex interactions between cortical and subcortical brain areas (Forstmann & Alkemade, 2017). Bickel, Jarmolowicz, Mueller, Gatchalian, and McClure (2012) explained that behavioral inhibition requires a combination of inhibitory behaviors to happen and consequently, a broad range of brain areas is usually involved in inhibition.

As it was already mentioned, there is neuroscientific agreement regarding the relevance of the PFC on EFs (C. D. Chambers et al., 2006). This brain structure is already well established as a fundamental structure for planning, decision making, and inhibition of behaviors. However, it is still not clear if specific parts of the PFC regulate specific cognitive functions (Aron, Robbins, & Poldrack, 2004), although several consistent findings are pointing to this theory (Forstmann & Alkemade, 2017).

Aron et al. (2004), reviewed various studies with neuroimaging that affirmed to have found activation in the right inferior frontal cortex while response inhibition was required. In a similar line, they found out that response inhibition deficits in children and adults with attention deficit hyperactivity disorder (ADHD) were also related to impairments in this region of the PFC. The suppression of an already initiated manual response seems to depend critically on this brain region (Aron & Poldrack, 2006; C. D. Chambers et al., 2006).

Giedd, Paus, and Keshavan (2008), studied extant literature that found increased activation in the prefrontal and parietal cortex while participating in tasks that included some form of response inhibition (Stroop test, stop task, anti-saccade task, Go/No-Go task, and Flanker task). Similar areas were activated while performing a working-memory task (Kwon, Reiss, & Menon, 2002), which might suggest the existence of underlying dimensions between these two EFs.

The Basal nuclei, mostly known as Basal ganglia (BG), were also suggested as relevant structures where response inhibition relies on. Figure 3 shows these structures in a figure adapted from S. I. Fox (2010), that includes the explanation of the motor circuit and the necessary interconnections between motor areas of the cerebral cortex, the BG, and other brain regions.

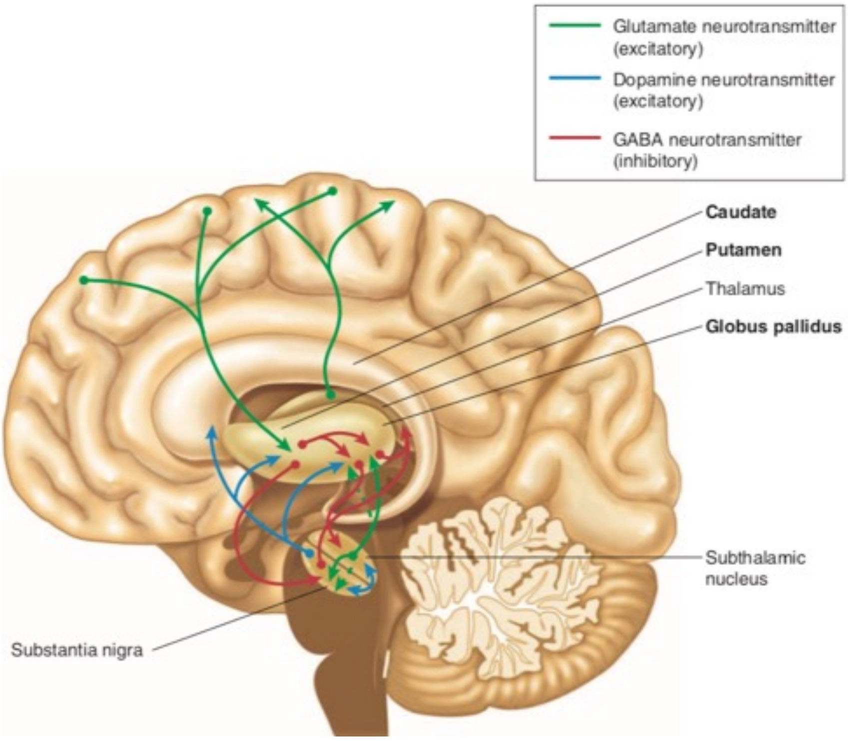


Figure 3. *Basal ganglia structures. Adapted from S. I. Fox (2010).*

Frank (2006), highlighted the role of the subthalamic nucleus (STN) in the decision-making process. According to this author, the SNT is a central basal ganglia structure that participates in both motor and cognitive processes. The SNT is activated while executing a response, and its function is to reduce the premature responding, therefore, having a significant effect on the ultimate response selection. Aron and Poldrack (2006), explained the possible role of this structure in the suppression of the "direct" fronto-striatal pathway that is activated by response initiation. Nambu, Tokuno, and Takada (2002), gave a brief extraordinary explanation of the entire process, whose schematic diagram can be seen in the Appendix (Figure A3):

> *"When a voluntary movement is about to be initiated by cortical mechanisms, a corollary signal conveyed through the cortico-subthalamo-pallidal "hyperdirect" pathway first inhibits large areas of the thalamus and cerebral cortex that are related to both the selected motor program and other competing programs. Then, another corollary signal through the cortico-striato-pallidal "direct" pathway disinhibits their targets and releases only the selected motor program. Finally, the third corollary signal possibly through the cortico-striato-external pallido-subthalamo-internal pallidal "indirect" pathway inhibits their targets extensively. Through this sequential information processing, only the selected motor program is initiated, executed and terminated at the selected timing, whereas other competing programs are canceled".*
>
> Nambu et al. (2002, p. 111)

According to several authors (Bickel et al., 2012; Cai & Leung, 2011; Hendrick, Luo, Zhang, & Li, 2012; Kaufman, Ross, Stein, & Garavan, 2003), in addition to the PFC, the insula (a brain structure deeply situated in the lateral sulci in both hemispheres) was strongly activated during behavioral inhibition tasks.

Forstmann and Alkemade (2017), summarized and explained the brain networks involved in response inhibition. These authors affirmed that response inhibition is possible thanks to brain structures like the cortex, the thalamus, and the BG, and gave the following clarification:

> *"Responses are driven from the cortex and the thalamus, which have extensive projections to the BG. The output nuclei signal to the motor nuclei of the brain stem as well as the motor cortical areas through the thalamus. From a functional point of view, the striatum and the STN form the main basal ganglia input structures for afferent signals from the entire cerebral cortex. The incoming signals are subsequently relayed via direct and indirect pathways to the substantia nigra pars reticulate (SNr), which makes up the main output nucleus of the basal ganglia. The globus pallidus (GP) and STN make up integral parts of the indirect pathway. It is likely that massive convergence of cortical signals occurs in the BG".*
>
> (Forstmann & Alkemade, 2017, p. 282)

In spite of the wide literature that tried to clarify the cerebral structures involved on IC, and besides some studies, like the one from Bickel et al. (2012), that affirmed that populations with inhibition deficits showed less inhibition-task-oriented brain activation that population without such deficits (control groups), more research is needed.

Forstmann and Alkemade (2017), highlighted that despite the development of non-invasive techniques to study the brain structures, it is possible that fMRI cannot provide a complete overview of the brain circuitries involved in inhibition. These authors explained that one of the reasons might be the limited visibility of small structures that can contribute to inhibitory processes but cannot still be seen with the available techniques. The different processes involved in different kinds of inhibition might include the activation of some similar structures but also some different ones. More research will make possible a better understanding of the anatomy of brain structures and will clarify these differences.

2.5. Inhibitory control development over the life

There is a broad literature that established the EFs mature stage around the late adolescence-early adulthood, and affirmed that this phase is reached thanks to the maturation of the prefrontal cortex (Diamond, 2013; Karbach & Unger, 2014; Liu et al., 2015; Steinberg et al., 2008; P. D. Zelazo et al., 2013).

As it was previously mentioned, several authors pointed to IC and WM as the two EFs with the earliest development and explained how this fact causes a subsequent development in other executive functions like CF and a successive development of some other higher order functions like reasoning, problem solving, and planning (Diamond, 2013; Guillén, 2017; Nigg, 2017).

Michel, Molitor, and Schneider (2018), affirmed that among EFs, inhibitory control is particularly crucial for ontogenetic development. IC presents a rapid development during the preschool years (Best & Miller, 2010; Best, Miller, & Jones, 2009; Liu et al., 2015; Stein, Auerswald, & Ebersbach, 2017; P. D. Zelazo & Carlson, 2012), gets mature throughout early to middle childhood (Phung, 2017), experiences changes across the lifespan (McAuley, Yap, Christ, & White, 2006), and declines remarkably in older adults (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008; Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005; Peltsch, Hemraj, Garcia, & Munoz, 2011; Zanto, Hennigan, Ostberg, Clapp, & Gazzaley, 2010).

Kvalo, Bru, Bronnick, and Dyrstad (2017), also emphasized the quick develop of EFs through the primary school years but affirmed that in the adolescence the development of these functions gets slower. Nevertheless, through continuous practice and by feedback application, development seems to emerge gradually. In any case, adolescence seems to be a critical stage at a global basis, and as it was already suggested, the profound changes that take place in the PFC during this stage are the leading cause of this fact (Diamond, 2013; Wimmer, Bellingrath, & von Stockhausen, 2016).

Riggs, Black, and Ritt-Olson (2014, p. 35), explained what they called *"one of the most profound neuroscientific discoveries of the late twentieth century"* which is none other than the intricate period of growth and development that suffers the adolescent brain, starting around the puberty (10 - 12 years) and continuing until the early adulthood (the twenties). According to these authors, the PFC is where most of the changes are happening. The changes start with an intense period of synaptogenesis (synapse formation), which sets and strengthens neural connections. It continues with a later succession of pruning (processes by which "redundant" synapses are being eliminated) and myelination periods (processes by which the axons of the neurons are covered by myelin to electrically insulates axons and allows fast propagation of nerve impulses by saltatory conduction) that continue to happen until adulthood (Birchmeier & Bennett, 2016; Giedd et al., 2008; Riggs et al., 2014). These processes allow the specialization of neural systems which increases neural processing speed (Riggs et al., 2014).

Steinberg (2010), enumerated some of the improvements reached as a consequence of the synaptic pruning and the continued myelination of prefrontal brain regions during the adolescence stage: improvements in response inhibition, in planning forward, in evaluating risks and recompenses, and in being able to consider multiple sources of information simultaneously. These authors also talked about improvements in the association between affection and cognition, due to the increment of available connections with brain areas associated with socio-emotional and cognitive control systems.

The PFC has connections with other brain structures like the limbic system (Kandel et al., 2013; Riggs et al., 2014). As it was already mentioned, this system also known as “emotional cerebrum”, besides of being a more primitive center, is responsible for the processing and regulation of more sophisticated and powerful urges and emotions. The areas related to emotions, reward, or novelty-seeking gets mature much earlier than the areas related to self-regulation and problem solving (frontal areas) (Robbins & Everitt, 1996). This heterogeneity in brain development is, according to authors like Riggs et al. (2014) and R. A. Chambers, Taylor, and Potenza (2003), the reason why adolescence is a period full of intense motivational drives with a marked tendency of new experiences seeking. However, this stage of life is also characterized by a lack of full capacity to regulate the drives and emotions, which can easily end up in non-healthy decisions (R. A. Chambers et al., 2003; Riggs et al., 2014).

Besides, irregularities in the profound maturational changes that happened in the adolescent’s brain might be the reason of several kinds of psychiatric illnesses (Giedd et al., 2008; Wimmer et al., 2016). In fact, a correct IC development was linked to critical growth-related outcomes (Alesi et al., 2016; P. D. Zelazo & Carlson, 2012), to fewer academic problems and better social competencies (X. Chen et al., 2009), along with an enhanced general situation at an economical, professional, and healthy level in adulthood (Moffitt et al., 2011). However, deficits on IC were linked to several disorders that would be further explained in the following section.

The developmental theories situated adolescence as a “changing” stage of life where prevention strategies can still be implemented to promote both behavioral and cognitive control (Riggs et al., 2014; Wimmer et al., 2016). It was proved that early experiences can cause changes at a neurological level due to the brain's plasticity (Courchesne, Townsend, & Chase, 1995), and a large amount of research already confirmed that diverse training interventions could alter the brain mechanisms involved in EFs deficits (Tamm et al., 2019), including inhibitory control.

Among IC components, developmental differences were also found. According to Liu et al. (2015), response inhibition develops earlier than interference control and therefore plays a more-fundamental role in early cognitive development. The presence of IC and other EFs deficits along the evolutive stages of life have been widely linked to the incidence of several disorders with high impact in our society.

2.6. Disorders related to a lack of inhibitory control

Deficits in EFs have been linked to several problems that severely damage the development of children's physical, mental, and social health (Xiong et al., 2018). This fact situated EFs as crucial keys for mental and physical health, academic achievement, and school success, among others (Diamond, 2013).

When the focus is made on the characteristics of a lack of inhibitory control, the presence of impulsivity appears. When talking about the most common disorders attributed to a lack of inhibitory control, eating disorders, substance abuse disorders, suicidal behaviors, academic problems, social incompetence, ADHD, schizophrenia, antisocial behaviors, problems to keep goals, and a general worse situation at an economical, professional, and healthy level in adulthood, among others, were confirmed (Alderson, Rapport, & Kofler, 2007; Alesi et al., 2016; Brocki et al., 2007; Chamorro et al., 2012; X. Chen et al., 2009; Grandjean & Collette, 2011; Houben & Wiers, 2009;

Jasinska et al., 2012; Moffitt et al., 2011; Raust et al., 2007; Young et al., 2009; P. D. Zelazo & Carlson, 2012).

2.6.1. Lack of inhibitory control and impulsivity

Impulsivity is a highly researched behavioral trait (Bezdjian, Tuvblad, Wang, Raine, & Baker, 2014), deeply related to personality (Bari & Robbins, 2013), with high relevance in several disorders of impact in our society. As it was affirmed by Whiteside and Lynam (2001) and paraphrased by Bezdjian et al. (2014, p. 2549), impulsivity appears *"in one form or another in almost every major personality system and numerous psychiatric disorders."*

The impulsivity concept has evolved remarkably in the last decades and is currently defined as a complex multifactorial construct with multiple manifestations that covers a wide range of moderately related characteristics (Caswell, Bond, Duka, & Morgan, 2015; de Wit, 2009; Evenden, 1999; Fischer, Smith, & Cyders, 2008; Whiteside & Lynam, 2001).

Impulsive behaviors are characterized by a general tendency to present quick and unplanned reactions to internal and external stimuli without considering the consequences (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Impulsive individuals cannot inhibit overbearing responses, they present an inability to delay rewards, and have the tendency to make risky decisions (Caswell et al., 2015; de Wit, 2009). Inattention, or lapses of attention, were proposed as an additional process that may result in impulsive behaviors (de Wit, 2009).

According to Diamond (2013, p. 3), "*errors of impulsivity are errors of not being able to wait.*" Several authors (Enticott, Ogloff, & Bradshaw, 2006; Jasinska et al., 2012; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009; Logan, Schachar, & Tannock, 1997;

Perales, Verdejo-Garcia, Moya, Lozano, & Perez-Garcia, 2009), affirmed that impulsivity is thought to appear due to inhibitory control deficits. However, interventions seem to be an open possibility to improve impulsive conducts: "*If someone can be helped to wait for, such errors can often be avoided*" (Diamond, 2013, p. 3).

In general, impulsive behavior is thought to be detrimental to the individual (Evenden, 1999). However, some authors reasoned that sometimes impulsivity might generate positive consequences depending on the context (Dickman, 1990). According to Bevilacqua and Goldman (2013), impulsive behaviors might cause an advantage in situations where it is critical to respond quickly in order to take advantage of the unpredicted opportunities.

Nonetheless, there is a broad evidence of the connection between impulsive behaviors and many psychological and psychiatric disorders like addictions (substance abuse, dependence on alcohol or drugs), eating disorders, gambling, aggressive behaviors, suicidal tendencies, criminal behavior, physical and sexual abuse, attention-deficit/hyperactivity disorder (ADHD), bipolar disorders, personality disorders (such as borderline personality disorder (BPD), and antisocial personality disorder (ASPD)), among others (Arce & Santisteban, 2006; Archer, Oscar-Berman, Blum, & Gold, 2012; Bevilacqua & Goldman, 2013; Fischer et al., 2008; Whiteside & Lynam, 2001).

In fact, in the Diagnostic and Statistical Manual of Mental Disorders - 5th Edition (DSM-V) (American Psychiatric Association, 2013), impulsivity was consolidated as a diagnostic criteria for psychological disorders such as ADHD, destructive disorders, disorders of impulse control and behavior, obsessive-compulsive disorder, personality disorders, and disorders related to addictive substances.

The two most popular methods to evaluate impulsivity are questionnaires and laboratory tasks. One of the most implemented questionnaires is the Barratt impulsiveness scale (Rodrigues, Perez, Carletti, Bissoli, & Abreu, 2006), from its first version (Barratt, 1959), to the latter (BIS-11) (Patton, Stanford, & Barratt, 1995). Regarding the laboratory tasks, the Matching Familiar Figures Test (MFFT), developed by the psychologist Jerome Kagan in 1966, is one of the most applied tasks to measure reflection-impulsivity. A renovated version of the test, the MFFT-20 by Cairns and Cammock (1978), appeared after solving some methodological problems presented in the first version. The Spanish computerized version of this test is the Escala Magallanes de Impulsividad Computarizada (EMIC) by Servera and Llabrés (2000). Several delay of gratification tasks were also developed along the years to assess the "temporal" component of impulsivity. However, the base of all these tasks was the original "Marshmallow Test" from Mischel (1974). These laboratory tasks are explained more extensively in the Study I of the current work.

It should be noticed that in samples of adolescents and adults, questionnaires are by far the most widely used option (Bezdjian, Baker, & Tuvblad, 2011). Despite this fact, several authors (Bari & Robbins, 2013; Reynolds, Ortengren, Richards, & de Wit, 2006; White et al., 1994) affirmed not to find significant correlations between questionnaires and laboratory task results.

According to Chamorro et al. (2012), most of the literature focused on impulsivity includes clinical samples or adolescent population, where high levels of impulsivity are theoretically expected. However, as it was affirmed by Enticott et al. (2006), impulsivity is observed in both clinical and non-clinical populations. Chamorro et al. (2012) were the first authors to investigate the prevalence of impulsivity in the general population through a national analysis carried out in the United States (*n* = 34.653). Their results showed a 17% prevalence of impulsivity in their sample. However, the sample composition was limited to adults, and the analysis was made by questionnaires and did not include laboratory tasks.

In any case, the distinction between impulsivity and lack of inhibitory control seem to be relevant. Nigg (2017), pointed out that both constructs, impulsivity and inhibitory control, include several components and that their specific failures must be differentiated. This author explained that, for example, the non-reflective selection or preference for the immediately rewarding response (an impulsivity component that will be further explained in the following sections) implies more than lack of inhibition. The given explanation to this fact is that this kind of impulsivity also reflects the implicit and explicit weighting of immediate versus delayed reward: *"It is modulated both by bottom-up reward valuation, and by top-down biasing related to goals. It depends on computations involving time"* Nigg (2017, p. 13).

Due to the relevance of impulsivity, its connection with several disorders, the lack of prevalence studies in a typically develop schoolers sample, and the knowledge of this construct as a trainable one, it might make sense to analyze its incidence in conjunction with the inhibitory control domain in a school setting. This analysis will give a more realistic view of the actuality in a scholar day-by-day basis.

Chapter 3: **State of research**

The study of inhibitory control is mainly addressed under the umbrella term of EFs. Not so many studies are focused explicitly on studying IC on its own, generating a gap of knowledge. Besides, the main two areas of research where IC is included are the examination of the connections between IC (and other EFs) with disorders (mainly including clinical populations) and the investigation of several training interventions to produce changes on IC and other EFs in both clinical and non-clinical samples.

To our knowledge, no study previously assessed the prevalence of IC deficits in a normally developed sample. Besides, normative data is not available to discriminate where IC problems start.

In the following sections of this chapter, a summary of the most commonly used tools to evaluate IC and the most widely implemented interventions to produce benefits on IC (among other EFs) are presented. As the main objectives of the current work are to analyze the reality of IC differences on a typically developed schoolers sample and to investigate the effects of an exercise intervention on IC, the benefits of both longitudinal and acute exercise interventions on IC and other EFs were reviewed to describe the current stage of research.

3.1. Inhibitory control evaluation

3.1.1. Behavioral tasks

A wide range of tools is available to assess, among other EFs, inhibitory control. In most of the cases, one single tool is selected, and its results are extrapolated to the whole IC domain. However, there are some tasks that, due to their nature, are more related to one component than to others. An explanation of the most implemented tasks is shown below.

Go/No-Go task: The Go/No-Go tasks permit the examination of the ability to inhibit prepotent responses (response inhibition) (Bari & Robbins, 2013). The traditional design of these tasks requires the execution or inhibition of motor response (Forstmann & Alkemade, 2017) and minimization other cognitive/behavioral processes (Simmonds, Pekar, & Mostofsky, 2008). The prepotent tendency to respond is created by weighing towards a Go stimulus. This tendency is created by presenting a notably higher amount of Go stimuli, and therefore increasing the need of IC to effectively suppress the response when a No-Go stimulus is presented (Simmonds et al., 2008).

The Stroop Test: The Stroop Test (Stroop, 1935), is a broadly used tool for detecting interference-control impairments (Wu et al., 2011). The test has three parts. The first part, where participants have to read the colored words (W); the second, where they have to name the ink in which the X's are colored (C); and the third, where participants have to name the ink color of the words when the color and the name are incongruent (WC) also known as interference condition. Therefore, the interference effect appears as a result of the different nature of word reading (extremely practiced and therefore highly automatic) and color naming (susceptible to interference from other conflicting processes due to its novelty) (Botvinick, Braver, Barch, Carter, & Cohen, 2001). This test is widely implemented to assess interference control (or the ability to inhibit responses to irrelevant information), an essential IC component for protecting goal-directed behavior (Barkley, 1997; Kertzman et al., 2006).

Flanker task: In the Flanker tasks, firstly implemented by Eriksen and Eriksen (1974), participants are usually presented with a group of visual stimuli and have to give the direction of the centrally presented one. For example, in the following stimulus presentation: “>><>>” the arrow situated in the middle of the group is the objective. Participants have to respond, pressing the left or right button indicating the direction of the stimulus. Left in the given sample. The flankers (the stimuli that are surrounding the objective) can be congruent (arrows pointing in the same direction as the stimulus) or incongruent (arrows pointing in the opposite direction). Incongruent trials are known to be the ones with the highest rate of distraction, while congruent trials are recognized to have lower rates of distraction (Jäger, Schmidt, Conzelmann, & Roebers, 2014; Schmidt et al., 2015). Some tasks also include neutral flankers (without direction) (Eriksen & Eriksen, 1974; Forstmann & Alkemade, 2017). This task also assess interference control (Liu et al., 2015).

Stop-signal task: In the Stop-signal tasks participants have to respond to a specific stimulus (objective) every time it appears, but only under the condition that the stimulus is not followed by a cue (e.g., a bomb or a specific tone). For those cases, participants are instructed to withhold the ongoing motor response (Forstmann & Alkemade, 2017; Rubia et al., 2008). Two different versions of the task were implemented by Logan (1994) and Rubia et al. (2008) under a similar stop signal base. Logan (1994) implemented a task where an arrow (pointing either to the left or to the right) required the consequent left or right response. However, in a minority of the trials, the go-stimulus was followed by a specific tone, instructing participants to withhold the ongoing motor response. In the task implemented by Rubia et al. (2008), a plane appeared on the screen followed (or not) by a zeppelin (250 milliseconds later). A keyword had to be pressed each time an airplane appeared whether or not it was followed by a zeppelin. However, a third condition included a bomb appearance also 250 milliseconds after the airplane (in 50% of trials). In this third condition (bomb presence) participants had to press the keyword if the airplane appeared alone, but to withhold the ongoing motor response of answering when the airplane was followed by a bomb. Response inhibition is the IC component assessed with this kind of tasks (Liu et al., 2015).

Furthermore, these are not the only tasks implemented to assess several aspects of IC. Some more examples are: The Simon task (Simon, 1990), where participants have to pay attention to the color of the stimulus (e.g., red or blue) and give the correct answer (e.g., red pressing the right keyword and blue pressing the left one), but ignoring the task-irrelevant stimulus location, that can be both: spatially matched (e.g., a red stimulus is shown in the right visual field) or non-matched (e.g., a red stimulus is shown in the left visual field); Stimulus-response (S-R) compatibility task: where participants are required to switch between two stimulus-response combinations. In the compatible combination, the stimulus suggests the response (e.g., an arrow pointing to the right side that requires to press a right button), while in the incompatible combination the stimulus does not suggest the response (e.g., a right-pointing stimulus that requires a left button answer) (Alluisi & Warm, 1990); Anti-saccade tasks are based on the eye movements (Barton, Raoof, Jameel, & Manoach, 2006; Luna et al., 2001). These tasks require a voluntary stop of a reflexive eye movement (characterized by the focus in any novel stimulus in the visual field / prepotent visual stimulus) and instead move their look to another specific location (Hallett, 1978).

In any case, all of this variety of tasks involve some form of inhibitory control. As it was implied by Giedd et al. (2008), Stroop tests, Anti-saccade tasks, Stop tasks, Go/No-Go tasks, and Flanker tasks involved some kind of response inhibition. Besides, several authors affirmed that this kind of conflict tasks seem to have underlying components (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Rueda, Posner, & Rothbart, 2005). However, due to their nature, some of the tasks can also be used to assess related domains. For example, the Stroop test to assess selective attention (Torbeyns et al., 2017; Wright et al., 2016).

3.1.2. Neuroimaging techniques

Another extended option to assess IC is by the implementation of electroencephalography (EEG) (to track event-related potential (ERP)), and functional magnetic resonance imaging (fMRI) techniques. As none of these techniques were employed in the current study, only a brief description is provided below.

As previously stated, the activity of billions of brain cells (that integrate information via electrical potentials) is the cause of human behavior and experiences (N. Thigpen & Keil, 2017).

Event-related potentials (ERPs) are minimal voltages generated in the brain structures in response to specific events or stimuli. Their analysis is carried out by a noninvasive procedure (EEG) to evaluate the electrical activity of the cells in connection to a specific event, using sensors attached to the scalp. Scientists have implemented this technique for over 80 years to study brain electrical activity following or preceding events of interest (Sur & Sinha, 2009; N. Thigpen & Keil, 2017; N. N. Thigpen, Kappenman, & Keil, 2017).

J. E. Chen and Glover (2015), explained that fMRI is a neuroimaging tool widely implemented to detect fluctuations in the oxygenation of the brain tissue resultant from altered metabolism. These metabolism variations can be caused by the need for performing a task designed to target a specific cognitive process or can also happen spontaneously while the subject is resting in the absence of conscious awareness.

3.2. Training possibilities to ameliorate inhibitory control

As it was affirmed by Moreno and Farzan (2015), one of the most passionate questions to answer in the neuroscience field is the brain plasticity. Plasticity is the ability of the brain to modify itself or to be transformed by the external environment (Moreno & Bidelman, 2014). To be able to answer questions like how our brain changes, how we can increase our capacities, how we can improve brain structures with deficits, or if training a specific function can cause transfer effects in other functions, could cause a significant impact on the knowledge of the field.

In the last decades, several attempts were made to develop training methods to improve executive functions. The growing knowledge of the relevance of a well-developed IC at a personal, professional, and social level has situated the improvement of this domain as a critical issue of public health. However, mixed results were found with the different programs implemented to improve such functions so far.

Numerous training options tried to improve IC, among other EFs, aiming to prevent, to intervene, and to find a remedy for the different diseases connected to deficits in such functions. The design of such methods was based on the knowledge that different interventions can alter the brain mechanisms involved in EFs deficits (Tamm et al., 2019).

Training a specific activity can ameliorate the performance on the trained task and can modify the underlying brain structures involved in this activity (Moreno & Farzan, 2015; Zhao et al., 2018). However, it is also known that at a theoretical level "*transfer may occur if both the training and transfer tasks share a common cognitive mechanism and activate similar brain regions or networks*" (Liu et al., 2015, p. 7).

In any case, the mixture of results emphasize the need of more research to clarify the already mentioned answers and to establish, as requested by Berkman, Kahn, and Merchant (2014), the base of whether and how IC performance can be improved with training.

Among all of the studied possibilities, computer-based training programs (Klingberg et al., 2005; Lindqvist & Thorell, 2009), musical interventions (Jaschke, Honing, & Scherder, 2018; Joret, Germeys, & Gidron, 2017; Moreno & Farzan, 2015), martial arts, mindfulness, and yoga (Enoch, 2015; Lawler, 2015; Oberle, Schonert-Reichl, Lawlor, & Thomson, 2012; Thurman & Torsney, 2014), acute bouts of exercise (Browne et al., 2016; Jäger et al., 2014), and chronic exercise interventions (Alesi et al., 2016; van der Niet et al., 2016) might be highlighted due to their broad application.

The key to the computer-based interventions relies on training the same or related EFs that need to be improved. Some computerized tasks implemented for training include an interactively adjusted level of difficulty (Klingberg et al., 2005), progressively increasing the IC (or any other EF that want to be trained) demands (Diamond & Lee, 2011). Some others include a training goal (a challenge). An example is the study of Liu et al. (2015), where the researchers asked the participants to try to slice thirty more fruits than the last time in the training game. Liu et al. (2015) implemented the game "Fruit Ninja" to train response inhibition in preschoolers. The training group improved its performance on the task, meaning that response inhibition can be improved in this age. However, these authors did not find transfer effects from the training task (Fruit Ninja) to a Go/No-Go task at a behavioral level but did find training-induced changes at the neural level (in girls). This fact could mean that training effects might be more easily evident at a neural level (EEG recordings) than on a behavioral level (tasks), due to their higher level of sensitivity to changes (Liu et al., 2015).

Bugos and DeMarie (2017), affirmed that music training during childhood is associated with higher levels of cognitive performance. Besides, two types of transfer have been found after musical interventions: near transfer, meaning a transference of skills in the same domain, and far transfer, meaning the transference of skills to an unrelated domain (Bugos & DeMarie, 2017). The base of musical interventions to improve IC relies on cognitive stimulation. This stimulation over a long period has resulted in benefits for several cognitive functions (Moreno & Farzan, 2015).

According to Diamond and Lee (2011), traditional martial arts emphasize IC while training self-control, discipline, and character development. Similar training possibilities were found to be mindfulness and yoga interventions (Diamond & Lee, 2011; Oberle et al., 2012; Zenner, Herrnleben-Kurz, & Walach, 2014).

Brown and Ryan (2003, p. 822), affirmed that mindfulness is commonly defined as "*the state of being attentive to and aware of what is taking place in the present.*" Oberle et al. (2012) talked about the self-regulatory nature of mindfulness that includes identifying our own thoughts and feelings deprived of judgment. Mindfulness is known to reduce stress, to promote well-being, to strengthen immune functions, to promote selfcompassion, empathy, and perspective-taking, and to increase several attentional capacities with high relevance to IC and self-regulation development (Oberle et al., 2012; Zenner et al., 2014; Zylowska et al., 2008).

Yoga seems to be useful to reduce behavioral and emotional problems (including stress) and to therefore improve cognitive functions (Bazzano, Anderson, Hylton, & Gustat, 2018; S. C. L. Cohen et al., 2018; Jarraya, Wagner, Jarraya, & Engel, 2019). Stress has, according to Diamond (2010), a devastating effect on EFs due to its impact on the prefrontal cortex. Mild stress inundates the PFC with dopamine and norepinephrine, which disturb the PFC function and consequently harm executive functions (Cerqueira, Mailliet, Almeida, Jay, & Sousa, 2007; Diamond, 2010). The reason of such positive impacts on IC and other EFs after mindfulness, martial arts, or yoga trainings, might be related to the inclusion of physical activity, self-control techniques, and conscious relaxation in the same intervention.

Regarding exercise interventions, Kubesch et al. (2009), pointed out the changes in brain chemistry as one possible mechanism for improving EFs by physical activity. According to these authors, physical activity influences positively central dopaminergic and serotonergic systems. A reduction of dopamine concentration was associated with adverse effects on inhibitory control processes (among other EFs) (Diamond, Briand, Fossella, & Gehlbach, 2004).

L. Chaddock-Heyman, Hillman, Cohen, and Kramer (2014) affirmed, after a review of literature, that physical activity and higher levels of aerobic fitness in children have been found to benefit brain structure, brain function, cognition, and school achievement. Diamond and Lee (2011) also highlighted the robust improvements that were found after aerobic exercise on PFC activity, which might be another clue for the benefits reported in EFs after exercise interventions.

According to Sibley and Etnier (2003), the mechanisms to explain the relationship between exercise and cognition can be classified into two categories: physiological mechanisms and learning/developmental mechanisms. The first category is based on all of the physical changes that occur in the body because of exercise: increased cerebral blood flow, brain neurotransmitters variation, structural changes in the central nervous system, and modified arousal levels. The second encompasses the benefits that movement and exercise provide for appropriate cognitive development, like the necessary learning experiences.

Sports practice has shown to be a useful activity to develop spatial and divided attention, working memory, and mental capacity. Besides, team sports practicing seems to provide the abilities to adapt quickly, to change strategies, and to inhibit responses (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). A study carried out with highly talented soccer players (Verburgh, Scherder, van Lange, & Oosterlaan, 2014) showed that these athletes had a significantly superior IC capacity when compared with controls. Several studies with basketball players, baseball players, and fencers reported similar results. Kida, Oda, and Matsumura (2005) found that intensive baseball practice improves the Go/No-Go reaction time. Nakamoto and Mori (2008a) obtained shorter RTs in baseball players, and Nakamoto and Mori (2008b) affirmed that basketball and baseball players had significantly shorter reaction times than the nonathletes in Go/No-Go tasks. In a similar line Di Russo, Taddei, Apnile, and Spinelli (2006, p. 113) concluded that "*the fencers' ability to cope to the opponent feint switching quickly from an intended action to a new more appropriate action is likely due to a faster stimulus discrimination facilitated by higher attention and by stronger inhibition activity in prefrontal cortex*".

Wang et al. (2013) compared the effect of open skills sports (those in which players are required to react in a dynamically changing, unpredictable and externallypaced environment, like basketball, football, tennis, baseball or handball) versus closed skill sports (those in which the environment it is relatively consistent, predictable, and self-paced for players, like running or swimming) on the modulation of the IC. Their results showed that IC in athletes can benefit more from open skill training and that sports that include both physical and cognitive demands might provide a potential clinical intervention for those who have inhibitory control problems.

At any rate, the assumption of the effects that regular physical exercise and sports practice have on biological responses of muscles and organs (that turns into structural and functional changes on the brain), comes from a multidisciplinary approach that agglutinates research from diverse disciplines such as neurosciences, kinesiology, biology, and anatomy among others (Alesi et al., 2014).

Exercise interventions can have a longitudinal/chronic nature or can be composed of a single bout of exercise (acute exercise interventions). Both possibilities are going to be explained in the following subsections of the current chapter and would be the base of two of the three included studies. In any case, knowing that children with initial worse IC might benefit the most from training (Diamond & Lee, 2011; Wang et al., 2013), early training interventions might be the key to intervene current problems and to prevent future related ones.

3.2.1. Longitudinal exercise interventions

Day by day, our lifestyle is becoming more sedentary. This fact is causing several associated problems with high impact in our society and is becoming a real threat to public health worldwide (Verburgh et al., 2013; World Health Organization, 2019b).

The World Health Organization (WHO) established that physical inactivity (insufficient physical activity) is one of the principal risk factors for noncommunicable diseases (NCD) and death at a worldwide level. According to the organization, individuals who do not have adequate levels of physical activity present an increment of the risk of suffering cancer, heart diseases, strokes, and diabetes ranging between 20% and 30%. The general overview also shows a shorten lifespan by 3-5 years (World Health Organization, 2019b).

Besides, active lifestyle benefits are not restricted to physical health (Verburgh et al., 2013). There are many studies that point out to the high relevance that physical activity and exercise have on a better cognitive performance, and benefits on EFs after exercise interventions have been found in both, children and adolescents (Singh et al., 2018; Verburgh et al., 2013; Xue, Yang, & Huang, 2019).

According to a recent systematic review carried out by an expert panel (Singh et al., 2018), the developmental stage between childhood and adolescence seems to be an excellent opportunity for experience-dependent plasticity, where the brain can be positively influenced (at a structural and functional level) by enriched environmental circumstances like physical activity.

As previously stated, exercise interventions can be classified as longitudinal/chronic or single bouts/acute. The main difference relies on the length of the intervention. While longitudinal exercise interventions contain several bouts of exercise over a long period of time, acute interventions are just composed by a single bout of exercise, in a single moment. Longitudinal interventions aim to evaluate the long-term effects of a specific intervention, usually comparing the pre-intervention results with the post-intervention results. The studies including longitudinal interventions generally contain information regarding the length of each session, the number of sessions per week, and the duration of the complete intervention (from the pre-test to the post-test measurements).

The length of a longitudinal intervention is variable. Verburgh et al. (2013) affirmed that the typical range of these interventions is between six and 30 weeks. Xue et al. (2019) stated that the typical length is over 6 weeks, being also possible to implement them over some years.

Comparing with the number of studies that include acute bouts of exercise, the number of studies that contain longitudinal interventions seem to be lower. In fact, according to Xue et al. (2019), the number of studies focused on the effects that longitudinal exercise interventions have on EFs is relatively small. The length of the interventions and the requirement of more resources might be possible explanations to this fact.

The general health benefits of regular physical activity are clear, but the results regarding the impact of exercise interventions at a cognitive level, on EFs, and on academic performance are still inconsistent (Singh et al., 2018; Xue et al., 2019). The expert panel (Singh et al., 2018) advocated for more "high-quality" research to clarify the real benefits of physical activity and physical exercise interventions on cognition.

3.2.2 Acute bouts of exercise

Another commonly implemented kind of exercise interventions is acute bouts of exercise, also known as acute exercise interventions. As in longitudinal interventions, this acute participation aims to investigate the effects of physical exercise on a specific domain (in the current document on IC). The exercise activity included in acute exercise interventions consists of a single short-term exercise bout that according to Verburgh et al. (2013) typically ranges between 10 and 40 minutes. The nature of the exercise can be variable, the same as in longitudinal interventions.

As it was already reported, physical activity seems to influence the central dopaminergic, noradrenergic, and serotonergic systems (Kubesch et al., 2009; Meeusen & De Meirleir, 1995). According to authors like Kubesch et al. (2009), aerobic resistance exercise, practiced for at least half an hour, leads to an exercise-induced serotonin biosynthesis that might have positive effects on EFs. Maddock, Casazza, Fernandez, and Maddock (2016) studied the impact of three vigorous exercise sessions (lasting between eight and 20 minutes) on brain structures, and results showed an increased cortical level of two neurotransmitters (glutamate and gamma-aminobutyric acid/GABA) highly relevant for the chemical connections within the brain. These authors also concluded that there were differences between the brain state associated with physical activity and the brain state associated with sedentarism and that both circumstances cause different changes in brain metabolism.

The needed length of an intervention to cause benefits with acute exercise is still not clear. In connection to this line of research, Kubesch et al. (2009) explained that there is an increase of tyrosine hydroxylase in the nucleus caudate (relevant for cognitive functions) only 3 minutes after the beginning of a movement, reaching its peak level within the first 20 min of exercise. Tyrosine hydroxylase is the enzyme responsible for catalyzing the conversion of the amino acid L-tyrosine to dihydroxyphenylalanine (DOPA). DOPA is the precursor of dopamine, and dopamine the precursor of norepinephrine and adrenaline. All of these enzymes are as important as hormones and neurotransmitters for the functioning of the nervous systems (Daubner, Le, & Wang, 2011).

Another relevant finding reported by Suwabe et al. (2018) showed that a single 10 minutes bout of exercise (at an intensity of the 30% of the VO_2 max) resulted in rapidly increased activity in several hippocampal and cortical regions, which according to

Gronwald et al. (2018) can be understood as a neurobiological mechanism that contributes to exercise-induced cognitive benefits.

In any case, as it was affirmed by Gronwald et al. (2018, p. 1), “*the neurobiological effects of acute exercise depend on the duration and intensity of the exercise, and on the training status of the participants.*” All of the possible benefit moderators of acute exercise interventions on IC will be further discussed in the discussion part of Study III.

Chapter 4: Research organization, hypotheses, and objectives

4.1 Research organization

As it was commented by Baggetta and Alexander (2016), the complexity of EFs makes the research of the construct both confusing and contradictory. A similar situation occurs when studying the IC.

To clarify the connection between the three studies that constitute the current work, this chapter aims to justify the design, the organization, and the research question of the studies as well as to present the hypotheses, and the objectives of all of them.

The acronym FINER (suggested by Hulley, Cummings, Browner, Grady, and Newman (2013)) was implemented to determine the research questions of the current work. According to these authors, a good research question should be feasible, interesting, novel, ethical and relevant. Based on these five characteristics, the studies have been designed to clarify several theoretical aspects related to inhibitory control (and its relationship with impulsivity), as well as the real possibilities that different types of intervention with physical exercise (acute physical exercise interventions, and longitudinal studies with physical exercise interventions) entail for the improvement of inhibitory control in samples with normal development (without any previously diagnosed disorder).

The first study (Study I), with a descriptive cross-sectional design, presents a double objective. First, to clarify the theoretical aspects of the relationship between the inhibitory control and impulsivity constructs, and, secondly, to analyze the differences in these two constructs in a sample of normally developed schoolchildren.

Given the variability detected in the inhibitory control of the sample composed by schoolchildren with normal development, and since the relationship between deficits in inhibitory control and numerous disorders with high social impact has been demonstrated, in the two following studies, the benefits that different physical exercise interventions produce in the inhibitory control have been analyzed.

Accordingly arises the second study of this work (Study II). The study includes a systematic review and meta-analysis of the effects that different physical exercise interventions carried out by previous single studies with longitudinal designs have on the inhibitory control of children and adolescents with normal development.

It should be noted that most of the included single studies contained different exercise intervention designs, mainly directed to produce benefits in the general executive functions construct, but not necessarily directed to attend the different needs of the EFs components (including IC).

In this second study, in addition to the effect size calculations (carried out by two different statistical procedures), an extent literature review was performed. This review of literature allowed us not just to discuss the obtained results, but also to discover another kind of exercise intervention that might cause benefits in the inhibitory control of children, adolescents, and adults. Several studies pointed to acute physical exercise interventions as an alternative to cause changes at a cognitive level. Unlike the "long-term" interventions proposed by the different studies with a longitudinal design included in the systematic review and meta-analysis, the acute physical exercise interventions are based on the premise that a single physical exercise intervention can cause immediate changes at a cognitive level. Besides, this kind of intervention might allow us to quickly check if a specific intervention design has the expected results in the inhibitory control capacity.

Given the lack of statistically significant benefits on the inhibitory control in the meta-analytical calculations of the included long-term but general exercise interventions, the third study emerged to investigate the viability of a specifically designed acute and goal-directed intervention in the inhibitory control.

Therefore, Study III was specifically focused on finding the best IC training possibility. With this aim, two training tasks with exercise, and a control task were included. One of the training tasks was specifically designed to demand a high level of inhibitory control, and the other training task included an aerobic exercise circuit. The design of the acute intervention aimed to allow the analysis of the possibilities of amelioration that this kind of intervention have on the inhibitory control of normally developed schoolers.

The age group of the samples included in the first and third studies (10 to 12 years of age) was selected due to the large number of maturational changes that take place in this stage of life (preadolescence and early adolescence) that can cause differences at a cognitive level because of, among other reasons, the maturation of the PFC (Steinberg, 2010). Besides, some authors pointed out to the lack of literature focused on this age group, although deficits in EFs performance seem to be observable during these years (Benzing et al., 2019).

4.2. Hypotheses and objectives

4.2.1. Study I: Inhibitory control and impulsivity in a schoolers sample

Hypotheses

- Impulsivity and inhibitory control components might have common underlying dimensions.
- Substantial individual differences can be found in both domains (IC and impulsivity) on typically developed schoolers.

Objectives

- To clarify the correlations between response inhibition, interference control (inhibitory control components), reflection-impulsivity, and delay of gratification (impulsivity components).
- To analyze the presence of differences on these domains in a normally developed schoolers sample.

4.2.2. Study II: Effects of exercise interventions on the inhibitory control of children and adolescents: A systematic review and meta-analysis

Hypotheses

- The exercise interventions with a longitudinal design will report benefits in the inhibitory control of children and adolescents.
- The effect size calculations (meta-analyses) will demonstrate the effectivity of this kind of exercise interventions on the IC domain of children and adolescents typically developed.

Objectives

- To provide synthesized information about the benefits of exercise training interventions with a longitudinal design on the inhibitory control of children and adolescents.
- To calculate the effect size of such interventions.
- To compare two statistical methods for the effect size calculation.

4.2.3. Study III: Effects of different acute exercise interventions on the inhibitory control of schoolers

Hypotheses

- A single bout of exercise intervention (both, the specifically designed to demand more inhibitory control and the intervention that includes aerobic exercise) will have a positive effect on the inhibitory control of children.
- The two interventions that include exercise will have higher positive effects on the inhibitory control of children than the intervention without exercise proposed (control group).
- The intervention that demands a higher level of inhibitory control will have higher benefits than the intervention that only includes aerobic exercise.

Objectives

- To elucidate the impact of acute exercise interventions with different characteristics in the IC of children in a scholar setting.

- To compare the effect of two different exercise interventions in comparison with a non-exercise intervention on the IC of schoolers.
- To validate the benefits of a specific exercise intervention with a high inhibitory control demand, in the amelioration of the inhibitory control capacity.

Chapter 5: **Studies**

5.1. Study I: Inhibitory control and impulsivity in a schoolers sample

5.1.1. Summary

Impulsivity and inhibitory control are two different domains with unclear connections. Both are widely studied due to their association with several disorders. Related problems begin to manifest during childhood, showing a special peak in adolescence. To date, no study has analyzed the primary connection of these domains and their presence in a school setting. The current study aims to clarify the connections between reflection impulsivity, delay of gratification (impulsivity components) and response inhibition, and interference control (inhibitory control components), and the individual differences in these domains in a normally developed sample. The sample included 102 children (10-12 years old). Results showed common underlying factors between response inhibition and interference control. However, no correlations were found between the study variables of the different inhibitory control and impulsivity components. Accuracy and reaction times seem to be the primary connection between all of these components. In conclusion, vast differences in individual performance were found in a normally developed sample of students. However, a differential trend is observed among the participants in the accuracy and speed of response results. Impulsivity and inhibitory control are independent domains with a common basis regarding accuracy and response times. More research is needed to detect, intervene, and prevent deficits.

5.1.2. Introduction

The base for good performance relies on the ability to present an appropriate behavior according to the demands of a specific situation. This process implies, both, accomplishing and inhibiting responses. In this context, two explanatory proposals have studied these phenomena: inhibitory control (IC), and impulsivity. Both are related to the study of why people respond adequately (or not) to stimuli demands, by starting or stopping the motor and cognitive responses. Both also studied the adaptive or non-adaptive nature of such responses. In any case, and in spite of the still unclear connections between these two domains, to talk about IC inevitably involves talking about impulsivity, to the point that both terms are frequently used interchangeably (Nigg, 2017).

Inhibitory control

IC is widely defined as a main component of the executive functions (EFs) (Bugos & DeMarie, 2017) that controls the ability to inhibit dominant, autonomic, or prepotent responses (Wu et al., 2011) as well as the ability to resist interferences (Nigg, 2000). The good functioning of IC is related to success in several areas of life, such as academic, professional, or sports performance, health, and social relationships (Moffitt et al., 2011; Zhao et al., 2015; Zhao et al., 2018).

According to Barkley (1997), a deficit in the IC might lead to a cascade effect in the rest of the EFs (working memory, and cognitive flexibility) (Alesi et al., 2016; Diamond, 2013). Meanwhile, a good IC permits the suppression of quick responses and reflexes to allow slower cognitive mechanisms to guide behavior (Jentsch & Taylor, 1999). Therefore, the IC seems to be a crucial domain for the correct functioning of EFs.

Inhibitory control construct consists of at least three interrelated processes: inhibition of a prepotent response, inhibition of an ongoing response, and interference control. Those three components, entitled by Barkley (1997) as “behavioral inhibition” were connected to their impulsivity antipode, “behavioral disinhibition”, by Bickel et al. (2012), meaning that the lack of those inhibition abilities ended up in impulsive behavior.

Bickel et al. (2012), based their theory of IC and impulsivity as “antipodes” on the superposition of definitions among their respective components and the coincidence of the brain regions that control each of the underlying processes. The shared operational measures and the study of the impulsive drug-dependent population that also presented EF deficits sustained their theory. However, a connection between “reflection-impulsivity” (defined as the tendency to make quick decisions without evaluating previous experiences that often results in undesirable consequences) and a specific IC component was not found (Bickel et al., 2012).

The study of IC has two main lines of research. The analysis of IC differences and its relationship with several disorders (Behan et al., 2014; Chmielewski et al., 2018; Fillmore & Rush, 2002; Jasinska et al., 2012; Schachar, Mota, Logan, Tannock, & Klim, 2000) and the use of different training options to improve IC (Browne et al., 2016; Dowsett & Livesey, 2000; Ludyga, Koutsandreou, Reuter, Voelcker-Rehage, & Budde, 2019; Zhao et al., 2018).

The already mentioned relevance of a well-developed IC was demonstrated due to its association with fewer academic problems, better social competencies (X. Chen et al., 2009), and better general life level in adulthood (Moffitt et al., 2011), among others advantages. Its direct implication in thinking and learning processes might explain this fact (Benson et al., 2012). In addition, deficits in the IC are related to several disorders and pathological conditions (Grandjean & Collette, 2011) as well as risk-taking tendencies (Pilatti, Fernández, Viola, García, & Pautassi, 2017) with high societal costs (Moffitt et al., 2011).

However, despite the importance of IC for ontogenetic development (Michel et al., 2018) and its capacity to predict important growth-related outcomes since childhood (Alesi et al., 2016), deficits in the IC are difficult to detect due to the absence of validated scales and the lack of research regarding its prevalence in a scholar setting.

The multifactorial nature of IC that includes different neuropsychological mechanisms (Ridderinkhof et al., 2004), situates this domain as a difficult one to study. In addition, despite the relative consensus concerning its components, the denomination of each of them varies depending on the authors, which sometimes hinders their correct understanding.

A wide range of tools is available to assess each one of the components. The ability to inhibit a prepotent response (response inhibition) is commonly assessed by

Go/No-Go tasks (Bari & Robbins, 2013). The traditional design of a Go/No-Go task permits the examination of this IC component, and therefore minimizing other cognitive/behavioral processes (Simmonds et al., 2008). The prepotent tendency to respond is created by weighing towards Go stimuli (presenting a notably higher amount of Go stimuli) and therefore increasing the need of IC to effectively suppress the response when a No-Go stimulus is presented (Simmonds et al., 2008). Stop-signal tasks are also implemented to assess response inhibition. However, as it was suggested by Littman and Takacs (2017), they operate with different mechanisms than Go/No-Go tasks. These authors differentiated between "controlled inhibition" assessed by stop-signal tasks, and "automatic inhibition" assessed by Go/No-Go tasks.

Interference control, or the ability to inhibit responses to irrelevant information, is an essential IC component for protecting goal-directed behavior (Barkley, 1997; Kertzman et al., 2006). The Stroop Test (Stroop, 1935), is a broadly used task for detecting interference-control impairments (Wu et al., 2011). The interference effect appears due to the different nature of word reading (extremely practiced and therefore highly automatic) and color naming (susceptible to interference from other conflicting processes due to its novelty) (Botvinick et al., 2001).

Impulsivity

While IC is a conceptually well-defined domain, the situation changes aiming to delineate impulsivity. To find a definition mostly accepted seems to be a frustrated desire of several researchers. As Evenden (1999) said:

> *"Most people, at some time or another, have engaged in impulsive behavior (...) But, even if it is easy to identify examples of impulsive behavior, there is considerably more difficulty in defining impulsivity precisely and there is likely to be a great deal of disagreement as to what differentiates socially acceptable*

> *impulsive behavior from the unacceptable – that varies from one culture to another, from one era to another, and depends upon the age of the person involved. These differences (...) do pose problems for the scientific study of impulsivity, and especially the study of the biological basis of that phenomenon".*
>
> (Evenden, 1999, p. 348)

Speed (reaction time) and accuracy seem to be essential aspects of impulsivity. Impulsive people would show shorter reaction times and a greater number of errors than non-impulsive ones. The so-called "conceptual tempo" (Evenden, 1999; Keller & Ripoll, 2001) is a crucial element to understand impulsivity since impulsive individuals seem to be induced by urgency: they present serious problems to wait for delayed rewards, and they have a characteristic tendency to finish tasks quickly, even if they commit several mistakes for acting rashly.

However, despite the widespread notion that impulsive behavior tends to be detrimental to the individual (Evenden, 1999), some authors argue that impulsivity does not always generate negative consequences, been maladaptive or adaptive depending on the context (Dickman, 1990). Bevilacqua and Goldman (2013) affirmed that impulsive behaviors might be even advantageous in situations where it is crucial to respond quickly and take advantage of unexpected opportunities. In fact, in decision-making, especially in cases of timing pressure, individuals tend to use heuristics, rather than complete logical reasoning (Kahneman, 2003). Heuristics are "mental-shortcuts" that help us to process information in a fast way, to reach an immediate goal. This approach of problem-solving is highly adaptive on numerous occasions (Cheung, Kroese, Fennis, & de Ridder, 2016; Kahneman, 2003).

Based on various authors (Caswell et al., 2015; Dougherty et al., 2009; Riaño-Hernández, Guillen Riquelme, & Buela-Casal, 2015; Stautz & Cooper, 2013), the impulsivity construct can be synthesized in the following components:

a) Fast decision-making, without the foresight of future consequences due to the incapacity to previously analyze the available information that can provide different alternatives: "reflection-impulsivity" (RI),
b) Lack of ability to inhibit prepotent or automatized responses: "motor-impulsivity" (MI) ("*also termed inhibitory control*" (Caswell et al., 2015, p. 68)), and
c) Inability to tolerate the delay of gratification: "temporal-impulsivity" (TI).

Consequently, impulsivity should not be considered a unitary construct; instead, it should be viewed as a construct that represents a series of independent subtypes, with a heterogeneous nature (Caswell et al., 2015; Reynolds et al., 2006), but connected among overlapping neural substrates (Dalley, Everitt, & Robbins, 2011; Romer-Thomsen et al., 2018).

Convergence points between inhibitory control and impulsivity

Although the investigation has obtained contradictory results when trying to establish connections between the IC and impulsivity constructs, a functional convergence can be intuited from the description of the components of these two domains. As it was already mentioned, authors such as Bickel et al. (2012), found relevant coincidences between some EFs (including IC) and impulsivity, in addicted populations. These connections were based on the involvement of the same brain regions on components of the two domains, and the given definitions (of previous literature) of such components. Besides, Caswell et al. (2015) even affirmed that the lack of ability to inhibit prepotent or automatized responses is known as "motor-impulsivity" but also termed as "inhibitory control".

Both constructs present similar lines of research. First, the analysis of their presence in several disorders of high social impact, and second the design and implementation of proposals to improve IC abilities or to decrease impulsive behaviors. Even the evaluation of some of their components has been made with tools implemented indistinctly (e.g., self-reported questionnaires, behavioral tasks, neuroimaging, and biochemical measurements).

In sum, although only some of the components of each domain seem to be "antipodes" (Bickel et al., 2012) or are somehow related (Caswell et al., 2015), IC deficits appear to be crucial for impulsivity (Bickel et al., 2012; Jasinska et al., 2012; Lawrence et al., 2009; Logan et al., 1997; Perales et al., 2009).

If IC and impulsivity are extremes of a continuum of the same phenomenon (inhibition vs. disinhibition, respectively), as it can be hypothesized to be, some of its components should show connections. If these connections do not exist, it should be assumed that they are independent constructs.

Most of the research on IC and impulsivity included children with pathologies. Despite the relevance of such research, the possible bias that pathologies could introduce make these results impossible to be extrapolated to the general population. Besides, the extended practice of evaluating these constructs with single measures and to extrapolate the results to the whole construct, led to poor characterization of the constructs and their included components (Caswell et al., 2015). To our knowledge, there is no study that analyzed the relationships between the components of both constructs in schoolchildren without pathologies.

The present study aimed to clarify the relationship between several IC and impulsivity components as well as to analyze the differences in such components detected in a normally developed sample of children. Gender performance differences were also studied in order to understand the presence of a gendered tendency towards being more or less acute and more or less fast in giving the answers in this stage of life as it was suggested in previous studies (Chapple & Johnson, 2007; Cross, Copping, & Campbell, 2011).

The sample of the current study was composed of participants between 10 and 12 years of age. This age group corresponds with the beginning of adolescence, according to the WHO definition that establishes adolescence between 10 and 19 years (World Health Organization, 2019a). This stage of transition from childhood to adulthood can be critical due to all of the neurological, physical, and emotional changes. Additionally, half of all mental health disorders (including IC disorders) begin before the age of 14, and the consequences of leaving them untreated can extend into adulthood (Kessler et al., 2007; World Health Organization, 2019a). Therefore, an analysis of the IC and its connection with impulsivity may be relevant at this stage of life due to the possibility of detecting and redirecting problems in those domains that can help to avoid future related deficits and to ameliorate the current situation of the schoolers.

For that purpose, besides the Go/No-Go and the Stroop test, two more tasks were included. First, the Matching Familiar Figures Test 20, MFFT-20 (Cairns & Cammock, 1978) in its Spanish computerized version (Escala Magallanes de Impulsividad Computarizada, EMIC) from Servera and Llabrés (2000), to delve more into the evaluation of the so-called reflection-impulsivity. Secondly, a delay of gratification task adapted from Wilson, Lengua, Tininenko, Taylor, and Trancik (2009), to assess the ability to withhold a prepotent response over a long period of time (temporal impulsivity).

5.1.3. Methods and materials

Inhibitory control and impulsivity were assessed by a battery of tasks that congregated the following criteria: all had been used in previous research, they were standardized, and they covered the specific components that wanted to be measured.

Study design

The present study has a descriptive cross-sectional design. All of the participants completed the same tasks. The participation was randomized without following a set pattern. Four participants were randomly selected each time to drop out of their physical education class and participate in the study. Each group of four participants was randomly placed in one of the four stations to perform a specific task. After finishing their first task, all of them rotated to complete the next one. The study finished when every participant completed the four tasks.

Participants

Eligible participants were 10 to 12-year-old students (*M* = 10.97; *SD* = 0.67) from A Coruña, Spain. This age range was chosen due to all of the changes at a neurological, physical, and emotional level that takes place at this stage of life (adolescence) which might cause destabilization in the IC. A number of 102 typically developed children participated (49 girls; 53 boys). The exclusion criteria involved any previously diagnosed cognitive, physical, or emotional disorders or diseases.

Study procedures

The Ethics Committee of the University of A Coruña approved the completion of the study. The project was presented to the director of a school in A Coruña. A meeting with the physical education teachers took place in order to explain the project and to solve any methodological or logistical doubts. Parents were appropriately informed about the methodology and objectives of the study and parental written consent was required to participate.

Inhibitory control tasks

Response inhibition was assessed with a traditional design Go/No-Go task adapted from Caswell et al. (2015). Participants were instructed to quickly respond (by pressing the space-bar) to every Go stimulus and to avoid responding to every No-Go stimulus. A total of 120 stimuli were presented in two separate sets of 60 presentations each. In order to create a prepotency towards the Go stimulus, the rate of the stimulus was 80% Go to 20% No-Go stimuli. According to Simmonds et al. (2008), response inhibition is evaluated by the capacity to properly avoid responding to a No-Go stimulus. Bruyer and Brysbaert (2011) proposed to use the Inverse Efficiency Score (IES) in order to combine the information on speed and accuracy into one measurement. This measurement is calculated by dividing the reaction times by the proportional correct responses. A low score on this ratio reflects a strong inhibition efficiency (Zhao et al., 2018).

The interference control was assessed by the Spanish adaptation (Golden, 2001) of the Stroop test (Stroop, 1935). The task had three parts. The first part's aim was to read the colored words (W), the second part's objective was to name the ink with which the X's were colored (C), and the third part's goal was to name the ink color of the words when the color and the name were incongruent (interference condition) (WC). The total number of correct responses in each part was registered. The interference index was calculated by the difference between the punctuation in the interference condition (WC), and the expected punctuation of this third part due to their performance in the other two parts (WC´). The formula to calculate WC´ is therefore: $WC' = [(W\ x\ C)/(W + C)]$. The difference between WC and WC´ is the interference index: $WC - WC' = INT$.

Higher scores indicate greater ability to inhibit interference and therefore greater inhibitory control (Barnhart & Buelow, 2017).

Impulsivity assessment tasks

The Spanish computerized version of the Matching Familiar Figures Test 20, (MFFT-20) (Cairns & Cammock, 1978), is the Escala Magallanes de Impulsividad Computarizada, (EMIC) from Servera and Llabrés (2000). This tool was used to evaluate the cognitive style of reflexivity-impulsivity. Participants observed a model figure on the top of the computer screen. Six other similar figures were presented on the screen under a separation line. Of those six options, only one was identical to the model and therefore, the correct answer. The objective was to give the correct answer as fast as possible. Reaction times and accuracy were registered. A direct measure of reflection impulsivity, T punctuations of the impulsivity index (PIT) and T punctuations of the efficiency index (PET) were calculated by the tool.

A delay of gratification task adapted from Wilson et al. (2009) was implemented to assess the ability to withhold a prepotent response for a longer period. According to Mischel (1974), the delay of voluntary gratification involves a double process. The success of the initial decision to delay the immediate reward for a late reward but with greater benefits, requires not only the initial decision but also the capacity to maintain that choice despite the temptations and obstacles that may appear along the way. For this task, the participants were videotaped while waiting in an empty room with a box on their table. If they were able to wait without opening the box, they got their selected prize. If they did not wait, they only got the balloon that was laying on the top of the box. This task aimed to wait without opening the box. Unlike the other tasks, the delay of gratification task did not have a temporary pressure to include self-control elements to inhibit behavior.

Statistical analyses

Three separate complete analyses were carried out with the Statistical Package for Social Sciences (SPSS) version 20. The first analysis included Pearson's correlations to analyze the connection between the different components of inhibitory control and impulsivity. This analysis was composed by three sub-analyses: the first concentrated on the study variables established by the literature (the IES score from the Go/No-Go task, the interference index from the Stroop test, and the impulsivity index from the EMIC test), and two more sub-analyses focused on the reaction times, and the accuracy results of each task.

The second analysis included the specific data reported by each particular task. The two tasks implemented to assess impulsivity gave immediate punctuation. To study the variability between subjects in the Go/No-Go task and the Stroop test percentile analyses were carried out. Besides, the coefficients of variation were also calculated with their correspondent confidence intervals and were represented by box-plots (Appendix, Figures A4.1 and A4.2), which allowed to understand between which values were the central half of the subjects. The Stroop test normative data was used to compare the results of the current sample. The lack of normative data available for the Go/No-Go task made impossible to perform such a comparison. In any case, extreme punctuations in both tasks were understood when the results of the participants were below the percentile 10 in the Stroop test and above the percentile 90 in the Go/No-Go task.

The third analysis included an independent t-test to analyze the gender group differences in the sample regarding all of the evaluation tasks.

Variables included in the analyses

EMIC PIT = EMIC impulsivity index T punctuations

GNG IES = Go/No-Go inverse efficiency score

STROOP INT = Stroop interference index

EMIC ACC = EMIC accuracy

GNG ACC = Go/No-Go accuracy

STROOP ACC = Stroop accuracy

EMIC RTs = EMIC reaction times

GNG RTs = Go/No-Go reaction times

STROOP RTs = Stroop reaction times

5.1.4. Results

First analysis

Study variables analysis

Correlation results are provided in Table 1. The non-existence of significant correlations between the study variables of reflection impulsivity and response inhibition (r (102) = .066, p = .512), and between the study variables of reflection impulsivity and interference control (r (102) = -.005, p = .964) indicated the independency of the inhibitory control and the impulsivity components. However, a small but significant correlation (r (102) = -.218, p = .027) was found between the two IC components (response inhibition and interference control). This fact manifests the underlying common factors of those two different components of the same construct. Data from the delay of gratification task was not relevant in the current analysis for its nature.

Accuracy and reaction times analysis

The ACC results from the reflection impulsivity evaluation task correlated significantly with those presented in the two inhibitory control assessment tasks: The Go/No-Go task (r (102) = .337, p = .001) and the Stroop test (r (102) = .455, p <.001). The mistakes in Stroop and Go/No-Go also correlated significantly with each other (r (102) = -.282, p = .004).

A similar situation occurred with the RTs outcomes. The RTs of the reflection impulsivity task correlated significantly with Stroop the RTs (r (102) = .245, p = .013) but did not correlated with those obtained in the Go/No-Go task (r (102) = .115, p = .250). The two inhibitory control assessment tasks (Stroop and Go/No-Go) significantly correlated again in their RTs (r (102) = -.367, p < .001) (Table 1).

Interestingly, the analysis of ACC and RT correlations revealed significant associations throughout the entire participation process of this study. Therefore, a faster or a slower response tendency, and a higher or a lower level of accuracy in their responses, appeared to be maintained for the participants with no connection to the specific demands of the different tasks. This fact suggested the existence of a specific response tendency (when analyzing accuracy and time responses) in all participants. Descriptive statistics (mean, standard deviation, minimum, and maximum range) are presented in the Appendix (Table A5).

Table 1. *Correlations between study variables, accuracy, and reaction time results.*

Variables [a]	**EMIC PIT**	**GNG IES**	**STROOP INT**	**EMIC ACC**	**GNG ACC**	**STROOP ACC**	**EMIC RTs**	**GNG RTs**	**STROOP RTs**
EMIC PIT	1								
GNG IES	.066	1							
	(.511)								
STROOP INT	-.005	-.218*	1						
	(.964)	(.027)							
EMIC ACC	.873**	.142	-.009	1					
	(.000)	(.157)	(.929)						
GNG ACC	.284**	.331**	-.046	.337**	1				
	(.004)	(.001)	(.645)	(.001)					
STROOP ACC	.411**	-.005	.219*	.455**	-.282**	1			
	(.000)	(.961)	(.028)	(.000)	(.004)				
EMIC RTs	-.900*	.023	.003	-.589**	-.177	-.287*	1		
	(.000)	(.817)	(.979)	(.000)	(.076)	(.004)			
GNG RTs	-.082	.865**	-.199*	-.036	-.185	-.150	.115	1	
	(.412)	(.000)	(.045)	(.720)	(.063)	(.135)	(.250)		
STROOP RTs	-.204*	.369**	-.587**	-.132	.023	-.486**	.245*	-.367**	1
	(.041)	(.000)	(.000)	(.190)	(.822)	(.000)	(.013)	(.000)	

Note. [a] Variables defined on the methods part; the first number is the correlation coefficient; the number in brackets is the significance. *Indicates significant correlation: *p < .05; **p < .01.

Second analysis

Specific data reported by each particular task

The tool implemented to assess reflection impulsivity (EMIC) offers immediate data of the results obtained by each participant. In addition, this tool situates participants in a continuum (reflection-impulsivity) which allowed for the distinction between impulsive, reflexive, or neutral participants, among other possibilities. Five groups were differentiated in this sample: impulsive inefficient, impulsive efficient, neutral, reflexive efficient, and reflexive inefficient. The results showed a sample composition of 30 impulsive participants (16 of them efficient and 14 inefficient); 60 participants with a normal level of reflection-impulsivity (neutral group); and 11 reflexive participants (10 of them efficient and one inefficient).

The delay of gratification task showed a sample of participants who were able to wait for the selected reward instead of opening the box and taking the immediate one. Just one participant opened the box and therefore showed a lack of capacity to wait for a long-term reward. A second participant rose from the chair, which was also against the rules of the task.

To study the differences between the components of the sample regarding response inhibition and interference control, percentile analyses were carried out (percentiles distribution, values, and results are presented in Table 2). To interpret the results, it should be noted that a lower IES score means a higher level of response inhibition. However, a higher score in the interference index (Stroop test) shows a higher capacity to control interference. Consequently, extreme punctuations were considered when the results were below the percentile 10 in the Stroop test and above the percentile 90 in the Go/No-Go task.

Table 2. *Percentile distribution and values of the Go/No-Go task and Stroop test study variables results.*

Percentiles	Values	GNG IES [a]	STROOP INT [b]
< 4	Very low	< 548.06	< 7.07
5 – 9	Low		
10 – 24	Low normal	548.06 – 744.81	7.07 – 28.04
25 – 75	Normal		
76 – 90	High normal		
91 – 95	High	> 744.81	> 28.04
> 96	Very high		

Note. [a,b] Variables defined on the methods part.

The coefficients of variation showed the following results: 12.14% (95% CI 11 to 14) for the Go/No-Go IES results and 44.18% (95% CI 39 to 51) for the Stroop INT results. These results indicate a great variability intrasubject. The box-plot representations can be found in the Appendix section (Figures A4.1 and A4.2).

Case analysis was carried out after the percentile distribution study. All of the participants scoring lower than percentile 10 in the Stroop INT ($n = 10$) and those scoring higher than percentile 90 in the IES score of the Go/No-Go task ($n = 10$) were analyzed case by case. The same was done with the participants defined as impulsive-inefficient ($n = 14$) and with the participant not able to delay reward ($n = 1$). Two of those 35 participants presented extreme scores both in response inhibition and interference control, and one presented extreme scores in interference control and reflection impulsivity.

Gender differences analysis

Independent t-tests were used to determine if the mean difference between girls and boys was statistically significant in this sample. Only the Stroop test accuracy results showed significant differences between genders ($t(77.94) = -2.223$, $p = .029$). According to the independent t-test, this fact can be attributed to a gender difference, suggesting that girls were more precise than boys in this specific variable. The rest of the results showed non-significant differences between genders. However, boys presented lower accuracy and shorter response times than girls in most of the tasks (Table 3).

Table 3. *Gender differences in the study variables.*

Variables ^{a}	Girls	Boys	t_value	p_value
EMIC PIT	52.35± 18.56	56.54± 16.07	-1.216	.227
GNG IES	638.65± 73.29	631.79± 81.03	.447	.656
STROOP INT	15.84± 6.56	17.87± 8.15	-1.378	.171
EMIC ACC	11.81± 6.04	13.96± 7.37	-1.591	.115
GNG ACC	5.18± 3.98	5.62± 7.94	-.348	.728
STROOP ACC	8.04± 7.06	12.76± 13.50	-2.223	.029*
EMIC RT	10406.35± 6315.70	9916.11± 4468.47	.454	.651
GNG RT	610.37± 67.06	600.05± 75.44	.728	.468
STROOP RT	939.83± 152.44	881.08± 161.83	1.883	.063

Note. ^{a} Variables defined on the methods part; Values are expressed as *M* (mean) ± *SD* (standard deviation); $t = t$ score; $p = p$-value; *Indicates significant correlation: *$p < .05$; **$p < .01$.

5.1.5. Discussion

The current study provided important insights into the connection between the constructs inhibitory control and impulsivity thanks to the analysis of several of their components: response inhibition and interference control (IC components), and reflection-impulsivity and temporal-impulsivity (impulsivity components). The results indicated the independence between these two domains when analyzing the correlations between the study variables (Go/No-Go IES, Stroop INT, EMIC PIT and the ability to delay gratification).

These data support that in spite of being possible to conceptually understand these two constructs as antipodes (Bickel et al., 2012) or as opposed poles of the same dimension (inhibition - disinhibition), the components of the inhibitory control and the impulsivity constructs might demand different mechanisms. The demands might depend on the nature of the tasks implemented for the evaluation of each one of the components. When the inhibitory control evaluation tasks require more automatic responses (stimulus-response), the impulsivity evaluation tasks require more information processing capacity and included a higher level of voluntary control.

Bailey, Barnes, Park, Sokolovic, and Jones (2018) compare the developmental domains that are involved in several measurement tasks and affirmed that in a Go/No-Go task and in a Stroop test only the cognitive domain is involved. However, in a delay of gratification test like the Marshmallow test (Mischel, 1974), both, cognitive and emotional domains are involved to maintain control.

In the current study, the results also showed that response inhibition and interference control have underlying common factors. The presence of significant correlations between those two IC components supports the theory of Friedman and Miyake (2004) that situates IC as a family of related functions with interrelated components. These authors assumed that the main common mechanism between response inhibition and interference control might be the ability to actively maintain critical goal-related information.

Bailey et al. (2018) established that both, the Go/No-Go task and the Stroop test are measures of inhibition that also require attention control to discriminate the different stimuli and that both rely on visual processing. Zhao et al. (2015); Zhao et al. (2018) also assessed these two different aspects of inhibition (response inhibition and interference control) with a Go/No-Go task and a Stroop test respectively. In any case, the connection between these two components of inhibition appears to be clear according to the previous literature and the results of the current study. However, while response inhibition is based on the capacity of inhibiting a prepotent response, interference control might require different mechanisms to resists interferences.

Regarding the connections between reflection impulsivity and the ability to delay a reward (also known as temporary impulsivity; TI), in the current study, such relations were not found. However, both components seem to have high relevance for better outcomes in adulthood (Mischel, 1974; Riaño-Hernández et al., 2015; Servera & Llabrés, 2000).

In the sixties, the origin of the reflection-impulsivity dimension appeared as a cognitive style (Kagan, 1965; Kagan & Kogan, 1970). This cognitive style was characterized by a tendency to respond spontaneously without deliberation (Colman, 2001). Dalley et al. (2011) suggested that this kind of impulsivity might include behavior that has not adequately sampled sensory evidence. According to the EMIC, impulsive participants are those with a notably quicker tendency to give answers in comparison with the reflexive ones, situated in the other extreme of the continuum. The accuracy level was also included in the study of the dimension, which gave the possibility to talk about reflection-impulsivity combined with an efficiency level, including the perspective of functionality in the construct (Servera & Llabrés, 2000).

The current study was implemented in a scholar setting with children without any previous pathology and showed a vast majority of participants with a neutral cognitive style (58.8%). However, 13.7% were impulsive inefficient, with short RTs and low levels of ACC. According to Dickman (1990), impulsivity can be functional or dysfunctional. Both kinds involve the tendency to deliberate less than most people before acting.

However, the outcomes are the key that defined the functional or dysfunctional nature of impulsivity (Dickman, 1990).

To our knowledge, the only study that estimated the prevalence of impulsivity in a general population was carried out by Chamorro et al. (2012). Their results confirmed the presence of impulsivity in 17% of a national sample (including residents of continental United States, District of Columbia, Alaska, and Hawaii) composed by 34.653 participants. However, the study was based on questionnaires and included an adult sample, which precludes any comparison with the results of the current study.

The delay of gratification task implemented in the current study was extracted from Wilson et al. (2009). The results disclosed that only one participant was not able to wait without opening the box until the end of the task. It should be highlighted that this participant was not presenting extreme scores in any other task. A second participant was standing up from the chair (which was against the rules of the task) but was not opening the box. However, this second participant was also presenting extreme ACC scores in both Go/No-Go and Stroop tasks, as well as high impulsivity scores according to the EMIC test.

Since the required response on the delay of gratification task corresponds to the top-down category (conscious and deliberate decision) (Diamond, 2009), the results of this task implied that participants were, in general, able to control their wishes and delay gratification, regardless of their other impulsivity and inhibitory control scores.

These facts demonstrated again the high personal variability existing in a normally developed sample of students and highlighted the possibility of presenting problems (or at least extreme scores or behaviors) in specific and different impulsivity and/or IC components.

The explanations of the lack of problems to delay a reward in the current sample might have different characteristics. First, the nature of the reward. Most of the delay of gratification tasks include sweets or sugary drinks. These kinds of rewards are considered primary reinforcers because they act inciting the desire of consuming them immediately, especially when either the glucose or the hydration levels are low (e.g., immediately before having lunch, or right after doing exercise). Meanwhile, toys are secondary reinforcers (they do not represent a basic necessity), and besides having proved their reinforcing capacity, is possible that this kind of reward cannot reach the same level of reinforcement than the ingestion of a substance that our organism perceives as a need to recuperate homeostatic levels (Delgado, Jou, & Phelps, 2011).

In this line, several studies (Beedie & Lane, 2012; Gailliot, 2008; Gailliot, Mead, & Baumeister, 2008) have already demonstrated the connection between glucose and self-control effort. In all of these studies, a cookie or a sugary drink facilitated the self-control in their participants. Contrarily, these participants performed worst in tasks that required self-control when their glucose levels were lower, in comparison with normal or higher glucose levels. Consequently, it can be supposed that the presence of sweet eatable rewards might incite kids to break the rules of a self-control task, due to the homeostatic demands perceived by their organism.

Second, the sample was motivated by the opportunity to achieve their selected prize under the condition of waiting. Third, the participants might have already developed the ability to control this behavior (even knowing that the peak of impulsive behaviors was situated in the adolescence due to the lack of maturation of the prefrontal cortex (Chamorro et al., 2012). Fourth, the task might be too easy for the age of the sample. However, this task was already implemented by Wilson et al. (2009) in a sample of students (n = 91) with an age range between 8 and 11 years. From this sample, 26 participants were not able to wait the established 10 minutes. This means that age might not be the key to the current results.

The analysis of participant´s effortful conduct to resisting temptation was not in the goal of the current work. However, the recordings showed several strategies implemented by the participants to control the temptation of opening the box before the established timing (to avoid looking at the box, to sing, to dance, to bite the nails, etc.). Future studies might go deep into the study of such data to contribute to the knowledge of the behavioral strategies of effort required in this kind of task.

It should be noted that a recent publication (Watts, Duncan, & Quan, 2018) that revisited the original Marshmallow test from Mischel (1974) (the base of every delay of gratification task) and replicated their original study (Shoda, Mischel, & Peake, 1990) found interesting results regarding the validity of the Marshmallow test to predict future success. Watts et al. (2018), presented a much larger and representative sample by incorporating diverse participant backgrounds (ethnicity, parent`s educational level, socio-economic status). The results revealed that the long-term success in life, firstly attributed by Shoda et al. (1990), to the ability to delay a reward, is more related to the background of the participants than to the capacity of delaying a recompense during childhood. The background of the participants might also be a key that explains the high capacity of the participants to delay a reward in the current study.

When analyzing the results of the interference index of the Stroop test, important score differences between participants were found. In comparison with the results obtained by Golden (2001), Martín et al. (2012), and Rivera et al. (2017) for Spanish populations, the mean of the interference scores in the current study is notably higher (*M* = 16.89; *SD* = 7.46) (see Appendix, Table A5). In the current study, none of the participants got negative scores (minimum score = 2.01), and the maximum scores were considerably higher (maximum score = 43.70) than in the other studies. The difference might be the use of the paper version of the test in the three studies while the current one implemented the computerized version of the test. The paper version requires a verbal response, the computer version requires a motor response (to press the spacebar on the keynote). However, Roe, Wilsoncroft, and Griffiths (1980) did not find overall significant differences when studying motor and verbal ways of responding to the Stroop test, but they affirmed that motor responses were generally faster.

The percentile analysis in the Go/No-Go showed notorious participant differences in the results throughout the whole sample, presenting a mean of *M* = 635.08, a standard deviation of *SD* = 77.10, and minimum/maximum scores of 477,96 and 840.79 respectively (see Appendix, Table A5). The lack of normative data available made impossible to compare the results of the current study with previous literature.

In the analysis of the reaction time and accuracy variables of every task, the current findings suggest a strong connection between all of the studied components. Significant correlations were found when analyzing these two variables in all tasks. In sum, results showed that regardless of how the components of the two constructs were evaluated (the specific formula), the response trend in terms of reaction times and accuracy was a common denominator among them.

Accordingly, each one of the participants might have their own personal tendency to answer (more or less quickly and more or less accurate) regardless of the nature of the task. More research is needed to clarify those findings and the possibility of implementing different inhibitory control techniques and interventions to help participants with mistakes and short reaction times and to retrain their immediate answers to achieve better results.

The gender differences analysis showed no significant differences between boys and girls within the sample. Only the Stroop accuracy level (Stroop ACC) presented significant differences between those two groups (*t*(77.94) = -2.223, *p* = .029). Those results confirmed that in this specific variable, the boys of the sample showed significantly more mistakes than the girls. In any case, a clear tendency of the boys to present more mistakes and shorter response times than girls was also a reality that can be found in Table 3. However, these results cannot be assumed to be caused by something different but chance and are therefore not generalizable.

Similar results regarding gender differences were found in previous studies that analyzed temperament (Else-Quest, Shibley Hyde, Goldsmith, & Van Hulle, 2006) or the ability to inhibit a prepotent response and the delay of gratification (Weafer & de Wit, 2014). The results are also in line with previous findings that situated male participants as more likely than female participants to present problems highly related to impulsivity and a lack of inhibitory control like risk-taking (Byrnes, Miller, & Schafer, 1999); antisocial behavior (Moffitt, Caspi, Rutter, & Silva, 2001); and behavior problems (Calvete & Cardenoso, 2005), among others.

Strengths and limitations

The exhaustive analysis of the two domains, inhibitory control and impulsivity, carried out is a strength of the current study. The analysis of the reaction times and the accuracy variables, in addition to the analysis of the established study variables, added relevant knowledge to the field regarding the connections between the two studied domains. Besides, several components of each domain were analyzed in the same sample. Previous literature criticized the study of one component and the extrapolation of the results to the whole construct. The analysis of different components by specific tools allowed us to have more specific results regarding the presence of different kinds of inhibitory control or impulsivity in the same sample.

Another strength is the sample composition. As was mentioned before, previous studies highlighted the lack of research including children samples when studying cognition in comparison with the amount of literature focused on adult samples. Furthermore, the analysis included a sample of normally developed children, instead of pathological samples. Due to the extended idea of a lack of inhibitory control or impulsivity like two domains that produce detrimental outcomes, the majority of research was made including pathological samples. However, this study is based on a lack of prejudice. The analysis was made through a neutral prism, with the main objective of analyzing the reality of the presence of inhibitory control and impulsivity extreme punctuations in a randomized sample of schoolers with normal development.

The statistical analysis performed allowed to the understanding of the objectives of the study, however, a main limitation might be the impossibility of generalizing the results to the general population due to the sample size. Future studies might be directed to extract normative data, which will facilitate the detection of problems connected to these constructs. Besides, more statistical analyses might be included for further explanations of the weight that each of the components have in a normally developed sample. Regarding the delay of gratification task, it would be interesting to analyze the control strategies that participants implemented to avoid taking the immediate reward.

5.1.6. Conclusions

In spite of being possible to conceptually understand inhibitory control and impulsivity as opposed poles of the same dimension (inhibition-disinhibition), the tasks to assess each one of the components varied in their nature and, therefore, require the involvement of different cognitive processes (bottom-up and top-down) and different level of voluntary control.

In the current study, the components of each construct were mainly independent among each other when analyzing the stablished study variables. No correlations were found between reflection impulsivity and temporal impulsivity (impulsivity components), but response inhibition and interference control (IC components) showed common underlying factors.

The presence of inhibitory control differences and different expressions of impulsive behaviors appear to be a reality in a normally developed schoolers sample. Strong differences were found between the individual tendency of the participants to give an answer or to behave in the implemented battery of tasks that included different levels of voluntary control and temporal pressure. In sum, independently of how each component was evaluated (the stablished formula), the response tendency of each participant (more or less fast and accurate) seems to remain unchanged.

Due to the negative outcomes that IC deficits and impulsive behaviors have in our society, more research is needed to detect, intervene, and prevent problems. The identification of the responsible components for problematic conduct might be useful to design more specific interventions to minimize the non-adequate responses and to prevent future related disorders.

5.2. Study II: Effects of exercise interventions on the inhibitory control of children and adolescents: A systematic review and meta-analysis

5.2.1. Summary

Inhibitory control is a main component of executive functions. Problems in inhibitory control have been associated with important psychological and behavioral disorders. Exercise has become a promising alternative to promote changes in this domain. This systematic review and meta-analysis aimed to provide synthesized information and effect size calculations of the benefits that longitudinal exercise training interventions have in the inhibitory control of children and adolescents. A systematic search in PubMed, PsycINFO, Medline, Eric, SPORTDiscuss, and PsycARTICLES identified 2735 articles to be screened for eligibility. The search led to 13 studies meeting the eligibility criteria. Eight of the 13 selected studies obtained benefits in the inhibitory control after exercise training interventions. The results showed small effect sizes in the multilevel analysis ($d = 0.124$, 95% CI -0.072 to 0.321, $p = 0.201$) as well as in two of the traditional meta-analysis conducted: single scores ($d = 0.21$, 95% CI -0.10 to 0.51, $p = 0.18$) and reaction times ($d = -0.14$, 95% CI -0.44 to 0.16, $p = 0.37$). However, these benefits were statistically non-significant. In conclusion, despite the high number of studies that reported benefits, no statistically significant overall benefits were found in the current study.

5.2.2. Introduction

Inhibitory control (IC) involves the ability to control and repress a prepotent response in favor to a different response or the absence of it (Alesi et al., 2016). IC governs the attention, the behavior, the thoughts, and even the emotions in order to invalidate a strong internal predisposition or external temptation (Diamond, 2013), and controls the ability to resist interferences, distractions, or habits to maintain focus (Hillman et al., 2014; Schmidt et al., 2015). Therefore, IC is understood as a family of related functions (Friedman & Miyake, 2004) that are highly connected to the ability to refrain from impulsive behavior (Bidzan-Bluma & Lipowska, 2018) with high relevance as a central component of the Executive Functions (EFs) (Bugos & DeMarie, 2017; Diamond, 2013; Liu et al., 2015).

EFs reach the mature stage around the late adolescence - early adulthood, due to the maturation of the prefrontal cortex (Diamond, 2013; Karbach & Unger, 2014; Liu et al., 2015; Steinberg et al., 2008; P. D. Zelazo et al., 2013). Among executive functions, inhibitory control seems to be especially important for ontogenetic development (Michel et al., 2018). IC presents a rapid development during the preschool years (Liu et al., 2015; P. D. Zelazo & Carlson, 2012), gets mature throughout early to middle childhood (Phung, 2017), experiences changes across the lifespan (McAuley et al., 2006), and declines remarkably in older adults (Darowski et al., 2008; Gazzaley et al., 2005; Peltsch et al., 2011; Zanto et al., 2010).

Substantial literature verifies that the development of the IC during childhood predicts important growth-related outcomes (Alesi et al., 2016; P. D. Zelazo & Carlson, 2012). A good inhibitory control during childhood was linked to fewer academic problems and good social competencies (X. Chen et al., 2009) along with a better general situation at an economical, professional, and healthy level in adulthood (Moffitt et al., 2011). Nevertheless, most of the research regarding this topic has been focused on adult samples (Tomporowski, Davis, Miller, & Naglieri, 2008).

IC promotes success in thinking and learning processes (Benson et al., 2012), reasoning and strategic capacities (Apperly & Carroll, 2009), and physical and mental health (Blair & Razza, 2007), among other benefits (Browne et al., 2016). It was also been associated with intelligence level (Lee et al., 2015).

Furthermore, deficits on IC have been linked to several disorders like attention deficit hyperactivity disorder (ADHD) (Alderson et al., 2007; Brocki et al., 2007; Young et al., 2009), schizophrenia (Young et al., 2009), unhealthy eating and obesity (Jasinska et al., 2012), drinking behavior (Houben & Wiers, 2009), suicidal behavior (Raust et al., 2007), among other pathological conditions (Grandjean & Collette, 2011). Chamorro et al. (2012) confirmed the link between IC and several behaviors with detrimental impact to society.

However, it has been proven that early experiences can cause changes in a neurological level due to the brain's plasticity (Courchesne et al., 1995). A large amount of research already confirmed that diverse training interventions can alter the brain mechanisms involved in EFs deficits (Tamm et al., 2019) including in IC. These include computer-based training programs (Klingberg et al., 2005; Thorell et al., 2009), musical interventions (Jaschke et al., 2018; Joret et al., 2017; Moreno & Farzan, 2015), mindfulness (Enoch, 2015; Lawler, 2015; Oberle et al., 2012; Thurman & Torsney, 2014), acute bouts of exercise (Browne et al., 2016; Jäger et al., 2014), and longitudinal exercise interventions (Alesi et al., 2016; van der Niet et al., 2016), among others.

Exercise interventions have been widely used with the aim of improving motor functions(Wegner, Koedijker, & Budde, 2014), as well as executive functions (Budde et al., 2010) or IC (Niemann et al., 2013). Though, according to several authors (Berkman et al., 2014; de Greeff et al., 2016), the literature is still impoverished regarding whether and how IC performance can be improved with an exercise training. Nevertheless, due to the relevance of the topic, understanding and improving inhibitory control is of crucial importance (Chevalier, Chatham, & Munakata, 2014).

Exercise interventions and their benefits on inhibitory control

Through the years, the relevance of including exercise training and physical activity in our lifestyle has become clear due to its reported benefits and the positive effects found in the prevention, intervention, and rehabilitation of different diseases (American Psychiatric Association, 2019; World Health Organization, 2019c). In the present review, exercise training interventions are included. These interventions are characterized by a longitudinal design that include multiple exercise sessions per week over a sustained period. Exercise is understood as a planned, structured, repetitive, and purposeful kind of physical activity that produces changes in fitness (Budde, Schwarz, et al., 2016; World Health Organization, 2019c). Physical activity encompasses every corporal movement produced by the contraction of skeletal muscles that increase the caloric requirements over resting energy expenditure (American College of Sports Medicine, 2013). As a consequence, it was decided to use the term “exercise” in the paper alongside “training” in order to reflect the longitudinal) nature of the selected interventions. Hence, the so-called physical activity interventions would be included if they incorporate a planned, structured, repetitive, and purposeful longitudinal intervention.

Highly important aspects of cognitive function, including EFs, are improved by exercise (Koutsandreou, Wegner, Niemann, & Budde, 2016). Moderate to vigorous aerobic exercise interventions have been effective in children populations with this particular goal (Alesi et al., 2016). Those results have been found in both cross-sectional and longitudinal studies with exercise interventions (Alesi et al., 2016; Chang, Tsai, Chen, & Hung, 2013; de Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018; Niemann et al., 2013; Verburgh et al., 2013).

Given the importance of inhibitory control during childhood and adolescence, the aim of the present systematic review is to analyze the available data regarding the benefits of exercise training interventions on inhibitory control in the youth and to calculate the mean effects of exercise training interventions on relevant variables for the inhibitory control assessment.

5.2.3. Methods and materials

Protocol registration

The protocol of this systematic review was registered on January 30, 2019 in PROSPERO (International prospective register of systematic reviews) at www.crd.york.ac.uk under the PROSPERO-ID CRD42019118820.

Eligibility criteria

The present study followed the PICOS approach to structure the eligibility criteria concerning the study characteristics. Thus "population", "intervention", "control groups/ comparators", "outcomes", and "study design" were defined.

1. Population: Children or adolescents; male and / or female; without any previous pathology diagnosed (samples with an ecological design that includes a small percentage of children with disabilities are included, samples composed by pathological populations are excluded); aged until 18 years;
2. Intervention: Participants must have attended an exercise training intervention; longitudinal; with one or several intervention arms related to physical exercise;
3. Control: Every included study must have a control group; wait-list or attending activities without IC component;
4. Outcomes: An analysis of the benefits of the intervention in the inhibitory control must be included;
5. Study design: Randomized Controlled Trials (RCTs) or Cluster Randomized

Controlled Trials; including a longitudinal / chronic exercise intervention (understanding longitudinal and chronic as interchangeable terms).

English language publication was also an inclusion requirement.

Information sources and search strategy

The databases PubMed, PsycINFO, Medline, Eric, SPORTDiscuss, and PsycARTICLES were searched. The search was last conducted on July 15, 2019. Medical Subject Headings were also considered. References were analyzed, and some authors were contacted in order to have access to relevant literature. The search was closed on July 29, 2019. The electronic search strategy was carried out through the following keywords combination in all of the databases: ((exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)). The literature research was not limited to a period of publication. The complete search strategy can be found as supplementary material in the Appendix (Table A6).

Study selection and data collection

The selection of the relevant studies was carried out by two independent researchers. Both took part in the screening process. When the information in the abstract was not sufficient, the full text was checked. Any divergence between researchers was solved with the help of a third researcher. The following information was extracted from each of the articles analyzed in a full text format: author/s, year of publication, objective/s, study design, population characteristics, sample, age, inhibitory control assessment, type of intervention, length of intervention, existence of a control group, and main significant results.

Exclusion criteria

Any article not meeting the inclusion criteria was excluded. This includes every article out of the age range; those including complete samples of non-healthy population or specific populations with disorders; articles without exercise training intervention; without control group; articles without a specific inhibitory control assessment; those without a detailed statistical procedure; studies without a longitudinal design; studies that were not RCTs; or those where the results were not clear regarding the inhibitory control. Cross-sectional studies are not included due to the lack of causal effects that this study design allows. More information about the full-text articles excluded and the exclusion reasons can be found as supplementary material in the Appendix (Table A7).

Quality assessment

The Delphi List (Verhagen et al., 1998) was selected to evaluate the methodological quality of the included studies. The Delphi list is a checklist with nine generic core items for quality assessment of RCTs (Verhagen et al., 1998). Two independent researchers assessed each of the articles separately according to the Delphi List. Any discrepancy was resolved through consensus.

Statistical analysis

Two different statistical analysis, a multilevel analysis and a traditional meta-analysis, were performed to calculate the effect size of the longitudinal exercise interventions on the inhibitory control of normally developed children and adolescents. The most extended model to calculate the effect size of a specific intervention is still nowadays the traditional analysis, however, the multilevel analysis has emerged as an interesting possibility to deal with dependency of effect sizes. In the current study both methods were implemented to explore if they might report remarkably different results.

As it was already mentioned, a multilevel model analysis was implemented to control for dependencies between effect sizes. Some of the included single studies reported information of different variables (e.g. accuracy, reaction times, single scores), allowing in some cases to compute more than one effect size. However, to consider these effect sizes as statistically independent would potentially bias the results by the infringement of the traditional meta-analysis assumptions. According to Assink and Wibbelink (2016) a multilevel analysis is a strong method for dealing with dependency of effect sizes. The statistical analyses and calculations of the analysis were carried out with the "metaphor" R package (Viechtbauer, 2010) of the R software (R Development Core Team, 2019). Results were evaluated according to Cohen's criteria, which established that effect sizes starting from 0.20 are small, 0.50 are medium, and 0.80 are large (J. Cohen, 1992).

To perform the traditional effect size calculation the standardized mean differences (SMD) of pre-post intervention were calculated, and a random-effects analysis model was implemented to pool the effect sizes of the included studies. This model to estimate the effect of the exercise interventions compared to the control groups was selected to reduce the potential bias associated with the heterogeneity between studies (The Cochrane Collaboration, 2011), based on the assumption of different true effect size (Borenstein, Hedges, Higgins, & Rothstein, 2009; Petitti, 2000; Xue et al., 2019). A visual inspection of the forest plots allowed for the exploration of the possibility of having statistical heterogeneity. Besides, the I^2 statistic test was performed to assess heterogeneity between studies. Potential publication bias was evaluated using a funnel plot. All statistical analyses and calculations were performed using the Review Manager (RevMan) software (The Cochrane Collaboration, 2014). Results were again evaluated according to Cohen's criteria (J. Cohen, 1992).

Additional analysis and calculations

Additional calculations were carried out: 1) when studies included more than one intervention groups. In these cases, a data set combination of the interventions (combined sample size, combined mean, and combined *SD*) was calculated and included in the analysis of the effect size; 2) when studies included more than one task to assess inhibitory control. In these situations, the more common-used one was included; 3) If studies reported several results for the cognitive tasks. In those cases, the most inhibitory control demanding variable was included (example: incongruent condition in the Flanker task, color-word/interference condition in the Stroop test); 4) when studies implemented several assessments of the inhibitory control over time. In these circumstances only the results obtained in the last assessment were included.

5.2.4. Results

Study selection

The literature search reported a total of 2735 articles identified through the following databases: PubMed, PsycINFO, Medline, Eric, SPORTDiscuss, and PsycARTICLES. After removing duplicates, a total of 2197 articles were reviewed by title or title and abstract. A number of 82 single studies were primarily selected. Through the references examination six more possible records were identified. Therefore, 88 articles were reviewed in full text format. When full texts were not available, they were requested from the authors. Nevertheless, only 13 studies met the eligibility criteria and were ultimately included in this systematic review and meta-analysis. The study selection process is shown in the Flow Diagram (Figure 4).

Study characteristics

The general characteristics of the included single studies were extracted and summarized in Table 4.

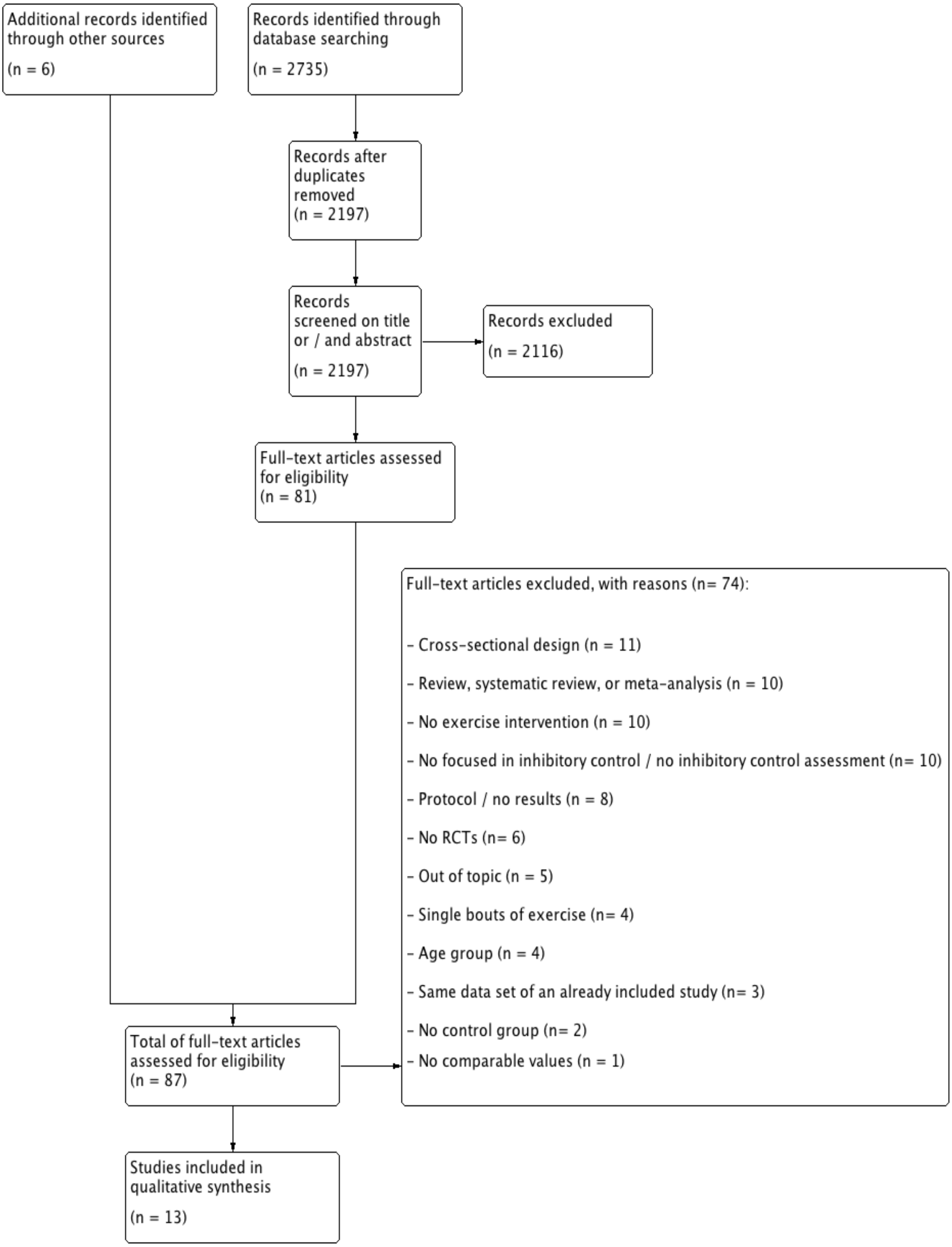


Figure 4. *Flow Diagram of the study selection process*

Methodological characteristics

All included studies in this review included a longitudinal exercise training intervention (Aadland et al., 2019; L. Chaddock-Heyman et al., 2013; de Greeff et al., 2016; Hillman et al., 2014; Kvalo et al., 2017; Ludyga, Gerber, Herrmann, Brand, & Pühse, 2018; Ludyga et al., 2019; Moreau, Kirk, & Waldie, 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; Schmidt et al., 2015; Tarp et al., 2016; Zhao et al., 2015). In all cases, pre-test and post-test before and after the intervention were carried out. In order to reduce bias, only Randomized Controlled Trials (RCTs) based studies were included. Standard RCTs designs (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga et al., 2019; Moreau et al., 2017), Cluster Randomized Controlled Trials (CRCTs) (Aadland et al., 2019; de Greeff et al., 2016; Kvalo et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; Schmidt et al., 2015; Tarp et al., 2016), a cluster randomized trial (CRT) (Ludyga, Gerber, et al., 2018), and a double-blind randomized controlled experimental design (DB-RCT) (Zhao et al., 2015) constituted the selection. Randomized Controlled Trials (RCTs) are known as the most powerful experimental studies to determine the existence of a cause-effect among the intervention and the results (Kendall, 2003; Stolberg, Norman, & Trop, 2004). Relevant studies have been dismissed for failing to meet this criterion. Therefore, relevant studies with other study designs (Alesi et al., 2016; Chang et al., 2013; Ishihara, Sugasawa, Matsuda, & Mizuno, 2017b; Moradi et al., 2019) were left out of the selection. Single bouts of exercise interventions were neither included in this review. As it was already mentioned, more information regarding excluded articles can be found in the Appendix (Table A7).

Table 4. *General characteristics of the included single studies.*

Study	Objective	Design	Population	Sample	Age	Inhibitory assessment	Intervention	Length	Control group
Aadland et al. (2019)	To examine the effects of a seven-month curriculum prescribed physical activity intervention (the Active Smarter Kids [ASK] intervention) on executive functions in 10-year-old Norwegian children.	CRCT[1]	Norwegian fifth grade children. (Different schools)	n = 1129	10 years	Stroop	ASK program with 3 intervention arms: 1. PA educational lessons; 2. PA breaks, and 3. PA homework (n = 564)	1. = 30 min[5]. / 3 times per week; 2. = 5 min. / school day; + 3. = 10 min. / school day / 7 months	The mandatory 135 minutes of PA and physical education (n = 503)
L. Chaddock-Heyman et al. (2013)	This study used fMRI[1] to examine the influence of a 9-month physical activity program on task-evoked brain activation during childhood.	RCT[2]	Children recruited from the Urbana, Illinois School District 116. (Same school)	n = 32 (+ 24 adults)	8 - 9 years	Event-related cognitive control task with 3 task condition: incongruent, neutral and No-Go	Fitness Improves Thinking in Kids Program (FIT Kids) (n = 14)	2 h.[6] per day / 5 times per week / 9 months (total: 150 h.) (after school)	Wait-list control group (n = 9)
Hillman et al. (2014)	Assessment of the effects of a PA[2] intervention on brain and behavioral indices of executive control in preadolescent children.	RCT	Children from East Central Illinois attending the Urbana School District 116. (Same school)	n = 221	7 – 9 years	Flanker task	FIT Kids (n = 109)	2 h. per day / 5 times per week / 9 months (total: 150 h.) (after school)	Wait-list control group (n = 112)
de Greeff et al. (2016)	To examine the effects of physically active academic lessons on cardiovascular fitness, muscular fitness and EF after 2 years.	RCT	Second and third graders from 12 primary schools in the Northern part of the Netherlands (Different schools)	n = 499		Stroop	Fit and academically proficient at school project (F&V). Physically active academic lessons group (n = 249) An average of 14 min. of MVPA per lesson	14 min. of MVPA per lesson / 3 times per week / 22 weeks per year / 2 years	Control condition group (n = 250)
Kvalo et al. (2017)	To explore whether increased PA in school affects children's	CRCT	5 intervention and 4 control schools (Different schools)	n = 429	10 – 11 years	Stroop	Three arms of intervention:	1. = 2×45 min.; 2. = 5×10 min.; 3. = 5×10 min. /	Control group (n = 212)

	executive function and aerobic fitness.						1. physically active lessons; 2. physically active breaks;3. physically active homework (n = 217)	Per week / 10 months	
Ludyga, Gerber, et al. (2018)	Evaluation of the effects of a school-break time exercise intervention, on the P300 component of event-related potentials and inhibitory control.	CRT[3]	Participants were recruited from 4 classes in a private school. (Same school)	n = 36	12 – 15 years	Stroop task	Aerobic and coordinative exercise group (n = 19)	20 min / 5 times per week/ 8 weeks (total: 13 h. 20 min.) (school-break)	Wait-list control group (n = 16) encouraged to have social interactions with their classmates
Ludyga et al. (2019)	Analysis of the effects of aerobic and coordinative training on behavioral and neurophysiological measures of inhibitory control.	RCT	All participants were recruited from local schools. (Different schools)	n = 37	9 – 10 years	Flanker task	2 experimental conditions: 1. Aerobic training [AER] (n = 11) 2. Coordinative training [COR] (n = 12)	45 min. / 3 times per week/ 10 weeks (total: 20 h. 30 min.) (after school)	Control group (n = 14) assisted homework sessions.
Moreau et al. (2017)	To test the viability of HIT as a substitute for aerobic exercise to induce cognitive improvements in school populations.	RCT	Participants recruited from 6 schools across New Zealand (Different schools) *22 children with disability diagnosis are included	n = 318	7 – 13 years	Flanker task, GNG, and Stroop	High-intensity training [HIT] intervention (n = 152)	10 min / 5 per week / 6 weeks	Active control group (quizzes and playing computer games) (n = 153)
Pesce, Marchetti, et al. (2016)	To verify (a) if a life skills program in PE[3] had a positive impact on physical fitness, sport skills, and executive cognitive function, and (b) if eventual physical and sport outcomes were mediated by gains in life skills and executive function.	CRCT	Senior high school students belonging to a Rome urban school (Same school) *7 students with mild intellectual disabilities are included	n = 90	14 – 15 years	The random number generation task (RNGT)	A multisport PE program (Life skills program) (n=45)	60 min. / 2 times per week / 6 months	Traditional PE program (n=45)

Pesce, Masci, et al. (2016)	To evaluate whether ‘enriching’ PE quality without enhancing its quantity would lead to joint coordinative and cognitive benefits.	CRCT	Preschool and primary school children belonging to eight schools of the municipality of Alba (Italy) volunteered.	n = 460	5–10 years	RNGT	Enriched PE lessons with playful coordinative and cognitive enrichment (n = 232)	60 min. / 1 time per week / 6 months	Traditional PE classes (n = 228)
Schmidt et al. (2015)	To investigate the effects of two qualitatively different longitudinal PA interventions on executive functions in primary school children.	CRCT	Participants from schools in the region of Bern, Switzerland (Different schools) *8 children with ADHD taking medication as usual are included	n = 181	10 – 12 years	Flanker task	PE program with 3 experimental conditions: 1.Team games (n = 69) 2.aerobic exercise (n= 57)	45 min. / 2 times per week / 6 weeks	3. control condition (n=55)
Tarp et al. (2016)	To study the effectiveness of a School-Based Physical Activity Intervention on Cognitive Performance in Danish Adolescents: LCoMotion—Learning, Cognition and Motion – A Cluster Randomized Controlled Trial	CRCT	Participants from five main regions of Denmark, including 40 classes of 14 schools (7 control and 7 intervention) (Different schools)	n = 632	12–14 years	Flanker task	4 intervention arms: 1. physical activity in academic subjects; 2. scheduled physical activity during recess; 3. physical activity homework; 4. active transportation (n = 180)	1. = 60 min. / 5 days per week; 2 = 5 -10 min. per day / 20 weeks	Control schools continued with their normal practice (n = 404)
Zhao et al. (2015)	To investigate the transfer effects of a 7-day training program using a game named “Wesley says”.	DB-RCT[4]	Participants from grades three to five in a primary school in Gansu province, China. (Same school)	n = 30	8 – 12 years	Go/No-Go + Stroop	Playground game training: “Wesley Says” (n = 15)	20 min. per day / 7 times (total: 2 h.) (integrated into daily school activities)	Control group playing other games without inhibitory control component (n = 15)

Note. [1]Cluster Randomized Control Trial; [2]Randomized Controlled Trial; [3]Cluster Randomized Trial; [4]Double-Blind Randomized Controlled; [5]Minutes; [6] Hours.

Inhibitory control assessment

The selected tools to assess the inhibitory control varied between studies as it can be seen in Table 4. However, the main implemented tools were the Stroop test and the Flanker task. In a meta-analysis, different kinds of studies with different kind of evaluation tools can be included (Borenstein et al., 2009). Besides, the Stroop test and the Flanker tasks (among other conflict tasks) seem to have underlying factors (Fan et al., 2003; Rueda et al., 2005) which makes the comparison between results and the calculation of the effect sizes even more robust.

Two articles (Moreau et al., 2017; Zhao et al., 2015) carried out an inhibitory control evaluation with three and two different tools respectively. Moreau et al. (2017) implemented a Flanker task, a Stroop test, and a Go/No-Go task to study inhibitory control. The data from the Stroop test was the selected one for the effect size calculation because the majority of the studies that reported a single score per task used the Stroop test. Zhao et al. (2015) used a Stroop test and a Go/No-Go task. The first tool as an indicator of interference control, and the second (Go/No-Go) to reflect the response inhibition capacity. The Go/No-Go results were discussed but not included in the analysis.

A Random Number Generation Task (RNGT) was implemented in two studies (Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016). This task provides, among other results, an inhibition index. This index was the selected one for the effect size calculation.

An event-related cognitive control task was included in one article (L. Chaddock-Heyman et al., 2013). This task included three task conditions: neutral, incongruent, and No-Go. However, as the neutral condition required less attentional, interference, and inhibitory control, and the No-Go condition showed some methodological limitations (L.

Chaddock-Heyman et al., 2013), just the incongruent flanker task condition results were selected for this review.

Six articles provided a single score as an inhibitory control variable Aadland et al. (2019); (de Greeff et al., 2016; Kvalo et al., 2017; Moreau et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016), the other seven included studies reported two main relevant variables: reaction times and accuracy (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga, Gerber, et al., 2018; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016; Zhao et al., 2015). In any case, when the studies contained the necessary information, more than one effect size was computed.

Intervention characteristics

The Fitness Improves Thinking Kids (FIT Kids) program was selected in two of the included studies (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014). The length of the intervention was the same in both: 2 hours per day, 5 times per week for 9 months reaching a total of 150 hours of training. Both included a wait-list control group and reported an average of 76.8 minutes of moderate to vigorous physical activity in the first case and at least 70-minutes in the second.

Another program, in this case consisted of 7 months of curriculum prescribed physical activity (the Active Smarter Kids [ASK]), was implemented by Aadland et al. (2019). The program included three intervention arms: PA educational lessons, PA breaks, and PA homework, adding a total of 165 minutes extra of PA to the mandatory 135 minutes PA and physical education. The control group continued with the mandatory PA education lessons.

The study of de Greeff et al. (2016) was a part of a project called “Fit and academically proficient at school” (F&V) that included physically active academic lessons during two years. F&V lessons had a duration of 20-30 minutes. These lessons included 10 - 15 minutes spent on solving mathematical problems, and 10 - 15 minutes spent on language tasks. The exercise component of these lessons was a combination between a basic physical exercise proposed at the beginning of the lesson, also implemented between tasks, and specific exercises after solving academic tasks (some examples can be found in the original study). On average the lessons had a moderate-to vigorous-intensity physical activity (MVPA) engagement of 60%, which according to the authors can be translated in 14 minutes of MVPA per lesson.

In the study of Kvalo et al. (2017), participants joined the project "Active school" for 10 months. The project included three intervention arms: physically active lessons (45 minutes, 2 times per week), physically active breaks (10 minutes, five times per week), and physically active homework (10 minutes, five times per week). Control schools followed the regular national curriculum of 135 minutes of physical activity.

Aerobic exercise and coordination exercise interventions were selected in two studies (Ludyga, Gerber, et al., 2018; Ludyga et al., 2019). In the first one (Ludyga, Gerber, et al., 2018), the intervention incorporated both aerobic and coordinative exercises together. It was integrated into the school breaks with a length of 8 weeks. The participants trained during 20 minutes for five days per week. They also included a wait-list control group and encouraged this group to have social interactions with their classmates. In the second study (Ludyga et al., 2019), the aerobic training program (AER) and the coordination training program (COR) were two different experimental conditions. The intervention took place in an after-school setting. The length was 10 weeks of training at a frequency of 45 minutes, 3 times per week. The control group was constituted by assisted homework sessions.

Moreau et al. (2017) tested the viability of High-intensity training (HIT) as a substitute for aerobic exercise to induce cognitive improvements in school populations.

Participants were randomly assigned to a HIT or an active control group (making quizzes and playing computer games). The length of the HIT intervention was 6 weeks. During this time, HIT was implemented 10 minutes every school day (five days per week)

Pesce, Marchetti, et al. (2016) tried to verify if a life skills program in physical education (PE) had a positive impact on executive cognitive function, among other domains. Participants were randomly assigned to either the intervention group (attending the experimental life skills program integrated in a multisport PE setting), or to the control group (traditional PE). The intervention was implemented for six months, including two sessions of 60 minutes per week.

Pesce, Masci, et al. (2016) aimed to evaluate whether a six months of 'enriching' PE would lead to coordinative and cognitive benefits. The intervention included one session of 60 minutes enriched PE lessons per week (with playful coordinative and cognitive enrichment) for the intervention group, and traditional PE lessons for the control group.

Schmidt et al. (2015) implemented a six-week intervention with three experimental conditions: a team games group with high amounts of both cognitive engagement and physical exertion; an aerobic exercise group with low cognitive engagement and high physical exertion; and a control group meeting the curricular requirements. The intervention was implemented 45 minutes, two times per week.

The design of Tarp et al. (2016) was implemented to study the effectiveness of a school-based physical activity intervention on cognitive performance in Danish adolescents: LCoMotion (Learning, Cognition, and Motion). The intervention schools participated in a four-arms exercise intervention that included: physical activity in academic subjects (60 minutes, five days per week, for 20 weeks); scheduled physical activity during recess (5 - 10 minutes per school day); physical activity homework; and active transportation. The control schools continued with their normal practice.

Zhao et al. (2015) included an intervention based on a playground game training ("Wesley Says") to train response inhibition in a real-world setting. The participants practiced the game during 20 minutes per day for seven days leading to a total of 140 training minutes. The included active control group played other games mainly involving physical exercise without inhibition component.

All of the interventions were carried out within the education system. This included three extra-curricular or after-school programs (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga et al., 2019) and 10 interventions integrated into the educational curriculum, daily school routine, or in the school breaks (Aadland et al., 2019; de Greeff et al., 2016; Kvalo et al., 2017; Ludyga, Gerber, et al., 2018; Moreau et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; Schmidt et al., 2015; Tarp et al., 2016; Zhao et al., 2015). Most of the samples were composed by participants coming from different schools (Aadland et al., 2019; de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Moreau et al., 2017; Pesce, Masci, et al., 2016; Schmidt et al., 2015; Tarp et al., 2016), only five were composed by participants coming from the same school (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga, Gerber, et al., 2018; Pesce, Marchetti, et al., 2016; Zhao et al., 2015). The frequency of the interventions varied between a minimum of 10 minutes per day (Moreau et al., 2017) to a maximum of 2 hours (L. Chaddock-Heyman et al., 2013; Hillman et al., 2014). The shortest intervention was implemented for 7 days (Zhao et al., 2015) and the longest for 2 years (de Greeff et al., 2016). The summary of the intervention characteristics can be found in Table 4.

Participants characteristics

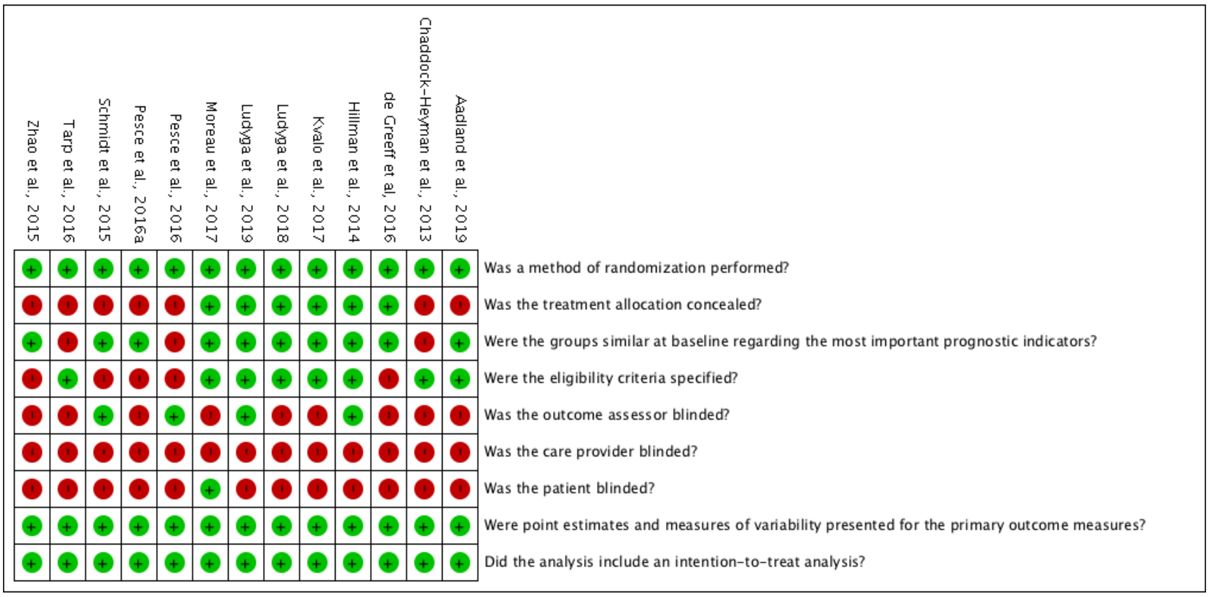
All of the studies included children and/ or adolescents' samples, males and females. None of the included articles used a sample composed by a pathological population. However, three studies included a low amount of participants with disorders: Pesce, Marchetti, et al. (2016) included seven students with mild intellectual disabilities (four in the intervention group and three in the control group); Schmidt et al. (2015) included eight children with ADHD taking medication as usual; and Moreau et al. (2017) included 22 children with any disability diagnosis in their sample. Therefore, the final sample of this paper is mostly comprised of healthy population.

The educational stages included in this review range from preschool to high school. Thus, the age of the participants ranges from 5 to 15 years. One study (L. Chaddock-Heyman et al., 2013) also included an extra group of adults as a comparison group. The data regarding the adult group were not taken into account in the present paper since results from studies imply that different mechanisms restrict performance early and late in life and suggest a non-linear relationship between electrophysiological markers and performance in tasks like the Flanker task across the lifespan (Reuter et al., 2019).

The number of participants varied from a minimum of 30 participants (intervention group n = 15 / control group n = 15) (Zhao et al., 2015) and a maximum of 1129 participants (intervention group n = 596 / control group n = 533) (Aadland et al., 2019). The total number of participants included in the 13 studies was 4094. However, only 3961 participants of the complete sample were included in the inhibitory control analysis (1945 participants being part of intervention groups and 2016 being part of control groups). The latest data was selected to calculate the effect sizes of the interventions in the inhibitory control of the children and adolescents included in the single studies.

Risk of bias within studies

Two independent researchers used The Delphi List (Verhagen et al., 1998) to assess the methodological quality of the included studies. There is no official agreement about how to establish the quality of the studies according to the number of meeting criteria. However, based on some previous scientific literature (Carter, Morres, Meade, & Callaghan, 2016; Radovic, Gordon, & Melvin, 2017), a consensus was reached to declare the following: at least six criteria rated as "met" = high quality; from three to five criteria "met" = moderate quality; and with two or less criteria "met" = low quality. The mean quality score of the included studies was 5.23 out of 9. The summary of the methodological quality assessment is shown in the Risk of Bias Summary of the included studies (Figure 5).



Zhao et al., 2015	Tarp et al., 2016	Schmidt et al., 2015	Pesce et al., 2016a	Pesce et al., 2016	Moreau et al., 2017	Ludyga et al., 2019	Ludyga et al., 2018	Kvalo et al., 2017	Hillman et al., 2014	de Greeff et al, 2016	Chaddock-Heyman et al., 2013	Aadland et al., 2019	
+	+	+	+	+	+	+	+	+	+	+	+	+	Was a method of randomization performed?
−	−	−	−	−	+	+	+	+	+	+	−	−	Was the treatment allocation concealed?
+	−	+	+	−	+	+	+	+	+	+	−	+	Were the groups similar at baseline regarding the most important prognostic indicators?
−	+	−	−	−	+	+	+	+	+	−	+	+	Were the eligibility criteria specified?
−	−	+	−	+	−	+	−	−	+	−	−	−	Was the outcome assessor blinded?
−	−	−	−	−	−	−	−	−	−	−	−	−	Was the care provider blinded?
−	−	−	−	−	+	−	−	−	−	−	−	−	Was the patient blinded?
+	+	+	+	+	+	+	+	+	+	+	+	+	Were point estimates and measures of variability presented for the primary outcome measures?
+	+	+	+	+	+	+	+	+	+	+	+	+	Did the analysis include an intention-to-treat analysis?

Figure 5. *Risk of bias summary of the included studies.*

The theoretical impossibility of blinding participants and care providers in exercise interventions (Larun, Nordheim, Ekeland, Hagen, & Heian, 2006; Radovic et al., 2017) makes this quality assessment tool less applicable in this area of research. Consequently, the obtained results should be analyzed carefully. It should also be considered for future analysis to include an exercise sham condition e.g. as in the methodology suggested by Budde, Akko, Ainamani, Murillo-Rodriguez, and Weierstall (2018).

Aerobic fitness analysis

Aerobic fitness was assessed in 9 of the 13 included studies. Four studies (Ludyga, Gerber, et al., 2018; Moreau et al., 2017; Pesce, Masci, et al., 2016; Zhao et al., 2015) did not include such assessment. The results of two studies including aerobic fitness evaluation reported no benefits after intervention in comparison with their control groups (Aadland et al., 2019; Kvalo et al., 2017).

The studies that found benefits on aerobic fitness exposed the following results: L. Chaddock-Heyman et al. (2013) affirmed that the increase in VO_2 was not significant comparing control (2%) and intervention group (6%), but the additional gains were attributed to the daily exposure to physical exercise in the intervention group; Hillman et al. (2014) showed improvements pointing towards the intervention group when comparing pre-test to post-test with the wait-list control group. Moreover, only the intervention group showed significant pre- to post-test changes in aerobic fitness percentile; de Greeff et al. (2016) assessed cardiovascular and muscular fitness. Results showed a larger improvement in cardiovascular fitness in the intervention group compared with the control group, and a smaller improvement in static strength (muscular fitness) in the intervention group compared with the control group; Ludyga et al. (2019) found significant pre- and post-test group differences in aerobic fitness after their two proposed interventions (AER and COR); Pesce, Marchetti, et al. (2016) concluded that the life skills program induced improvements in aerobic fitness; Schmidt et al. (2015) reported benefits after both team games and aerobic exercise interventions on children’s aerobic fitness (4–5% increase in estimated VO_2 max); and Tarp et al. (2016) found an intervention effect for cardiorespiratory fitness in girls (21 meters (95% CI: 4.4 - 38.6) and body-mass index in boys (-0.22 kg/m2 (95% CI: -0.39 - 0.05)

Synthesis of results

The objective of this article is to systematically review the studies focusing on the effects of exercise interventions on IC in children and adolescents with normal development in order to synthesize the information and make it available for future interventions. With this aim, the results of the individual studies were analyzed, and the effect sizes of the interventions calculated. A supplementary summary of the individual studies results can be found in the Appendix (Summary A8).

The effect size calculations were performed by two different statistical analysis: a multilevel analysis and a traditional meta-analysis in order to explore if the implementation of such different analysis might report remarkably different results.

To properly deal with the dependence of effect sizes, a multilevel analysis was performed. In this analysis, all available measures reported by the single studies were included (accuracy and reaction times, or single scores). The analysis included three-levels: the sampling variance, the variance within studies, and the variance between studies. The results of the analysis reported a small effect size (d = 0.124) according to Cohen's criteria (J. Cohen, 1992), with a standard error of 0.094. However, this overall effect was non-significant ($t(19)$ = 1.326, p = 0.201) and the confidence interval (CI) ranged from an almost null effect to a small effect size (-0.072 to 0.321). In brief, considering the results of this model (d = 0.124, 95% CI -0.072 to 0.321, p = 0.201), it can be assumed that the overall of the exercise interventions included in the meta-analysis showed no significant benefits on the IC. The complete information of the multilevel analysis can be found as supplementary information in the Appendix (A9).

The traditional effect size calculation also showed no significant overall benefits of the analyzed longitudinal exercise interventions on the IC of children and adolescents.

In this analysis, three effect sizes were calculated, each effect size based on one study variable: single scores, accuracy, and reaction time.

The effect size calculation of the single scores variable (*d* = 0.21, 95% CI -0.10 to 0.51, *p* = 0.18) was small according to Cohen's criteria (J. Cohen, 1992), as well as the effect size of the RT variable (*d* = -0.14, 95% CI -0.44 to 0.16, *p* = 0.37). The analysis of both, single scores and RTs, despite presenting a small effect, did not show significant *p*-values. Besides, the CI values crossed the null effect, which made the results not statistically significant.

The ACC effect size results (*d* = -0.01, 95% CI -0.20 to 0.17, *p* = 0.92) showed no general improvements, neither deterioration, in the accuracy variable. However, results were again not statistically significant due to the *p* and CI values. The forest plots and the combined funnel plot of the analysis can be found in the Appendix as supplementary material (A10).

5.2.5 Discussion

The present study is the first meta-analytical review to investigate the scientific literature focused on the effect of exercise training interventions in the inhibitory control of children and adolescents without any previous disorder. A total of 13 single studies met the inclusion criteria. Eight of the 13 included studies (Aadland et al., 2019; L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga, Gerber, et al., 2018; Moreau et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; Zhao et al., 2015) revealed improvements in the inhibitory control after intervention in favor of the intervention group. Five studies (de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016) found no intervention effects on IC. Benefits in aerobic fitness after intervention in comparison with control groups were seen in seven of the nine studies that included an aerobic fitness evaluation. Four studies did not include such analyses.

There is a large number of available tools to assess inhibitory control. The tools employed in the included studies comprised Stroop tests, Flanker tasks, two Random Number Generation Task (RNGT), and an Event-Related Cognitive Control Task. Nonetheless, the scope of options is more extended (Bachorowski & Newman, 1985; Davidson et al., 2006; Diamond & Taylor, 1996; Oberle et al., 2012; Ponitz, McClelland, Matthews, & Morrison, 2009), which manifests the different processes that underlie inhibitory control.

The definition of inhibitory control itself already presents two different components of the same construct: the ability to withhold prepotent responses (response inhibition) (Alesi et al., 2016) and the ability to resist interferences (interference control) (Hillman et al., 2014; Schmidt et al., 2015). Nevertheless, those different components appear not to be the only ones. Up to eight underlying processes of IC have been already featured (Nigg, 2000). However, the elucidation of the real underlying connections among these components is still a challenge of research. Consequently, there are problems to clarify how this family of related functions known as IC (Friedman & Miyake, 2004) is linked, and the use of complex tasks involving numerous processes in addition to inhibition is making the measurement problem even bigger (Khng & Lee, 2014). Though, two main study variables are broadly used to assess inhibitory control: RT and ACC. Seven of the included studies investigated those variables to evaluate the benefits of different exercise interventions on inhibitory control. Regarding the study conditions available on the different tasks (congruent, incongruent, and neutral), the incongruent condition appears to be the most suitable for the IC assessment due to the elevated inhibitory control demand required for this condition in comparison with the others (Brassell et al., 2017; Hillman et al., 2014; Kubesch et al., 2009; Tamm et al., 2019).

Another possible evaluation of the obtained benefits on IC after an intervention can be made based on a single score variable. Six studies included in this analysis selected this option. Some examples of the single scores selected for the included articles are the following: the color-word naming (also called interference condition) of the Stroop test, was selected by Aadland et al. (2019), de Greeff et al. (2016), and Kvalo et al. (2017) under the theoretical base of being the one requiring the most significant demands of inhibitory control; the index score of inhibition was extracted by two articles (Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016) after analyzing the results of the Random Number Generation Tasks implemented in both studies with higher index scores meaning better inhibitory control.

The overall effect of the longitudinal exercise interventions included in the current study on the IC of normally developed children and adolescents is not significant. The multilevel analysis results (d = 0.124, 95% CI -0.072 to 0.321, p = 0.201) cannot be assumed as statistically significant because the p-value is higher than 0.05 and the CI values crossed the null effect. This finding makes it impossible to assume that the observed group difference is meaningful because the true group difference in the population could be zero (Field, 2009).

A similar situation occurs with the results obtained in the traditional effect size calculation. None of the three effect size calculations: the single score effect size (d = 0.21, 95% CI -0.10 to 0.51, p = 0.18), the RT effect size (d = -0.14, 95% CI -0.44 to 0.16, p = 0.37), and the ACC effect size (d = -0.01, 95% CI -0.20 to 0.17, p = 0.92) can be considered as statistically significant due to the non-significant p-values and the CI values. Therefore, it can be concluded that the overall effect of the studied interventions is not significant on the inhibitory control of the studied sample of children and adolescents according to both statistical procedures.

The heterogeneity tests performed in the two different analysis of data (multilevel and traditional) detected in both cases a substantial level of heterogeneity according to the Cochrane Handbook for Systematic Reviews of Interventions, which stablished that results from 50% to 90% on the I^2 statistic test may represent substantial heterogeneity (The Cochrane Collaboration, 2011). In any case, the obtained results may mean that the included studies are different due to a reason other than chance. However, as it was affirmed by Higgins, G., Deeks, and Altman (2003) since a meta-analysis always includes diversity at a clinical and methodological level, statistical heterogeneity in their results is generally expected. Besides, according to the Cochrane Handbook for Systematic Reviews of Interventions (The Cochrane Collaboration, 2011), the interpretation of the already mentioned heterogeneity tests should be made carefully due to the low power of such tests when the included studies have small sample sizes or are few in number. In the current study, the implementation of different assessment tools as well as the small sample sizes of some of the included studies might be the cause of such high levels of heterogeneity.

To our knowledge, this is the first meta-analysis specifically focused on the effects of longitudinal exercise interventions on inhibitory control. Therefore, comparisons with previous meta-analysis focused on the same topic are not possible. Nevertheless, since the IC construct overlaps with cognitive and executive functioning, several relevant reviews should not be ignored. Besides, some meta-analysis focused on EFs benefits, also specified the inhibitory control results in their analysis (Wilke et al., 2019; Xue et al., 2019).

A recent meta-analysis (Xue et al., 2019) focused on the effects of longitudinal exercise interventions on executive function among children and adolescents, showed improvements in the overall EFs (*SMD* = 0.20, 95% CI 0.09 to 0.30, $p < 0.05$). These authors also analyzed the specific effects on the inhibitory control domain, and improvements were found (*SMD* = 0.26, 95% CI 0.08 to 0.45, $p < 0.05$). However, a previous meta-analysis carried out to study the effects of different exercise interventions on the executive functions of children, adolescents, and young adults (Verburgh et al., 2013) found, like in the current study, no significant overall benefits of longitudinal exercise interventions on EFs ($d = 0.14$, 95% CI -0.04 to 0.32, $p = 0.19$).

Aerobic exercise training was one of the most common implemented longitudinal exercise intervention in the last decades. P. J. Smith et al. (2010) studied the connection between aerobic exercise training and neurocognitive performance. Their results showed improvements in executive functions ($g = 0.123$, 95% CI 0.021 to 0.225, $p = 0.018$) but IC results were not specified.

Among longitudinal exercise interventions, acute exercise interventions have also been widely implemented, and several systematic reviews and meta-analysis have studied the benefits of these short-based interventions on different populations. Verburgh et al. (2013) in addition to the longitudinal interventions previously discussed, also analyzed the benefits of acute physical exercise interventions. Their results showed an effect size of ($d = 0.46$, 95% CI 0.33 to 0.60, $p < 0.001$) on executive functions pointing to the intervention groups, meaning relevant benefits after such interventions.

Another relevant meta-analysis focused on the acute effects of resistance exercise on cognitive function (Wilke et al., 2019) showed positive results on the inhibitory control of healthy adults after single bouts of resistance exercise (*SMD* = 0.73, 95% CI 0.21 to 1.26, $p = 0.01$).

Ludyga, Gerber, Brand, Holsboer-Trachsler, and Puhse (2016) went deeper in their analysis of the acute effects of moderate aerobic exercise on executive function. These authors carried out a meta-analysis to study the effects of acute bouts on different age and aerobic fitness subgroups. Results disclosed that preadolescent children and older adults seem to benefit more from aerobic exercise than other age groups. According to their investigation, both low-fit and high-fit individuals similarly benefit from exercise, situating aerobic fitness as a no moderator for benefits on temporary EFs improvements.

Chang, Labban, Gapin, and Etnier (2012), found an overall positive but small effect of acute exercise interventions on cognitive performance in their study covering all range of ages ($g = 0.097$). These authors also included the analysis of the effects on three specific moments of time: during exercise ($g = 0.101$, 95% CI 0.041 to 0.160), immediately following exercise ($g = 0.108$, 95% CI 0.069 to 0.147), and after a delay of time ($g = 0.103$, 95% CI 0.035 to 0.170). Besides, these authors unlike the study of Ludyga et al. (2016), affirmed that participant fitness was a significant benefits moderator, among other moderators like exercise duration, exercise intensity, and type of cognitive performance assessed.

As it was demonstrated by Ludyga et al. (2016), the age of the sample seems to be a relevant variable in the study of the effects of exercise interventions on EFs. Besides, due to the developmental changes that IC suffers over life and the brain plasticity already commented in the introduction of the current document, in some stages of life, training interventions might be especially relevant to prevent and to ameliorate cognitive deficits (Budde, Wegner, Soya, Voelcker-Rehage, & McMorris, 2016).

With this aim, and due to the already known increase of age-related cognitive impairments, in addition to samples of children and adolescents, several studies have also been focused on samples of old adults. Kelly et al. (2014) accomplished a systematic review and meta-analysis focused on the impact of aerobic exercise, resistance training, and Tai Chi on the cognitive functioning of healthy older adults to find the best intervention for delaying the onset of cognitive decline. The results revealed significant improvements on reasoning ($p < 0.005$) after resistance training in comparison to stretching/toning, and on attention ($p < 0.001$) and processing speed ($p < 0.00001$) after Tai Chi interventions in comparison with controls no attending any exercise intervention. Nevertheless, no more significant differences between exercise and controls were found in other domains.

However, the existence of studies with no benefits in the IC after exercise training or physical activity interventions (de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016), should not be forgotten. According to a recent systematic review (Singh et al., 2018), there is inconclusive evidence for the beneficial effects of physical activity interventions on cognitive performance and overall academic achievement in children. These authors concluded that more high-quality research was needed to clarify the doubts in this field.

The kind of exercise, the intensity, the length, the level of cognitive engagement, the curricular or extra-curricular nature of the intervention, among others, are variables to discuss and to adjust. In any case, finding the reasons why some exercise training interventions reported benefits in a cognitive level and others did not is already at the heart of the debate.

A recent commentary (Diamond & Ling, 2019) situated aerobic exercise and resistance training interventions as the least effective ways to improve executive functions. Exercise modalities appear to reach different levels of improvements in the IC (Alvarez-Bueno et al., 2017; Diamond & Ling, 2019; Hillman, McAuley, Erickson, Liu-Ambrose, & Kramer, 2019). It has also been suggested that training programs included in the school curriculum lead to greater benefits for inhibitory control than extracurricular ones (Alvarez-Bueno et al., 2017; Ludyga et al., 2019), and it has been shown that with practicing a task or a procedure, the performance gets better (Diamond & Ling, 2016). Therefore, goal-directed exercise interventions could be the clue for reaching more benefits when EFs in general or IC in particular are the challenge.

The results obtained in the present systematic review and meta-analysis point in this direction. Zhao et al. (2015) implemented the shortest intervention within the daily school activities (20 minutes per day for 7 days) training the specific inhibitory control game “Wesley Says”. However, this study also reached the highest benefits in the IC in comparison with the rest of the interventions analyzed in this review. Though, those results should be interpreted carefully due to some methodological limitations of the study. Moreau et al. (2017) also found improvements on IC after a 6-week HIT intervention, training only for 10 minutes per day.

Nevertheless, given the large interindividual differences in personal and physical traits, might make sense not to expect the same benefits from the same exercise intervention in different participants (Chang et al., 2012). Future investigations should use an accurate dose-response relationship, which takes into account that standardized exercise intensity has a profound impact on mental health issues including cognition (Budde, Velasques, et al., 2018; Gronwald et al., 2019; Gronwald et al., 2018). The current lack of statistically significant results should not be taken as a negative outcome but as a realistic result that opened the door to a new work field based on the promotion of adjustments and the generation of specific exercise intervention designs based on the specific capacity that needs to be improved.

Strengths and limitations

The strict inclusion criteria of the meta-analysis are a strength of the current study.

Only RCT designs were included. The performance of two different statistical analysis to calculate the effect sizes is another strength. To our knowledge, this is the first meta-analysis performed in both ways. In the traditional analysis, the presentation of the results in three different forest plots allows to have a better idea of the changes in several independent but related variables.

One of the main limitations of the current review and meta-analysis may be the inclusion of several inhibitory control assessment tasks. This might be the reason for the high heterogeneity of the results obtained. The inclusion of children and adolescents in the same analysis might be positive to the generalize results. However, the effects might be different depending on the developmental stage of the participants and therefore, results might be considered carefully.

It should be also noted that the main objective of most of the included studies was not the specific enhancement of the IC but were more directed to produce benefits on the EFs in general. In spite of having the IC included in all of the analysis, the exercise interventions might lack the needed specificity to be able to cause relevant benefits specifically on the IC.

Future studies should be particularly focused on IC. The diverse nature of IC needs to be better addressed. The overlapping structure of this construct is still a challenge of research, and the connections between IC components must be better explained. More specific assessment tasks might be implemented in order to assess all of the IC components, and when a specific component is studied it should be well specified to avoid misunderstandings. The different stages of EFs development, and the differences between children and adolescents should also be considered in future investigations. The list of moderators with an impact on this domain should be clarified, and the long-term effects of these kind of interventions must be monitored in order to reach better conclusions.

5.2.6 Conclusions

The specific results of the present review and meta-analysis are in line with papers like the recent systematic review carried out from an expert panel (Singh et al., 2018) that found inconclusive evidence for the beneficial effects of physical activity on cognitive performance, or the meta-analysis (Verburgh et al., 2013) that found no significant overall benefits of longitudinal exercise interventions on the EFs of children, adolescents, and young adults.

In the current study, the results of the included longitudinal RCT exercise interventions on IC showed non-statistical significance on the positive effect sizes. In summary, it can be assumed that there is non-conclusive evidence for the beneficial effects of the studied longitudinal exercise interventions on the IC of normally developed children and adolescents.

Due to the fact that most of the interventions are not specifically focused on the improvement of the IC but in the general of improving EFs, more high-quality research is needed to clarify the real possibilities of specific exercise intervention accurately designed to produce changes on the IC.

As it was already mentioned, the design of the exercise interventions implemented seems to be a relevant factor that needs to be clarified. Goal-directed exercise interventions could open new doors in this relevant research field to improve inhibitory control. Due to the negative impact that a bad inhibition capacity have in our daily lives (Moffitt et al., 2011), to find an alternative that caused benefits on this capacity would be highly helpful for the people who have problems and also extremely relevant at a social level.

5.3 Study III: Effects of different acute exercise interventions on the inhibitory control of schoolers

5.3.1 Summary

The relevance of inhibitory control for a suitable development over life is already well established in the literature, and the lack of it is broadly connected with several disorders with high impact in our society. Exercise seems to be a promising alternative to ameliorate inhibitory control insufficiencies. Acute bouts of exercise interventions have received great interest due to its short implementation. However, results are still incongruent. This study aims to determine the effects of two different acute exercise interventions (a common aerobic intervention and a new designed Go/No-Go motor intervention) on inhibitory control. The study design also includes a control group. The Go/No-Go motor intervention was specifically designed to demand inhibitory control. A total of 59 children (28 female; 31 male) between 10-12 years (*M* = 10.97; *SD* = 0.742) participated in the study. Results showed no significant differences on the inhibitory control abilities when comparing between interventions. Besides, any of the acute exercise interventions implemented can be assumed to cause significant observable benefits in this domain. In conclusion, acute bouts of exercise with a goal-directed design might improve inhibitory control, but several moderators should be further studied and better adjusted to cause immediate observable improvements.

5.3.2 Introduction

A well-developed IC during childhood has been linked to better academic results (Latzman et al., 2010), better sociological skills (due to its implication in the development of emotion regulation, conscience, and social competence) (Carlson & Moses, 2001), and a better general situation in the adulthood, in terms of physical and mental health, economic situation, and general success in life (Moffitt et al., 2011). Besides, an IC deficit might have a cascade effect to the rest of EFs (Barkley, 1997). Therefore, to find any chance of improvement in this domain is of outstanding importance.

Several studies have already proved that IC, jointly with other components of the EFs, can be trained (Tamm et al., 2019; Zinke, Einert, Pfennig, & Kliegel, 2012). A wide range of EFs training alternatives has been developed in the last years. To recap some examples: play-based interventions (Zhao et al., 2015), computer-training/ gaming programs (Flynn, 2014; Klingberg et al., 2005), musical interventions (Habibi, Damasio, Ilari, Sachs, & Damasio, 2018; Jaschke et al., 2018; Joret et al., 2017; Moreno & Farzan, 2015), mindfulness and yoga (Enoch, 2015; Lawler, 2015; Oberle et al., 2012; Thurman & Torsney, 2014), long term exercise training interventions (Aadland et al., 2019; Alesi et al., 2016; L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga, Gerber, et al., 2018; Moreau et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; van der Niet et al., 2016; Zhao et al., 2015), and acute bouts of exercise (Browne et al., 2016; Jäger et al., 2014). Among all of these possibilities, this paper is focused on the latter, the acute bouts of exercise interventions.

Talking about acute bouts of exercise means talking of a single short-term exercise bout intervention. This kind of intervention is specifically designed to take place only once, and the length used to range between 10 and 40 minutes (Verburgh et al., 2013). The benefits are calculated by extracting the difference between pre-test (before the intervention) and post-test (after intervention) measurements and comparing the intervention and the control group.

Two main variables are broadly assessed to analyze improvements in IC: reaction times and accuracy (L. Chaddock-Heyman et al., 2013; Tarp et al., 2016; Zhao et al., 2015). When there is a decrease in mistakes after the intervention (higher accuracy level) in comparison with the obtained mistakes in the control group, there is an improvement in the IC. When with a similar level of mistakes between pre and post-intervention, the RTs are shorter, the participant has responded faster than before, meaning IC improvement too. Another option of evaluation is the calculation of a single study variable. To give some examples: the interference index of the Stroop test, or the Inverse Efficiency Score (IES) from Bruyer and Brysbaert (2011) that combines both ACC and RTs in a single score.

There is a broad literature that studied the impact of this kind of acute exercise interventions on several aspects of EFs (A. G. Chen et al., 2014; Hillman et al., 2009; Jäger et al., 2014; O'Leary, Pontifex, Scudder, Brown, & Hillman, 2011), specific components of the EFs: response inhibition (Chu, Alderman, Wei, & Chang, 2015), selective attention (a particular case of behavioral inhibition according to Miller and Cohen (2001)) (Niemann et al., 2013), or academic achievement (Hillman et al., 2009) among other domains, and affirmed to find benefits.

A meta-analysis (Verburgh et al., 2013), carried out to analyze the effects of physical exercise on executive functions in preadolescent children, adolescents, and young adults showed a significant overall effect of acute physical exercise on executive functions ($d = 0.52$, 95% CI 0.29 to 0.76, $p < 0.001$). The effect size of the specific benefits of acute physical exercise on inhibitory control was ($d = 0.46$, 95% CI 0.33 to 0.60, $p < 0.001$). Another meta-analysis (Sibley & Etnier, 2003), had an effect size of $g = 0.37$ (Hedge’s g) including different exercise designs (acute, chronic, or cross-sectional) and different kinds of activity (resistance training, aerobic training, perceptual-motor, PE program) in the calculation.

However, there are also single studies that did not find this kind of benefits after diverse types of acute exercise interventions in the domains mentioned before (Jäger, Schmidt, Conzelmann, & Roebers, 2015; Stein et al., 2017; Stroth et al., 2009).

Therefore, despite the amount of literature focused on the effect of acute bouts of exercise on EFs in general, and IC in particular, current results are still inconclusive, and several doubts are still not answered. Besides, some authors like A. G. Chen et al. (2014) highlighted the lack of studies, including children samples, when studying acute exercise and cognition. Jäger et al. (2015) also remarked that most of the studies investigating the immediate effect of a single bout of exercise, were conducted in laboratory settings and included interventions mostly comprised of treadmill walking (Drollette et al., 2014; Hillman et al., 2009) or ergometer cycling (Stroth et al., 2009).

Regarding the nature of the intervention, an article (Zhao et al., 2018), affirmed to find potential in a response-inhibition training program (training with an adapted Go/No-Go task consisting of one 600-trial session for 20 weekdays) aiming to improve different aspects of cognitive functioning in children. Besides, another article (Zhao et al., 2015) found improvements on IC after a short-longitudinal training (7 days) with a specific IC game called "Wesley says."

As it was reported by Ginsburg (2007), play is crucial for children and youth development due to its contribution to the cognitive, physical, social, and emotional well-being. The WHO recognized the right of every child to grow up in a healthy environment that satisfies their need to live, learn, and play in proper places (World Health Organization, 2003).

Due to the background on the topic, and under the theoretical base of a single bout of physical exercise as a useful alternative for facilitating cognition (Ishihara, Sugasawa, Matsuda, & Mizuno, 2017a), the current study aimed to combine exercise, game, and goal-directed components in a single training task. A Go/No-Go motor task was designed to achieve this goal. The benefits of the intervention implementing this task were compared with a single bout of aerobic exercise intervention with the same duration, and a control group.

As it was suggested by Jäger et al. (2015), to examine the acute exercise interventions benefits in more natural settings it is necessary to discover if this kind of interventions have the same effects as when they are executed in highly controlled laboratory settings. The scholar setting was the selected environment to examine the effects of acute exercise interventions with several characteristics.

5.3.3 Methods and material

Participants

The protocol of the intervention was discussed with and approved by the school board of the school where the intervention was implemented. A total of 59 children (28 female; 31 male) between 10-12 years (*M* = 10.97; *SD* = 0.742) participated in the study after giving an informed written parental consent. Participants presented no psychiatric, neurological, or any other significant medical problem. One child had diabetes but did not have any problem to participate under the same conditions than the rest of the participants. All of them participated in two different sessions. In the first session, the aerobic fitness of the participants was evaluated with the Shuttle Run Test. The second session included the pre-intervention IC assessment, the intervention, and the post-intervention IC assessment. All of the participants were randomly allocated in one of the three intervention groups: aerobic exercise intervention group, GNG motor intervention group, or control group. The randomization procedure was made with a specific internet-based tool called Research Randomizer (Urbaniak & Plous, 2013).

Aerobic fitness assessment

Aerobic fitness was assessed using the 20 m Shuttle Run test (SRT). Their creators define this test as "*a maximal multistage 20 m shuttle run test to determine the maximal aerobic power of schoolchildren, healthy adults, and athletes*" (Leger, Mercier, Gadoury, & Lambert, 1988, p. 93). The SRT is one of the most implemented tests worldwide to estimate the VO_2 max (maximal oxygen consumption) in the area of health, school, and sports (García & Secchi, 2014). The test is also known as "Course Navette" or "Test de Ida y Vuelta en 20 metros" in its French and Spanish respective versions. It applies to children from 6 years of age until adulthood, although its application is recommended from 8 years of age on (García & Secchi, 2014).

To implement the SRT, the following material was used: 20 meters marked lineal running space, the test´s audio file, speakers, spreadsheets to record the results, and pencils. The group was split in two. When half of the group was participating, the other half was collecting the data of their counterparts and vice versa.

The test consists of running as long as possible between two lines situated 20 meters far away from each other, on a round trip. The auditive signals mark the running pace. In the first stages, the speed between one signal and the next are "low speed" to become familiar with the test and to warm-up. However, the speed of the auditive stimuli presentation increases each round. The initial speed is 8.5 km/h and increases 0.5 km/h every minute, which means its incremental and continuous until reaching fatigue. The participants must step behind the 20-meter line at the exact moment when the sound is presented ("beep"). The test ends when the participant reaches fatigue and cannot continue with the audible impose rhythm, or after two consecutive rounds where they are not able to step behind the line with the audible stimulus.

The data regarding the speed reached in the last complete stage for each participant was collected. This data is called the final speed reached (FSR) and can be used to estimate the VO_2 max (García & Secchi, 2014). The following formula was proposed by Leger et al. (1988) for kids with ages ranging from 6 to 17 years (with age (A) assessed in years and FRS in km/h):

$$\text{VO2}\max = 31.025 + (3.238\ \times\ FRS) - (3.248\ \times\ A) + (0.1536\ \times\ FRS\ \times\ A)$$

Inhibitory control assessment

Interference control was assessed by the Spanish computerized adaptation (Golden, 2001) of the Stroop test (Stroop, 1935). This test has shown to be appropriate for measuring executive functions in children (Aadland et al., 2017; Peru, Faccioli, & Tassinari, 2006) and the moderate to good test-retest reliability in children (r = 0.50 - 0.80) of the computerized versions of the test has been highlighted (Penner et al., 2012; van den Berg, Saliasi, de Groot, Chinapaw, & Singh, 2019). The task had three parts. The first part's aim was to read the colored words (W); the second's part objective was to name the ink in which the X's were colored (C); and the third's part goal was to name the ink color of the words when the color and the name were incongruent (interference condition) (WC). The total number of correct responses in each part was registered. The interference index (Stroop I) was calculated by the difference between the punctuation in the interference condition (WC), and the expected punctuation of this third part due to their performance in the other two parts (WC´). The formula to calculate WC´ therefore is: $WC' =\ [(W\ x\ C)/(W\ +\ C)]$. Consequently, the difference between WC and WC´ is the interference index: $WC - WC' = INT$. Higher scores indicate greater ability to inhibit interference and therefore, greater inhibitory control (Barnhart & Buelow, 2017).

Response inhibition was assessed with a traditional design Go/No-Go task adapted from Caswell et al. (2015). Criaud and Boulinguez (2013) affirmed the broad implementation of this task to study the development of response inhibition. Participants were instructed to quickly respond (by pressing the space bar) to every Go stimulus and to avoid responding to every No-Go stimulus. A total of 120 stimuli were presented in two separate sets of 60 presentations each. In order to create a prepotency towards the Go stimulus, the rate of the stimuli presentation was 80% Go to 20% No-Go stimuli. According to Simmonds et al. (2008), response inhibition is evaluated by the capacity to avoid responding to a No-Go stimulus appropriately. Bruyer and Brysbaert (2011) proposed to use the Inverse Efficiency Score (IES) in order to combine the information on speed and accuracy into one measurement. This measurement is calculated by dividing the reaction times by the correct proportional responses. A low score on this ratio reflects a strong inhibition efficiency (Zhao et al., 2018).

Interference control was also assessed with a computerized Flanker task adapted from Eriksen and Eriksen (1974). The visual stimuli were arrows. Every stimulus presentation was located in the center of the screen. Five arrows were appearing, and participants were instructed to attend to the specific direction of the central arrow (the one situated in the center of the five) and to ignore therefore flanking arrows. There were two kinds of stimulus: congruent and incongruent. Congruent when the target arrow pointed in the same direction than the rest (<<<<<; >>>>>), and incongruent when the target arrow is pointing to a different direction (<<><<; >><>>). The task included 40 randomized trials. A total of twenty congruent and twenty incongruent stimuli were presented. Ten of each with the directions of the arrows already commented. Therefore, the four different kinds of stimuli included in this task had the same proportion, and their appearance was randomized. When a stimulus appeared on the screen, participants were asked to respond as quickly and accurately as possible. In this specific case, the “f” and “j” keys were marked in the keyboard to give the responses. Participants must press the "left" key (= f) when the target arrow pointed left and the right key (= j) when the target arrow pointed right. To analyze the IC with this task, some studies analyzed the incongruent trials due to the literature that found these stimuli to require more IC (Brassell et al., 2017; Hillman et al., 2014; Kubesch et al., 2009; Tamm et al., 2019). However, this task mistakes and reaction times are also registered, and some other studies used these variables to analyze the IC changes (L. Chaddock-Heyman et al., 2013; Zhao et al., 2015). In any case, in order to combine the information on speed and accuracy into one measurement, the Inverse Efficiency Score (IES) from Bruyer and Brysbaert (2011) might also be used.

Study variables

The study variables included in the analyses are presented in Table 5.

Table 5. *The variables of study included in the analyses.*

Pre-test	Post-test
Stroop ACC_1	Stroop ACC_2
Stroop RTs_1	Stroop RTs_2
Stroop I_1	Stroop I_2
GNG ACC_1	GNG ACC_2
GNG RTs_1	GNG RTs_2
GNG IES_1	GNG IES_2
Flanker ACC_1	Flanker ACC_2
Flanker RTs_1	Flanker RTs_2
Flanker IES_1	Flanker IES_2

Note. ACC = accuracy (mistakes); RTs = mean reaction times; I = interference index; IES = inverse efficiency score.

Intervention groups

The current study included three intervention groups. Each of the groups participated in a different intervention. Two of the interventions included a different design of an exercise intervention: A Go/No-Go motor intervention, and an aerobic exercise intervention. The activity of the control group consisted on reading a book and writing a summary of their reading.

For the Go/No-Go motor intervention, a Go/No-Go motor task was designed in order to include three characteristics theoretically relevant for inhibitory control training: a play component, a goal-directed activity, and a high motoric component. The intervention was based on a traditional Go/No-Go task design. The participants started in a “ready position” without crossing a line on the floor. Another line was situated in front of the starting line at 12.5 meters of distance. There were two different auditive stimuli: the sound of a cat (No-Go) and the sound of a cow (Go). Participants had to act according to the stimulus they heard. They had to run to the front line when the cow´s sound appeared and not run to the front line (avoiding a motoric response) when the cat´s sound appeared.

The task design included 120 trials with ten stimuli per trial at a set of 2 No-Go stimuli and 8 Go stimuli per trial. A new stimulus was sent after every participant response (to run and cross the front line after a Go stimulus or to avoid a motoric response after a No-Go response). The researcher on charge corrected any mistake in the execution of the task and told immediately to the participants if their response was incorrect. The intervention had a limit of 10 minutes of training. To shorten the denomination of this group of intervention from now on it would be called GNG motor group.

For the aerobic exercise intervention, a running circuit was delimited in a pavilion with a zig-zag structure in order to make it more interesting for the contestants. Participants had to run in this setting for 10 minutes. From now on, this group would be called aerobic group.

As it was already mentioned, the length of the three interventions performed by the three different groups lasted 10 minutes (including the control intervention). In the two interventions that included exercise, the intensity was intermediate (between 60 and 70% of their maximum heart rate), which was equivalent to mild jogging or light walking. The heart rate established for the intervention based on the age group (using the formula 220 - age, already implemented in similar study designs like the one by Egger et al. (2018)) was between 125-147 beats per minute. Pulsometers were implemented in both exercise intervention groups in order not to exceed the heart rate limits established.

Statistical analysis

Descriptive statistical tests were first carried out to report participants demographic characteristics. A chi-square test was performed to analyze the variable gender, and a one-way ANOVA test compared the means of the three groups regarding the rest of the demographic data (age, height, weight, body mass index (BMI), and maximal oxygen uptake (VO_2 max)).

An independent-samples t-test analysis was performed to analyze the exercise intensity manipulation (the existence of significant differences in the heart rates of the two exercise intervention groups).

Normality tests (Shapiro-Wilk) were performed to determine if the study data fulfills the normal distribution in all of the included study variables. Because most of the variables were normally distributed and the sample size was large ($n = 59$), parametric tests were used. The parametric test implemented to evaluate whether the participants in the different groups have different RTs in the three IC implemented tasks (Stroop, GNG, and Flanker) before and after interventions, was a mixed (Split-Plot) ANOVA with one between-subject factor with three levels (groups), and one within-subject factor with two levels (time). The same test was implemented to evaluate the ACC variables (mistakes), and the direct variables to assess interference control (Interference index of the Stroop and Flanker task IES) and the ability to suppress prepotent responses (GNG IES). Post hoc analysis were carried out when the interaction effect (time x intervention) of the ANOVA was statistically significant.

5.3.4 Results

Participant characteristics

The descriptive statistics on participants demographic characteristics were reported in Table 6. A chi-square test was performed to compare the gender composition of the three different groups. This test revealed no significant differences between aerobic, GNG motor, and control group in terms of gender ($\chi^2(2) = 2.12$, $p = 0.34$).

Multiple t-tests on multiple pairs of means were avoided in order not to add multiple chances of error as it was suggested by Kim (2014) when comparing the rest of the demographic data (age, height, weight, BMI, and VO_2 max) of the three groups. Instead, a one-way analysis of variance (Stroganova, Tsetlin, Posikera, Orekhova, & Malakhovskaya, 2002) was carried out to compare the means of the three groups. The results showed no statistically significant differences ($p > 0.05$) between the three groups in age, $F(2, 56) = 0.58$, $p = 0.566$; height, $F(2, 56) = 0.70$, $p = 0.499$; weight, $F(2, 56) = 0.11$, $p = 0.900$; BMI, $F(2, 56) = 0.02$, $p = 0.980$ and VO_2 max, $F(2, 55) = 2.02$, $p = 0.143$.

Exercise intensity manipulation

Heart rates for aerobic and GNG motor groups were scheduled to range between 60% and 70% of the maximal heart rate in order to have a moderate level of intensity during both interventions. These recommendations were made due to the previous literature that reported that moderate-intensity exercise interventions benefit cognition (Chang, Chu, Chen, & Wang, 2011; Chang & Etnier, 2009; A. G. Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009).

The maximal heart rate was calculated according to the formula 220 - age, attributed to S. M. Fox, Naughton, and Haskell (1971). For this group of age, the beats per minute (BPM) to exercise at a moderate level must range between 125 and 147. The maintenance of this range was controlled with pulsometers.

The heart rate during aerobic (M = 143.15, SD = 13.32) an GNG motor (M = 139.60, SD = 13.38) interventions were 68,5% and 66.8% of the maximum respectively. The independent-samples t-test analysis revealed no significant differences in the heart rates of these two exercise intervention groups ($t(38) = 0.873$, $p = 0.388$).

Table 6. *Participant demographics and heart rates during the exercise interventions (mean ± standard deviation).*

Variables	Aerobic group	GNG motor group	Control group
n	20	20	19
Female/male	7/13	10/10	11/8
Age (years)	10.95 ± 0.75	10.85 ± 0.58	11.11 ± 0.87
Height (m)	1.51 ± 0.06	1.49 ± 0.06	1.49 ± 0.07
Weight (kg)	46.75 ± 12.76	45.85 ± 11.09	45.02 ± 11.36
BMI (kg/m^2)	20.13 ± 4.14	20.31 ± 3.90	20.03 ± 3.81
VO$_2$ max (mL/kg/min)	43.68 ± 3.63	45.39 ± 4.37	42.45 ± 5.44
Heart rate (bpm)	143.15 ± 13.32	139.60 ± 13.38	

Note. n = number of participants per group.

Inhibitory control analysis

The Shapiro-Wilk test showed that all the study variables related to reaction times, as well as interference indexes of the Stroop test, were normally distributed in both pre and post-test assessments. Conversely, accuracy variables, were not normally distributed (comprising the two IES variables of both GNG and Flanker tasks too). To support these results, histograms and Q-Q plots were also checked, and skewness and kurtosis values were analyzed. However, due to the sample size n = 59, and the composition of the intervention groups (aerobic n = 20, GNG motor n = 20, and control group n = 19) parametric tests can be quite robust to the normality assumption (Field, 2009). Therefore, all of the study variables were analyzed with parametric tests.

Descriptive statistics analyses for each one of the variables is shown in tables 7, 8, and 9.

***Table** 7. Descriptive statistics analyses (mean ± standard deviation) for RTs variables.*

Study variable	Aerobic	GNG motor	Control
Stroop RTs_1	853.00 ± 169.17	862.93 ± 145.08	867.01 ± 136.67
Stroop RTs_2 (post)	819.64 ± 163.41	880.79 ± 160.38	831.99 ± 130.84
GNG RTs_1	547.10 ± 109.54	568.42 ± 86.87	534.09 ± 86.16
GNG RTs_2 (post)	525.16 ± 94.72	549.51 ± 94.82	505.47 ± 80.77
Flanker RTs _1	761.27 ± 159.99	786.14 ± 142.46	760.50 ± 155.23
Flanker RTs_2 (post)	691.66 ± 115.70	707.64 ± 136.85	667.46 ± 148.14

Note. RTs = mean reaction times; GNG = Go/No-Go.

The Box´s Test of Equality of Covariance Matrices was not significant for any of the variables including RTs data: Stroop test RTs ($p = 0.735$), GNG task RTs ($p = 0.678$), and Flanker task RTs ($p = 0.075$).

The mixed ANOVA of the RTs values of the Stroop test showed that the interaction effect time x intervention was not statistically significant ($F(2,56) = 2.280$, $p = 0.112$, $\eta_p^2 = 0.075$). This indicated that the way the reaction times of this IC task developed over time was not dependent on the intervention group. It was also found that the IC values of this variable were not significantly different between the pre and post evaluations (main effect time: $F(1,56) = 2.129$, $p = 0.150$, $\eta_p^2 = 0.037$) and that the IC values in the intervention groups were not significantly different (main effect group: $F(1,56) = 0.306$, $p = 0.738$, $\eta_p^2 = 0.011$).

The results of the mixed ANOVA of the RTs in the GNG task showed no statistically significant effects on the interaction time x intervention ($F(2,56) = 0.080$, p

= 0.923, η_p^2 = 0.003) meaning again that the way the reaction times of this IC task developed over time was neither dependent on the intervention group. However, it was found that the reaction time values at the post-test measurement, were statistically significantly lower over the three groups than at the beginning of the study (main effect time $F(1,56) = 5.300$, $p = 0.025$, $\eta_p^2 = 0.086$). Nevertheless, in the three intervention groups the average of the RTs values were not statistically significantly different among each other (main effect group: $F(1,56) = 1.064$, $p = 0.352$, $\eta_p^2 = 0.037$).

The ANOVA of the RT values on the Flanker task showed that the interaction effect measurement time x group was not statistically significant ($F(2,56) = 0.223$, $p = 0.800$, $\eta_p^2 = 0.447$) indicating that the development over time of the reaction times of this IC task was not dependent on the intervention group. Reaction time values at the post-test measurement, were again in this case statistically significantly lower over the three groups than at the beginning of the study (main effect time $F(1,56) = 31.332$, $p = 0.001$, $\eta_p^2 = 0.359$). The RTs values were not statistically significantly different among each other in regard to the intervention groups (main effect group: $F(1,56) = 0.307$, $p = 0.737$, $\eta_p^2 = 0.011$).

Table 8. *Descriptive statistics analyses (mean ± standard deviation) for ACC variables.*

Study variable	**Aerobic**	**GNG motor**	**Control**
Stroop ACC_1	16.85 ± 35.59	6.50 ± 5.84	6.84 ± 8.64
Stroop ACC_2 (post)	27.70 ± 159.58	7.50 ± 11.79	8.63 ± 8.65
GNG ACC_1	6.90 ± 4.66	4.80 ± 5.82	5.37 ± 4.69
GNG ACC_2 (post)	8.85 ± 6.02	6.45 ± 5.46	5.79 ± 4.53
Flanker ACC _1	2.40 ± 3.72	3.70 ± 4.97	2.31 ± 3.00
Flanker ACC_2 (post)	2.35 ± 2.81	3.20 ± 5.01	2.26 ± 1.96

Note. ACC = accuracy (mistakes); GNG = Go/No-Go.

The Box´s Test of Equality of Covariance Matrices was not significant for the ACC variable of the GNG task ($p = 0.518$) but was significant ($p = < 0.05$) for both ACC Stroop variable and ACC Flanker task variable, meaning that the covariance matrix was different between the groups in the analyses of ACC variables of the Stroop and the Flanker task.

The mixed ANOVA of the ACC values of the Stroop test showed that the interaction effect time x intervention was not statistically significant ($F(1,56) = 0.915$, $p = 0.407$, $\eta_p^2 = 0.032$). This indicated that the way the accuracy values of this IC task developed over time was not dependent on the intervention group. The accuracy values at the post-test measurement, were not statistically significantly different than at the beginning of the study (main effect time $F(1,56) = 2.186$, $p = 0.145$, $\eta_p^2 = 0.038$). Besides, the accuracy values were not statistically significantly different among the intervention groups (main effect group: $F(1,56) = 1.667$, $p = 0.198$, $\eta_p^2 = 0.056$).

The ANOVA results of the ACC values of the GNG task also showed a lack of statistical significance in the interaction effect time x intervention ($F(1,56) = 0.525$, $p = 0.594$, $\eta_p^2 = 0.018$), meaning that the way the ACC results developed over time was not dependent on the intervention group. In this case, the ACC values at the post-test measurement, were statistically significantly higher than at the beginning of the study, meaning that more mistakes were committed after the interventions than before (main effect time $F(1,56) = 4.381$, $p = 0.041$, $\eta_p^2 = 0.073$). The ACC values were not statistically significantly different between the intervention groups (main effect group: $F(1,56) = 1.593$, $p = 0.212$, $\eta_p^2 = 0.054$).

Lack of statistical significance in the interaction effect time x intervention $F(1,56) = 0.146$, $p = 0.865$, $\eta_p^2 = 0.005$) was also found in the ANOVA results of the ACC values of the Flanker task. This showed that the way the ACC results developed over time in this task was not dependent on the intervention group. There were not statistically significant differences among the ACC values at the post-test measurement and the values at the beginning of the study (main effect time $F(1,56) = 0.261, p = 0.612, \eta_p^2 = 0.005$), neither between the intervention groups (main effect group: $F(1,56) = 0.692, p = 0.505, \eta_p^2 = 0.024$).

Table 9. *Descriptive statistics analyses (mean ± standard deviation) for single combined scores.*

Study variable	**Aerobic**	**GNG motor**	**Control**
Stroop I_1	22.13 ± 7.09	18.97 ± 7.28	16.87 ± 5.75
Stroop I_2 (post)	18.65 ± 5.76	16.47 ± 8.52	18.20 ± 5.59
GNG IES_1	580.20 ± 114.16	592.39 ± 87.34	558.42 ± 83.16
GNG IES_2 (post)	567.74 ± 103.62	581.15 ± 100.07	531.11 ± 82.87
Flanker IES _1	809.79± 148.90	904.63 ± 352.96	815.55 ± 244.47
Flanker IES_2 (post)	736.58 ± 119.71	781.09 ± 202.28	712.68± 160.14

Note. I = interference index; IES = inverse efficiency score; GNG = Go/No-Go.

The Box´s Test of Equality of Covariance Matrices was not significant for the Interference index of the Stroop test ($p = 0.082$), nor for the IES of the GNG task ($p = 0.483$) meaning that the covariance matrix was the same between groups. However, it was significant ($p = < 0.05$) for the IES of the Flanker task as expected due to the previous normality tests.

The mixed ANOVA of the Interference Index of the Stroop test showed statistically significant differences on the interaction effect (time x intervention) ($F(2,56) = 3.511, p = 0.037, \eta_p^2 = 0.111$). This indicated that the values of this study variable developed dependently on the intervention group over time. A Simple Effects test showed that participants in the aerobic group, performed significantly different in the pre-intervention assessment than in the post-intervention assessment ($p = 0.012$). Results showed higher Interference Index scores in the pre-test than in the post-test. As higher scores in the Interference Index of the Stroop test indicate greater ability to inhibit interference (greater inhibitory control) (Barnhart & Buelow, 2017), it can be assumed that the aerobic group performed better over interferences in the pre-test (test previous to the intervention) than in the post-test (assessment after the intervention).

Besides, the pairwise comparison of the independent variable measured at a repeated measure level (time) showed that the aerobic intervention group and the control group performed significantly different in the pre-intervention assessment (p = 0.018), meaning that the initial performance of the aerobic group (pre-test) showed significantly higher control over interferences than in the control group.

Both, time effects (main effect time $F(1,56) = 3.963, p = 0.051, \eta_p^2 = 0.066$), and intervention effects (main effect group: $F(1,56) = 1.375, p = 0.261, \eta_p^2 = 0.047$) were not statistically significantly different.

The mixed ANOVA of the GNG IES values showed a non-significant interaction effect time x intervention ($F(1,56) = 0.289, p = 0.750$)., $\eta_p^2 = 0.010$) meaning that the way the results of this task developed over time was not dependent on the intervention group. No statistically significant effects of time (main effect time $F(1,56) = 3.191, p = 0.079, \eta_p^2 = 0.054$), as well as non-significant differences between the intervention groups were found (main effect group: $F(1,56) = 1.137, p = 0.328, \eta_p^2 = 0.039$).

The ANOVA results of the Flanker task IES values showed that the interaction effect time x intervention was not statistically significant ($F(1,56) = 0.298, p = 0.744, \eta_p^2 = 0.011$). This meant that the way the results developed over time was not dependent on the intervention group. However, the IES values of the Flanker task were statistically significantly lower at the post-test measurement than at the beginning of the study (main effect time $F(1,56) = 13.440$, $p = 0.001$, $\eta_p^2 = 0.196$), but there were not statistical differences among the intervention groups (main effect group: $F(1,56) = 0.970$, $p = 0.385$, $\eta_p^2 = 0.034$).

5.3.5. Discussion

The main objective of this study was to assess the effects of two different acute exercise interventions on the inhibitory aspect of executive function. A new task was designed to find the best intervention to improve inhibitory control. The design of the new Go/No-Go motor task had the base of a traditional Go/No-Go task. However, the new task included three components theoretically relevant for improving inhibitory control: a game-based design, a goal-directed objective, and a high motoric component (Dowsett & Livesey, 2000; Zhao et al., 2015). The other two intervention groups participated either in a commonly implemented aerobic intervention or in an active control group (reading and writing activity). The three interventions had the same length, 10 minutes.

Demographic characteristics did not differ significantly among the three different groups of participants. The heart rates of the exercise intervention groups, during intervention, ranged between 68,5% of the VO_2 max in the aerobic group and 66.8% of the VO_2 max in the GNG motor group, showing no significant differences between groups. The heart rate tracking aimed to control the intensity of the interventions. A heart rate between 60% and 70% of the VO_2 max is equivalent to moderate intensity of training. Previous exercise interventions where this intensity was applied have reported benefits at a cognitive level according to several authors (Chang et al., 2011; Chang & Etnier, 2009; A. G. Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009).

The analysis of results was based on three different variables: reaction times, accuracy, and single combined scores. The RT variable outcomes disclosed the lack of statistically significance in the interaction effect (time x intervention). However, the effect of time was statistically significant in two tasks: GNG task (F(1,56) = 5.300, p = 0.025, $\eta_p^2 = 0.086$), and Flanker task (F(1,56) = 31.332, p = 0.001, $\eta_p^2 = 0.359$) meaning that the participants were on average significantly faster in their reaction times during the post-test than in the pre-test in these two tasks. Nevertheless, according to these results, improvements in the RTs cannot be assumed to happen because of the interventions.

In general, no statistically significant effects were found in the ACC analysis in any of the three factors: interaction, time, and group. Only the time factor of the ACC results of the GNG task was statistically significantly higher at the post-test than at the beginning of the study (pre-test), meaning that significantly more mistakes were committed after the interventions than before (main effect time $F(1,56) = 4.381$, $p = 0.041$, $\eta_p^2 = 0.073$).

In the analysis of the single combined scores, the Stroop Interference Index, showed a significant interaction factor (time x intervention) ($F(2,56) = 3.511$, $p = 0.037$, $\eta_p^2 = 0.111$) meaning that there were significant differences between the pre and post-intervention results, in relation with the three groups. A notably decrease of the Stroop I was found after intervention in both exercise intervention groups, while the control group suffered an increase in comparison with the pre-test results. A higher interference index means a better capacity to control interferences. However, contrary to expected, after the two exercise interventions, a decrease in this capacity was found, but only in the aerobic group this decrease was significant. These results might be explained by a decrease in attention caused by the physiological activation.

The mixed ANOVA of the GNG IES values showed non-significant effects in any of the analyses: interaction (time x intervention), time, and intervention group. In the analysis of the Flanker task IES, only the time factor was significant. The IES values of this task were statistically significantly lower at the post-test measurement than at the beginning of the study (main effect time $F(1,56) = 13.440$, $p = 0.001$, $\eta_p^2 = 0.196$). As a lower score on this score reflects a better inhibition efficiency, it can be assumed that the three groups had a better inhibitory capacity in the flanker task after interventions, being this capacity significant in the GNG motor group ($p = 0.040$) and the control group ($p = 0.010$) but not in the aerobic intervention ($p = 0.120$). However, there were not statistically significant differences in the results of the three groups among each other.

As a summary, no significant differences between group interventions were found in the general performance of the tasks. Consequently, any of the exercise interventions proposed can be assumed to have caused benefits in the IC of this sample of children, or at least, non-observable benefits. This assumption would just be possible if the intervention groups would have been significantly better in the tests than the control group, but that was not happening in the current study. Besides, the significant results that were found over time in the RTs of the Go/No-Go and the Flanker task (showing that participants gave the answers faster after the interventions than before) might have been the cause of the decrease of their accuracy levels (like in the analysis of the ACC results of the Go/No-Go task).

The study sample was composed of normally developed schoolers. The first study of this work already demonstrated that substantial differences on IC can be found in a sample of typically developed children. An interesting study performed by Drollette et al. (2014) showed how children with lower inhibitory control capacity might benefit the most from a single bout of exercise. Future research interventions might first evaluate the inhibitory control capacity of the sample and afterwards, propose different interventions to ameliorate this domain with the previous knowledge of the IC different capacities among the participants. In this way, it might be easier to clarify the improvement margin of children.

In any case, non-significant results were not expected in the current study, because even knowing the existence of some studies that did not reported benefits after acute exercise interventions (Jäger et al., 2015; Stein et al., 2017; Stroth et al., 2009) an extent amount of studies obtained benefits after implementing different kinds of acute exercise interventions in normally developed samples from pre-kindergarteners to adolescents (A. G. Chen et al., 2014; Chu et al., 2015; Hillman et al., 2009; Jäger et al., 2014; O'Leary et al., 2011; Peruyero, Zapata, Pastor, & Cervelló, 2017; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012).

Besides, a significant positive relationship with an overall effect size of 0.25 between exercise and cognition was found in a meta-analysis that studied the effects of physical activity on cognition across the lifespan (6 to 90 years) (Etnier et al., 1997). In a similar line, (Sibley & Etnier, 2003) found a positive overall effect size of 0.32 between exercise and executive functions in children. In a more recent meta-analysis (Verburgh et al., 2013), the results showed a significant overall effect of acute physical exercise on executive functions (d = 0.52, 95% CI 0.29 to 0.76, $p < 0.001$) for samples with ages ranging between 6 and 35 years. The specific results on the IC domain also revealed a significant effect (d = 0.46, 95% CI 0.33 to 0.60, $p < 0.001$).

Nevertheless, the explanation to the fact that most of the literature that studied the effects of single bouts of exercise interventions in EFs mainly include positive results, might be given by a specific type of bias that received the name of “publication bias”. It was demonstrated that studies with statistically significant results were more likely to be published than those finding no differences between the study groups (Dickersin, Chan, Chalmers, Sacks, & Smith, 1987; Easterbrook, Berlin, Gopalan, & Matthews, 1991).

In the current study, better results after the GNG motor intervention were expected in comparison with both, aerobic intervention and the control group, because according to Best (2010, p. 347), *"the evidence suggests that aerobic activity alone influences EF, but that the interaction of aerobic activity and cognitive engagement has an even stronger effect"*. Diamond (2015) agreed with such an affirmation and encouraged researchers to look for more interesting activities than just running and to examine the critical elements for improving EFs included in such activities. The GNG design might still be a possibility to improve IC, but several other moderators should be adjusted.

Gronwald et al. (2018) affirmed that moderators like the intensity and the duration of the exercise, as well as the fitness level of the participants, can be relevant to originate neurobiological changes when implementing acute exercise interventions. However, the age of the sample (Budde, Wegner, et al., 2016), the cognitive component of the intervention (Best, 2010; Diamond, 2015), the time of day when the testing occurred (Chang et al., 2012), the setting where the exercise intervention is performed (Jäger et al., 2015), or the feedback application (Keith & Frese, 2005; Leidinger & Perels, 2012) might also have an influence in the benefits.

The intensity of the interventions implemented in the current study was based on previous literature on EFs that affirmed that moderate-intensity exercise interventions lead to more significant effects than light and vigorous intensities (Chang et al., 2015; Chang et al., 2011; Chang & Etnier, 2009; A. G. Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009). Chang and Etnier (2009) explained that high-intensity exercise benefits processing speed, but moderate-intensity exercise is most beneficial for executive function. In the meta-analysis performed by Chang et al. (2012) intensities of moderate to vigorous levels occurred to be the most beneficial ones to improve cognition.

As it was already mentioned, the typical length of acute bouts of exercise interventions used to range between 10 and 40 minutes (Verburgh et al., 2013). According to Kubesch et al. (2009), an increase of tyrosine hydroxylase in the nucleus caudate happen only 3 minutes after the beginning of a movement. The production of this enzyme seems to be relevant for cognitive functions. Even knowing that the peak level of production of this enzyme under exercise conditions is reached within the first 20 minutes of intervention, it was expected to find changes in cognitive performance by the length of 10 minutes. Besides, Suwabe et al. (2018) affirmed to find a rapidly increased activity in several hippocampal and cortical regions after a single 10 minutes bout of exercise.

Chang et al. (2012) affirmed to find a significant influence of time in cognitive changes in their meta-analysis. These authors did not find effects after 10 minutes of exercise interventions on cognitive functions but discovered positive results when the intervention was longer than 20 minutes. According to their data, durations ranging from 11 to 20 minutes seem to be most useful to enhance various measures of cognitive performance in children. In a similar line, Chang et al. (2015) affirmed that in their sample composed by young adults, an exercise session including 5 minutes of warm-up, 20 minutes of moderate-intensity exercise, and another 5 minutes to cool down improved cognition but shorter or longer durations of moderate exercise had insignificant benefits. Kubesch et al. (2009) suggested that the duration of a school sports program was decisive for finding improvements on EFs and that longer interventions (30 minutes) produced effects while a 5 minutes short intervention did not.

The length of the currently implemented interventions (10 minutes) might have been too short for producing notable immediate changes at a cognitive level. Besides, even if some changes were produced at a brain structural level after this short period of exercise implementation, behavioral signals of these changes might have been still not detectable with the behavioral tasks implemented. Future studies should include EEG and fMRI techniques to clarify if there are immediate brain structure changes produced by the participation in this GNG motor task design. These techniques might be more sensitive to changes than behavioral measures (Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007).

The fitness level of the participants could also be a moderator for benefits on cognitive functions. Chang et al. (2012), affirmed to find differences between highly fit participants, who had positive effects on cognitive functions after the exercise intervention, and low fit participants who had negative effects. Results from some other studies pointed to the same direction (Chang et al., 2014; Hogan et al., 2013). However, this theory is still a cause of controversy due to the existence of studies that found no connection between the impact of exercise interventions on cognition independently of the aerobic fitness level of the participants (Magnie et al., 2000; Niemann et al., 2013).

The mean BMI of the current sample composition was normal-high, according to the WHO (World Health Organization, 2007). The VO^2 max results showed a general good fitness level Casajús et al. (2012). In their meta-analysis, Chang et al. (2012), found non-significant effects of acute exercise interventions on moderately fit participants. Fitness level might also be one of the explanations for the lack of significant effects on the IC after the exercise interventions performed in the current work.

The age might also be relevant due to the diverse developmental trajectories of the different executive function components. In a study (A. G. Chen et al., 2014) including third grade (9 years) and fifth grade (11 years) schoolers, an acute bout of 30 minutes of jogging at moderate intensity was found to produce performance benefits in three EFs (inhibitory control, working memory, and shifting). Nonetheless, fifth-graders showed better performance in inhibition and working memory but not shifting when comparing with the performance of the third-graders. As it was already stated, due to the maturational differences of the EFs, in some stages of life exercise interventions might be especially appropriate to prevent and to ameliorate cognitive deficits (Budde, Wegner, et al., 2016).

The cognitive component of the training task may also be relevant for benefits on IC and the rest of EFs (Best, 2010; Diamond, 2015). Best (2010) affirmed that cognitive demands are inherent in many forms of exercise, and Jäger et al. (2014) found immediate positive effects of acute physical activity including cognitive engagement by exercise activities with games on children's inhibition. A high number of studies focused on comparing different types of acute physical activities with more or less cognitive engagement reported different results (Egger et al., 2018). Besides, these authors found that an acute bout of exercise intervention with cognitive engagement may deteriorate children's cognitive performance (Egger et al., 2018). The polemic results reveal the uncertainty of the real role of cognitive engagement during physical activity and exercise interventions. However, some activities and more specifically the practice of some sports, seem to be relevant to benefit IC (Wang et al., 2013). Wang et al. (2013) found that the athletes´ IC could benefit from open skills training and that sports, including both physical and cognitive demands, might provide a remarkable intervention for those who have IC problems.

In order to differentiate the cognitive component level on each one of the interventions implemented in the current study, the cognitive engagement factor was manipulated. While the aerobic exercise intervention had a low cognitive component, the GNG motor intervention was designed for demanding higher cognitive requirements. However, differences among these two interventions were not found, as well as in comparison to the control group. Participants on the active control group performed a reading and writing task, which also includes cognitive engagement. Future studies might include non-active control groups to avoid the inclusion of unexpected variability.

Another possible moderator for benefits mentioned by Chang et al. (2012) was the time of day when the testing occurred. According to these authors, significantly large effects were found when exercise was performed during the morning in comparison with interventions during the afternoon or at different times of the day. According to this, and due to the participation of children along with their daily educational routines (from 9:00 to 14:00) in groups of three, inter-subject differences might be possible according to this moderator. Children participation might happen at the same time of the day to avoid this variability in future studies.

Another argued moderator is the setting where the exercise interventions are performed. Several studies reported benefits after acute exercise interventions implemented in laboratory settings, usually including treadmill walking or cycling (Drollette, Shishido, Pontifex, & Hillman, 2012; Hillman et al., 2009; Hillman, Snook, & Jerome, 2003). Precisely, Jäger et al. (2015) affirmed that most of the results in this field have been conducted in highly controlled laboratory settings and that the translation of such interventions in more natural settings is difficult, especially with children populations. These authors, (Jäger et al., 2015) did not find effects after different acute physical activities (with and without cognitive engagement) on the EFs while implementing the interventions in a real-world setting. Meanwhile, Ludyga, Puhse, Lucchi, Marti, and Gerber (2018) affirmed to find improvements on IC and information processing after moderately-intense intermittent exercise in a classroom setting.

Most of the psychological programs to train self-control included feedback to help the subjects to focus their attention in the correct response, strategy, or behavior (Keith

& Frese, 2005; Leidinger & Perels, 2012). The feedback application in combination with exercise training interventions was still no extensively applied. Besides, the GNG motor task implemented in the current study, in spite of including feedback, was not causing observable changes in the IC of the participants. However, new kinds of feedback application might help to reach better results. Further research is needed.

Strengths and limitations

One of the main strengths of the current study is the evaluation of several IC components in the same sample of schoolers. Both, accuracy and reaction times were assessed by several specific behavioral tasks. Besides, the evaluation was carried out in a randomized group of schoolers with normal development while most of the research related to IC used to include pathological populations. The study included a structured methodology that integrated a previous session of fitness level assessment, a pre-test IC evaluation, the implementation of the different interventions, and a post-test IC evaluation. Participants were randomly assigned to one of the three intervention groups. This group assignation allowed to avoid selection bias and permitted to compare the results between the different intervention groups.

The design of a specific training task (GNG motor) and its implementation in the study is another strength. Despite not having found positive results, the task can be better adjusted for future interventions. Several possible benefit moderators have been discussed, and their adjustment in future works might be the key to designing acute bouts of exercise intervention with higher success rates on the IC improvement. The exhaustive study of factors like exercise intensity, length, feedback inclusion, the cognitive component, time of the day to perform the intervention, fitness level of the participants, or age, among others, might clarify the real possibilities of this kind of short-term exercise interventions.

As it was already mentioned, the use of several behavioral tasks in the IC assessment in the same sample of children is a strength. However, the implementation of other methods like imaging techniques such as EEGs and fMRI could have contributed to a better understanding of the non-observable changes that might be caused by acute bouts of exercise on the IC. Therefore, the non-inclusion of such evaluation techniques in the current study could be a limitation. Future works might complete the evaluation with such techniques which may be positive to understand the most immediate changes in the brain induced by this kind of exercise intervention.

5.3.6 Conclusions

Despite the amount of literature that confirmed to find benefits on EFs (including IC) after acute exercise interventions, some studies, like the current one, did not find such improvements. Despite the general lack of positive statistically significant results of the proposed exercise interventions on the IC of this sample of children and adolescents, the deep analysis of all of the study variables of each task, as well as the inclusion of three different intervention groups, made possible to compare the possibilities of differently designed exercise interventions.

The broadly demonstrated benefits that physical activity has on health promotion throughout life, situate this kind of occupation as an economic and reasonable health-promoting alternative to stimulate a change into a healthier lifestyle. Some of the advantages of the implementation of acute bouts of exercise are their length, their ecological design, their inclusion of common materials, and their positive impact on the general health of schoolers. These facts situate such interventions as good alternatives to be further studied. The existence of literature that demonstrated changes at a cognitive level caused by exercise interventions it was a revolutionary discovery that according to the facts should be deeper studied.

A combination of several benefit moderators (already mentioned in the discussion part) could be the cause of the lack of positive results in the current study. Future research should clarify the real impact of all of these moderators to be able to adjust them to reach optimal results with acute exercise interventions. To design short exercise interventions with high impact on cognitive capacities is a relevant issue not just for preventing future problems, but also as a tool to reconduct them when they are already present.

In any case, to achieve positive effects with acute physical activity in real-world settings appears to be more difficult than in laboratory settings (Jäger et al., 2015). However, more individualized interventions might be the key.

Chapter 6: **General discussion**

Inhibitory control and impulsivity are two domains that can conceptually be understood, at some points, as opposed poles of the same dimension (inhibition-disinhibition) (Bickel et al., 2012; Caswell et al., 2015). However, Study I results denoted the independence between these two constructs when analyzing the correlations between the study variables (Go/No-Go IES, Stroop INT, EMIC PIT and the ability to delay gratification).

Therefore, despite being possible to theoretically understand these two constructs as "antipodes" (Bickel et al., 2012), the components of the inhibitory control and the impulsivity constructs might demand different mechanisms. The nature of the assessment tasks designed for each component manifest this diverse requirement of mechanisms. When in a Go/No-Go task or a Stroop test only the cognitive domain is involved, the delay of gratification demands both, cognitive and emotional domains to maintain control (Bailey et al., 2018). Mischel (1974) also admitted that the delay of voluntary gratification involves a double process: the initial decision to delay the reward as well as the capacity to maintain that choice despite the temptations that may appear along the way.

The correlations found in the current study between response inhibition and interference control (inhibitory control components) support the theory of Friedman and Miyake (2004) that situates IC as a family of related functions, and the ability to actively maintain critical goal-related information as the main common mechanism between these two inhibitory components.

The lack of correlations disclosed in the current study between reflection impulsivity and the ability to delay a reward (impulsivity components) can be explained by the fact that the first component (reflection impulsivity) define a cognitive style (Kagan, 1965; Kagan & Kogan, 1970) that analyzes the personal way of giving an answer (accuracy and reaction times) when a visual stimuli is presented. Meanwhile, the ability to delay a reward implies, as it was previously mentioned, a response that corresponds to the top-down category (conscious and deliberate decision) (Diamond, 2009), and therefore might involves different mechanisms.

As deficits in the IC are related to several disorders and pathological conditions (Grandjean & Collette, 2011; Moffitt et al., 2011), most of the research on IC and impulsivity include children with pathologies. The current study was implemented in a scholar setting with children without any previous pathology. The results showed that the vast majority of participants presented a neutral cognitive style (58.8%). Nevertheless, 13.7% were impulsive inefficient, meaning that their personal tendency drives them to deliberate less than most people before acting, which in this task (EMIC) was resulting on bad outcomes. This kind of impulsivity was named by Dickman (1990) as dysfunctional impulsivity.

Conversely, the results of the delay of gratification task implemented in the current study (extracted from Wilson et al. (2009)), disclosed that only one participant was not able to wait, and that another participant was standing up from the chair (which was against the rules of the task) but was not opening the box. In the first case, the participant was not presenting any other “extreme” punctuation, but in the second case, the participant was presenting extreme ACC scores in both Go/No-Go and Stroop tasks, as well as high impulsivity scores in the EMIC test. In sum, the sample of participants was, in general, able to control their wishes and to delay gratification, regardless of their other impulsivity and inhibitory control scores. This data can be explained according to the demands and characteristics of each task.

Important score differences between participants were found in the results of the interference index of the Stroop test. In comparison with the results obtained by Golden (2001), Martín et al. (2012), and Rivera et al. (2017) for Spanish populations, the mean of the interference scores in the current study was notably higher (*M* = 16.89; *SD* = 7.46) (see Appendix, Table A5). As higher scores in the interference index indicate greater ability to inhibit interference (Barnhart & Buelow, 2017), the participants of the current sample appear to have a greater general inhibitory control than in the other three studies.

The Go/No-Go percentile results showed important participant differences, presenting a mean of *M* = 635.08, a standard deviation of *SD* = 77.10, and minimum/maximum scores of 477,96 and 840.79 respectively (Appendix, Table A5).

However, the lack of normative data available made not possible to associate the obtained results with previous studies.

The gender analysis showed no general significant differences in the performance of boys and girls. Only one variable, the Stroop accuracy level, showed significant differences between gender ($t(77.94) = -2.223$, $p = .029$), meaning that in this specific variable the boys of the sample committed significantly more mistakes than the girls. Still, the tendency of the results showed that, in general, boys had more mistakes and gave the answers faster than girls (Table 3). Previous findings already affirmed that male subjects as more likely than female to have problems related to a lack of inhibitory control and impulsivity (Byrnes et al., 1999; Moffitt et al., 2011). However, in the current study, this tendency of results was not statistically significant and, therefore, cannot be assumed to be caused by something different but chance.

In any case, the results of this first study emphasized the high variability existing between the participants in a normally developed sample of students as well as the possibility of detecting difficulties (or extremes scores) in the different impulsivity and IC components assessed. Each one of the participants seems to have their own personal tendency to answer (more or less quickly and more or less accurate) regardless of the nature of the task.

Once demonstrated the high variability inter subjects in a normally developed schoolers sample, Study II emerged with the aim to analyze the real possibilities that exercise interventions with a longitudinal design represent to ameliorate the inhibitory control in healthy students. To do it, a meta-analytical review was carried out.

The scientific literature search reported a total of 13 single studies that met the inclusion criteria. Eight of the 13 included studies (Aadland et al., 2019; L. Chaddock-Heyman et al., 2013; Hillman et al., 2014; Ludyga, Gerber, et al., 2018; Moreau et al., 2017; Pesce, Marchetti, et al., 2016; Pesce, Masci, et al., 2016; Zhao et al., 2015) revealed improvements in the inhibitory control after intervention in favor of the intervention group, while five studies (de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016) found no intervention effects on the IC after the intervention.

Two different statistical methods were implemented to calculate the effect size. A multilevel analysis and a traditional meta-analysis. The multilevel analysis results showed that the overall effect of the longitudinal exercise interventions on the IC of normally developed children and adolescents was not statistically significant ($d = 0.124$, 95% CI -0.072 to 0.321, $p = 0.201$). As the p-value was higher than 0.05, and the CI values crossed the null effect it is impossible to assume that the observed group difference is meaningful because the true group difference in the population could be zero (Field, 2009).

With the results obtained by the traditional effect size method calculation the situation was similar. None of the three effect size calculations: the single score effect size ($d = 0.21$, 95% CI -0.10 to 0.51, $p = 0.18$), the RT effect size ($d = -0.14$, 95% CI -0.44 to 0.16, $p = 0.37$), and the ACC effect size ($d = -0.01$, 95% CI -0.20 to 0.17, $p = 0.92$) were statistically significant because, again, the p-values were higher than 0.05, and the CI values crossed the null effect.

In sum, it can be concluded that the overall effect of the included interventions was not significant on the inhibitory control of the studied sample of children and adolescents according to both statistical procedures.

In spite of being the first meta-analysis specifically focused on the effects of longitudinal exercise interventions on inhibitory control, as the IC construct overlaps with cognitive and executive functioning, comparisons with other related studies are possible.

Xue et al. (2019) carried out a meta-analysis to analyze the effects of longitudinal exercise interventions on executive function among children and adolescents. Their results showed improvements in the overall EFs ($SMD = 0.20$, 95% CI 0.09 to 0.30, $p < 0.05$) as well as in the inhibitory control domain ($SMD = 0.26$, 95% CI 0.08 to 0.45, $p < 0.05$). Though, Verburgh et al. (2013), in a similar line to our current work, did not find such overall benefits of longitudinal exercise interventions on EFs ($d = 0.14$, 95% CI -0.04 to 0.32, $p = 0.19$).

It should be noted that most of the exercise interventions of the single studies included in the current meta-analysis were aiming to cause benefits in the general EF domain. The only intervention specifically designed to train the inhibitory control belongs to the study of Zhao et al. (2015). According to the results of the analysis, this activity was also the one that reported higher benefits in the inhibitory control of the participants in comparison with the rest of the interventions. It should be also emphasized that this intervention was the shortest (20 minutes per day for 7 days) of the included in the meta-analysis.

One of the most implemented exercise interventions in the last decades was aerobic exercise. According to P. J. Smith et al. (2010), this kind of exercise training produce improvements in the executive functions ($g = 0.123$, 95% CI 0.021 to 0.225, $p = 0.018$). However, a recent commentary (Diamond & Ling, 2019) situated aerobic exercise and resistance training as the two less effective activities to improve executive functions.

Other kind of exercise that have cached the attention of researchers have been the acute exercise interventions. The benefits of these short-based interventions have been studied on different populations. Verburgh et al. (2013) showed a medium effect size ($d = 0.46$, 95% CI 0.33 to 0.60, $p < 0.001$) after acute exercise interventions on executive functions. In a similar line, Wilke et al. (2019) showed positive results on the inhibitory control of healthy adults after single bouts of resistance exercise (*SMD* = 0.73, 95% CI 0.21 to 1.26, $p = 0.01$), and Chang et al. (2012), found an overall positive but small effect of acute exercise interventions on cognitive performance in their study covering all range of ages ($g = 0.097$). Kelly et al. (2014) analyzed the impact of aerobic exercise, resistance training, and Tai Chi on the cognitive functioning of healthy older adults and found significant improvements several domains like reasoning, attention, and processing speed in the intervention groups in comparison with controls (no attending exercise training).

Nonetheless, there are also studies that found no benefits on the IC (and other EFs) after physical activity and exercise interventions (de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016). A recent panel of experts (Singh et al., 2018), affirmed that there is nonconclusive evidence for the beneficial effects of physical activity interventions on cognitive performance, and determined that more high-quality research is needed to clarify the doubts of the field.

Study III emerged to assess the immediate effects that different acute exercise intervention designs can have, specifically, in the inhibitory control of a sample of normally developed schoolers. This study included a new designed (Go/No-Go motor task) that was based on a traditional Go/No-Go task and included three theoretically relevant components to improve inhibitory control: a novel game-based design, a goal-directed objective (high IC demand), and a high motoric component (Dowsett & Livesey, 2000; Zhao et al., 2015). The other two intervention groups included an aerobic intervention or an active control group activity (reading and writing). All three interventions had the same length (10 minutes).

The three groups of intervention did not differ significantly in their demographic characteristics, neither in the heart rates during intervention (groups including exercise). The design of the exercise interventions included a moderate intensity (heart rate between

60% and 70% of the VO_2 max). This intensity was selected due to the previous literature that confirmed to find the peak of benefits at a cognitive level while training at this heart rate (Chang et al., 2015; Chang et al., 2011; Chang & Etnier, 2009; A. G. Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009).

Three different variables were analyzed in the pre-test and the post-test: reaction times, accuracy, and single combined scores. The interaction effect (time x intervention) was only statistically significant in the Stroop interference index (single combined score) ($F(2,56) = 3.511$, $p = 0.037$, $\eta_p^2 = 0.111$). This meant that there were significant differences between the pre and post-intervention results, in relation with the three intervention groups. The post hoc analysis showed that the Stroop interference index results suffered a decrease after the two exercise interventions, while in the control group the interference index increased in comparison with the pre-test results. As a higher interference index means a better capacity to control interferences, it has to be admitted that after the two exercise interventions, the participants of the sample were less able to control interferences. However, this decrease was only statistically significant in the aerobic group.

As the rest of the interaction effects were not statistically significant, it cannot be assumed that any of the interventions have caused a significant change in the inhibitory control capacity of the participants that participated in the different intervention groups.

When the effect time was analyzed, two tasks showed statistically significant changes in the RTs results. The GNG task ($F(1,56) = 5.300$, $p = 0.025$, $\eta_p^2 = 0.086$), and the Flanker task ($F(1,56) = 31.332$, $p = 0.001$, $\eta_p^2 = 0.359$). These results showed that the participants were, on average, significantly faster (shorter RTs) during the post-test than in the pre-test in these two tasks.

In the ACC analysis only the time factor of the GNG task was statistically significantly higher at the post-test than at the beginning of the study (pre-test), meaning that significantly more mistakes were committed after the interventions than before (main effect time $F(1,56) = 4.381$, $p = 0.041$, $\eta_p^2 = 0.073$).

In a similar line, the time factor was significant in the Flanker task IES, where the IES values of this task were statistically significantly lower at the post-test measurement than at the beginning of the study (main effect time $F(1,56) = 13.440$, $p = 0.001$, $\eta_p^2 = 0.196$), meaning that the three groups had a better inhibitory capacity in the flanker task after interventions, being this capacity significant in the GNG motor group ($p = 0.040$) and the control group ($p = 0.010$) but not in the aerobic intervention group ($p = 0.120$).

However, in any of the three cases the changes can be assumed to happen because of the different group interventions due to the lack of statistically significant differences in the results of the three groups among each other.

As a summary, no significant differences between group interventions were found in the general performance of the tasks. Consequently, any of the exercise interventions proposed can be assumed to have caused benefits in the IC of this sample of children, or at least, non-observable benefits. Moreover, the significant effect time results that were found in the RTs of the Go/No-Go and the Flanker task (showing that participants gave the answers faster after the interventions than before) might have been the cause of the decrease of their accuracy levels (like in the analysis of the ACC results of the Go/No-Go task).

Due to the amount of studies that affirmed to find positive results in the inhibitory control (or any other executive function) in normally developed samples from pre-kindergarteners to adolescents after acute exercise interventions (Chang et al., 2012; A. G. Chen et al., 2014; Chu et al., 2015; Hillman et al., 2009; Jäger et al., 2014; O'Leary et al., 2011; Peruyero et al., 2017; Röthlisberger et al., 2012; Verburgh et al., 2013) , the current non-significant results were not expected. However, there are also some studies that, in the same line as our study, did not find such benefits at a cognitive level after acute exercise interventions (Jäger et al., 2015; Stein et al., 2017; Stroth et al., 2009), nevertheless, they are a minority.

The fact that most of the literature that studied the effects of single bouts of exercise interventions on the EFs have found positive results, might be explained by a possible publication bias. As it was affirmed by several authors, it was proven that studies with statistically significant results were more likely to be published than those that did not find such significant differences (Dickersin et al., 1987; Easterbrook et al., 1991).

In any case, due to the large interindividual differences in personal and physical qualities, it cannot be expected to achieve the same outcomes from the same exercise intervention in different participants (Chang et al., 2012). Future investigations should be focused on designing goal-directed and more individualizable interventions, having into account several benefit moderators that can have an impact in the outcomes. The intensity and the length of the intervention, the fitness level of the participants, the age of the sample, the cognitive component of the intervention, the time of day when the intervention happened, the setting where it is performed, or the feedback application (among others) might have an influence in the final outcomes of the exercise interventions on the IC and other EFs ((Best, 2010; Budde, Wegner, et al., 2016; Chang et al., 2012; Diamond, 2015); Gronwald et al. (2018); (Jäger et al., 2015; Keith & Frese, 2005; Leidinger & Perels, 2012), .

Chapter 7: **General conclusions**

- It is possible to conceptually understand inhibitory control and impulsivity as opposed poles of the same dimension (inhibition-disinhibition), however, the tasks to assess each one of the components of these two constructs varied in their nature and, therefore, require the involvement of different cognitive processes, and different level of voluntary control.
- Response inhibition and interference control (inhibitory control components) showed correlations, which mean the existence of underlying common connections between them.
- No correlations were found between the components of impulsivity (reflexivity-impulsivity and temporal impulsivity), nor of these with the components of inhibitory

control, which highlights the independence between the two constructs (inhibitory control and impulsivity) when analyzing the established study variables.

- When accuracy and response time variables were analyzed, strong differences were found in the individual tendency of the participants to give an answer or to behave.
- In sum, independently of how each component was evaluated (the stablished formula), the response tendency of each participant (more or less fast and accurate) seems to remain unchanged in a normally developed schoolers sample.
- According to previous literature, the implementation of physical exercise interventions with both, longitudinal and acute designs, could produce changes in the inhibitory control as well as in the rest of executive functions.
- The results obtained in the meta-analysis performed (Study II) did not show statistically significant benefits in the inhibitory control of children and adolescents with normal development after their participation in exercise interventions with a longitudinal design.
- As most of the exercise interventions included in the single studies were focused in the general objective of causing benefits on the EFs, the lack of design specificity to produce changes on the IC might be the cause for the nonexistence of significant results.
- In the acute exercise intervention proposed in this work (Study III), none of the proposed exercise intervention designs have obtained significant statistical benefits in the inhibitory control.
- Despite having designed a specific task to explicitly train the demand for inhibitory control, the results of this intervention have not obtained statistically significant differences compared with the other two intervention designs.

- None of the intervention groups with exercise have shown statistically significant differences compared to the control group in their inhibitory control results assessed immediately after the intervention.

7.1 Future research directions

- The lack of normative data should be addressed to facilitate the detection of problems and deficits, which will accelerate the process of preventing related future problems.
- To avoid misunderstandings, IC components should be better differentiated, and the results of the studies should always specify the exact IC component assessed, instead of extrapolating the results to the general IC construct.
- Within the field of psychology, there are several inhibitory control techniques available to nurture more conscious and less automatic behaviors (like the immediate feedback application (Keith & Frese, 2005; Leidinger & Perels, 2012)). However, to implement such techniques, the components that cause a lack of control have to be previously detected. Future interventions have to be directed to these specific components that are failing.
- Several benefit moderators (intensity, duration, the cognitive component, etc.) should be further studied and better adjusted to design future exercise interventions that may cause greater benefits in the inhibitory control and other executive functions.
- The inclusion of other evaluation methods (such as neuroimaging techniques) could complement the results obtained through behavioral tasks.

Chapter 8: **References**

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Chapter 9: **Appendix**

Figure A1. Central nervous system. Adapted from Kandel et al. (2013)

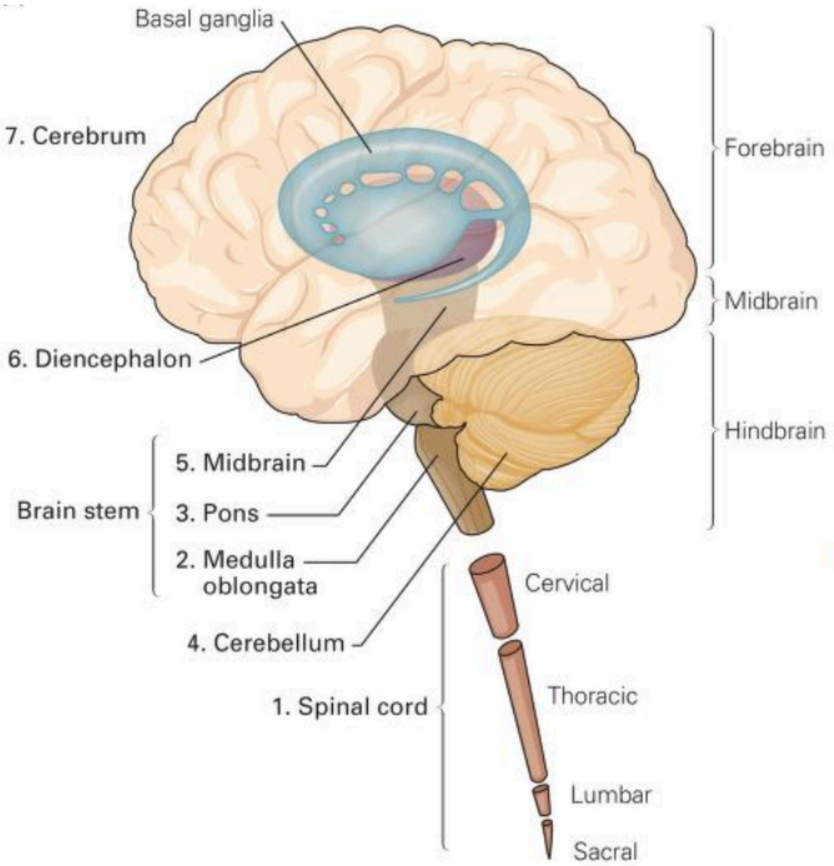


Figure A2. Lobes and areas of the left cerebral hemisphere. Adapted from S. I. Fox (2010)

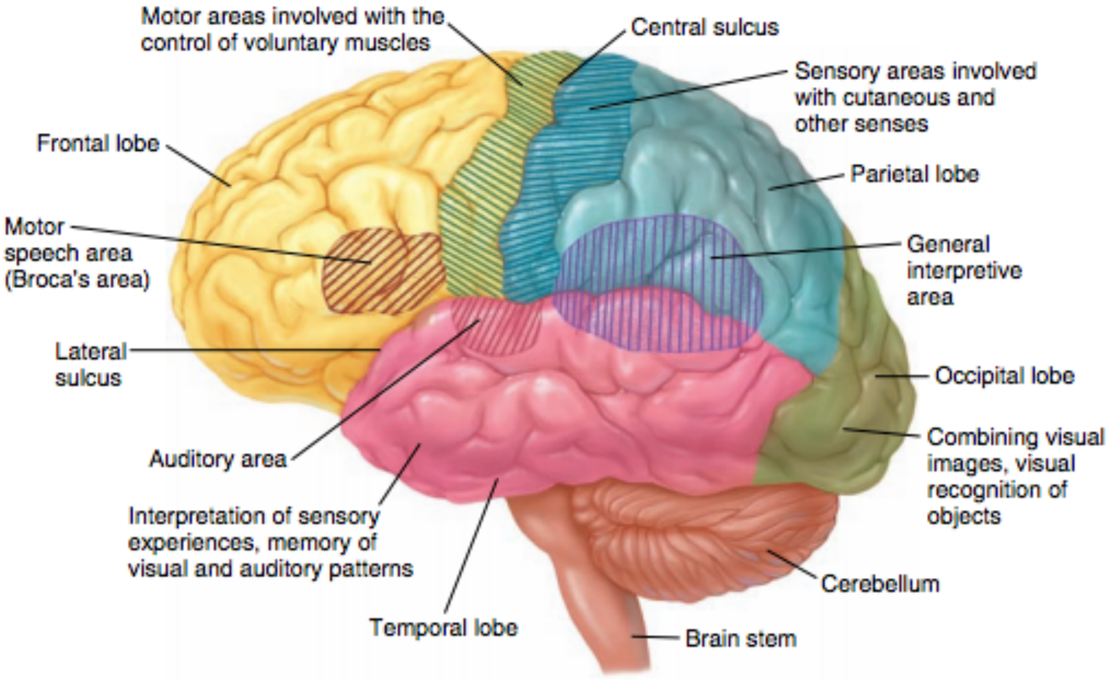
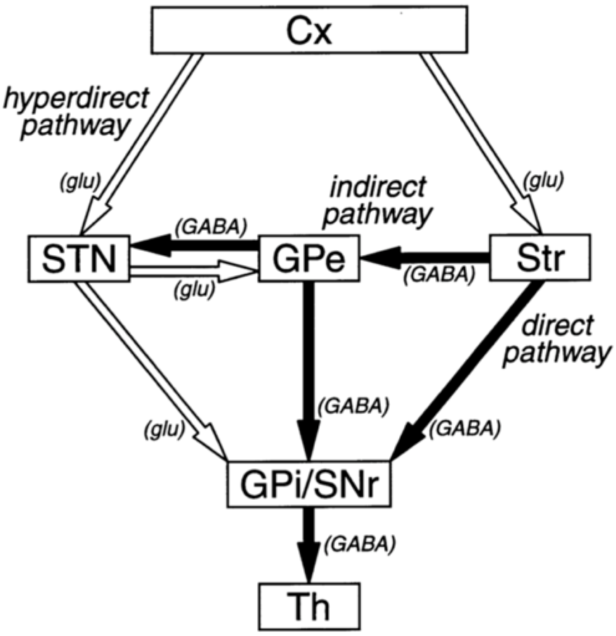


Figure A3. Schematic diagram of the cortico-STN-GPi/SNr "hyperdirect" pathway, cortico-striato-GPi/SNr ‘direct’ pathway, and cortico-striato-GPe-STN-GPi/SNr ‘indirect’ pathway. Adapted from Nambu et al. (2002)



Figures A4.1 and A4.2

Figure A4.1. Go/No-Go IES values box-plot

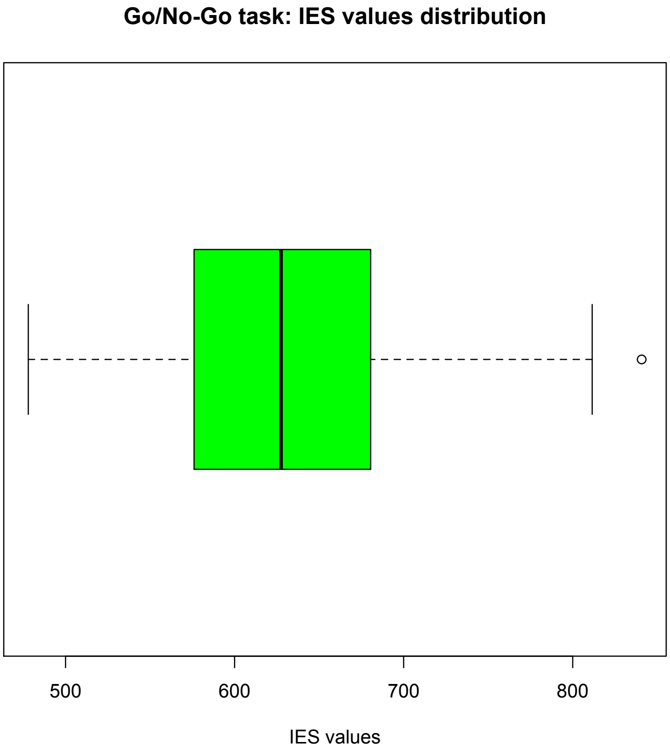


Figure A4.2. Stroop INT values box-plot

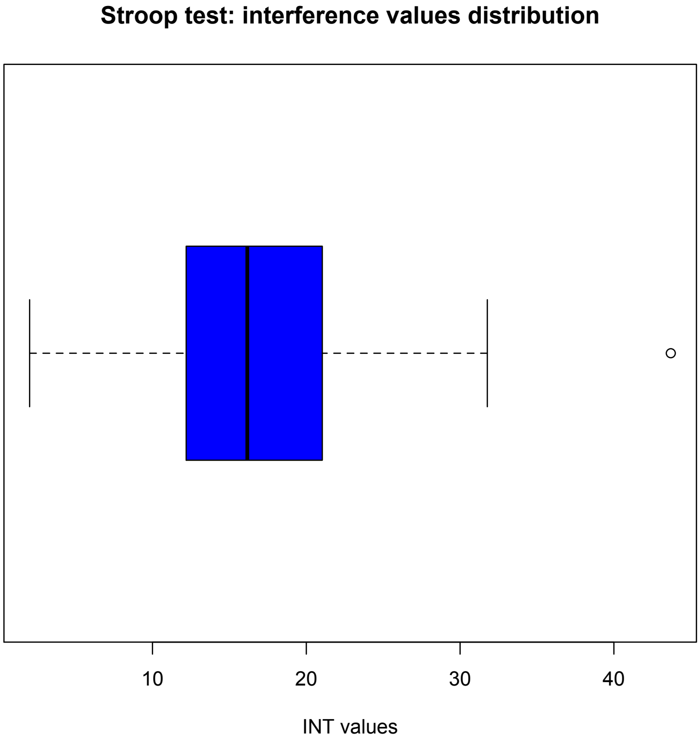


Table A5. Descriptive statistics (mean, standard deviation, minimum, and maximum) of all variables[1]

	EMIC PIT	GNG IES	STROOP I	EMIC ACC	GNG ACC	STROOP ACC	EMIC RTs	GNG RTs	STROOP RTs
M	54.46	635.08	16.89	12.94	5.41	10.47	10059.40	605.01	909.30
SD	17.39	77.10	7.46	6.83	6.32	11.07	5451.84	71.37	159.36
Min.	-12.00	477.96	2.01	1.00	1.00	1.00	2718.00	437.19	515.14
Max.	110.00	840.08	43.70	44.00	51.00	81.00	38446.00	770.72	1326.86

Note. [1]Variables defined on the methods part.

Table A6. Search terms used for each database

Sources	Search strategy
PubMed	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)
PsycINFO	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)
Medline	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)
Eric	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)
SPORTDiscuss	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)
PsycARTICLES	(exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)

Table A7. Excluded articles and reasons

	Study	Reason for exclusion
1	Aadland et al, 2017	Same data set of an already included study
2	Alesi et al, 2016	No RCT
3	Alesi et al, 2014	No exercise intervention
4	Álvarez-Bueno et al, 2017	Systematic review and meta-analysis
5	Benzing et al, 2019	No exercise intervention
6	Bervoets et al, 2018	Protocol / no results
7	Castelli et al, 2011	No control group
8	Chang Y. K. et al., 2013	No RCT and no control group
9	Cho et al, 2017	No focused in inhibitory control / no inhibitory control assessment
10	Cho et al, 2017a	No focused in inhibitory control / no inhibitory control assessment
11	Costigan et al, 2016	No focused in inhibitory control / no inhibitory control assessment
12	Dalziell et al, 2015	Protocol / no results
13	de Greeff et al, 2018	Meta-analysis
14	Domazet et al, 2016	Cross-sectional
15	Drollette et al, 2018	Same data set of an already included study
16	Egger et al, 2019	No control group
17	Emerson et al, 2017	No RCT and no control group
18	Fisher et al, 2011	No focused in inhibitory control / no inhibitory control assessment
19	Friedrich et al, 2019	Age group
20	Goodwil et al, 2012	Age group
21	Graham et al, 2018	Out of topic
22	Hillman et al, 2009	Cross-sectional
23	Hillman et al, 2011	Review
24	Ishihara & Mizuno, 2018	No RCT
25	Ishihara et al, 2018	Cross-sectional
26	Ishihara et al, 2017	Cross-sectional
27	Ishihara et al, 2017a	Single bouts of exercise
28	Ishihara et al, 2017b	Cross-sectional
29	Jarraya et al, 2019	No focused in inhibitory control / no inhibitory control assessment
30	Kamijo et al, 2011	No focused in inhibitory control / no inhibitory control assessment
31	Kamijo, 2016	Out of topic
32	Karch et al, 2013	Review
33	Keeley and Fox, 2009	Review
34	Konijnenberg and Fredriksen, 2018	No RCT
35	Lakes and Hoyt, 2004	Out of topic
36	Leahy et al, 2019	Protocol / no results
37	Lees and Hopkins, 2013	Systematic review
38	Lind et al, 2018	No focused in inhibitory control / no inhibitory control assessment

39	Lo et al, 2019- -	No focused in inhibitory control / no inhibitory control assessment
40	Lubans et al, 2016	Systematic review
41	Ludyga et al, 2018a	Single bouts of exercise
42	Ludyga et al, 2019a	Same data set of an already included study and out of topic
43	Mazzoli et al, 2019	Cross-sectional
44	Niemann et al, 2013	Single bouts of exercise
45	Pietsch et al, 2017	Out of topic
46	Pontifex et al, 2011	Cross-sectional
47	Razza et al, 2015	No exercise intervention
48	Sanchez-Lopez et al, 2019	Protocol / no results
49	Sánchez-López et al, 2019a	No focused in inhibitory control / no inhibitory control assessment
50	Santner et al, 2018	Protocol / no results and no inhibitory control assessment
51	Singh et al, 2018	Review
52	Staiano et al, 2012	No exercise intervention and wrong population
53	Subramanian et al, 2015	No focused in inhibitory control / no inhibitory control assessment
54	Takehara et al, 2019	Protocol / no results
55	Torbeyns et al, 2017	No exercise intervention
56	Traverso et al, 2015	No exercise intervention
57	van der Niet et al, 2015	Cross-sectional
58	Van der Niet and Smith 2016	No RCT
59	Vandenbroucke et al, 2016	No exercise intervention
60	Verburgh et al, 2016	Cross-sectional
61	Walk et al, 2018	No exercise intervention
62	Wang et al, 2013	Age group
63	Wassenaar et al, 2019	Protocol / no results
64	Wick et al, 2018	No exercise intervention
65	Wickel, 2016	Cross-sectional
66	Wimmer et al, 2016	No exercise intervention
67	Wirt et al, 2015	Cross-sectional
68	Wright et al, 2016	Protocol / no results
69	Xue et al, 2019	Systematic review and meta-analysis
70	Zenner et al, 2014	Systematic review and meta-analysis
71	Zhang et al, 2015	Age group
72	Zinke et al, 2012	Single bouts of exercise
73	Zoghi et al, 2016	Out of topic

Summary A8. Results of individual studies

Aadland et al. (2019) found no significant effect of their implemented intervention (S. M. Fox et al.) on executive functions in their intention-to-treat analyses. However, due to the participation of control schools in more physical activity than agreed, another analysis (per protocol) were considered to study the results. In this case, statistically significant intervention effects were found on the composite score of executive functions and cognitive flexibility. Aadland et al. (2019) concluded that cognitively engaging and coordinative demanding activities/games seems to be feasible alternatives to increase executive functions and to improve academic performance.

L. Chaddock-Heyman et al. (2013) applied the Fitness Improves Thinking in Kids program (FIT Kids) to evaluate how the improvement of aerobic fitness influences performance on a task of cognitive control as well as the brain function associated with cognitive control. They included the resonance imaging (fMRI) technique to examine those influences. The results showed decreases in fMRI brain activity in the right anterior prefrontal cortex, which was connected with improvements in both attention and interference control. The control group did not show such variations. Task performance improvements were found in all participants after their nine months of intervention. Although the initial analyses (group x condition x time interaction) did not show significance for RT or ACC, further analyses found a tendency of displaying increased ACC and shorter RT in the intervention group in incongruent trials.

de Greeff et al. (2016) aimed to investigate the effects of physically active academic lessons on executive functions, among other domains. Positive results were found in speed-coordination and static strength, but significant benefits in executive functions were not found after the participation in their physically active academic lessons.

Hillman et al. (2014) also included the FIT Kids program as intervention. Their objective was to assess the effect of a PA intervention on brain and behavioral indices of executive control in preadolescent children. ACC was increased in both groups, with a greater improvement in the intervention group between pre- and post-test. However, RT showed no influence of group assignment.

Kvalo et al. (2017) explored whether increased physical activity in school had benefits on executive functions and aerobic fitness. Results did not find were significant effects on executive functions, including inhibitory control. However, a tendency for a time × group interaction on these functions was noticed by the authors. Consequently, they concluded that increased physical activity in school may benefit executive functions, but a longer intervention might be necessary to find significant effects.

Ludyga, Gerber, et al. (2018) discovered improvements in both behavioral and neurophysiological indices of inhibitory control after eight weeks of regular engagement in structured exercise. Regarding the behavioral performance in the Stroop task, decreased reaction times were found. However, accuracy remained unaltered. This fact was explained by the authors, with a possible ceiling effect due to the high ratio of correct responses of the participants in the pre-test (90%).

Ludyga et al. (2019), did not find significant differences between groups in the performance on the Flanker task (RT and ACC). Only an increase of ACC was reported after the intervention period but without between groups differences. Changes in P300 (an event related potential (ERP) involved in the process of decision making that permits the examination of inhibitory mechanisms) between pre- and post-test evaluations were not different between groups. Hence, no benefits in the IC were observed in this study following the exercise interventions.

Moreau et al. (2017) found improvements on cognitive control (inhibitory control) after a 6-week HIT intervention. These authors proposed that this kind of brief but potent exercise intervention might be a promising alternative to improve cognition. They also found positive benefits on working memory.

Pesce, Marchetti, et al. (2016) found benefits after the implementation of the life skills program inhibitory control in comparison with the control group. Aerobic fitness and sport passing skills were also improved. Consequently, they assume that the life skills training program, implemented in a sport education context, is beneficial for both the cognitive dimension of mental health and the fitness dimension of physical health.

Pesce, Masci, et al. (2016) affirmed to find a differential effect of intervention type on children´s inhibition with higher post-intervention values for the enriched physical education lessons than for the traditional physical education type. The enriched PE intervention also showed further improvements in all motor coordination assessments (manual dexterity, ball skills, static/dynamic balance). These authors concluded that specially personalized physical activity games offer an exceptional form of enrichment that impacts on the cognitive development through motor coordination improvements, particularly object control skills, among others.

Schmidt et al. (2015) aimed to investigate the effects of two qualitatively different longitudinal physical activity interventions on executive functions in primary school children. The results showed no effects on inhibition and updating. However, shifting performance increased in the team games intervention. According to their general results, authors concluded that the inclusion of cognitive engagement in physical activity seems to be the most promising type of longitudinal intervention to enhance executive functions in children.

Tarp et al. (2016) had the objective of describing the effectiveness of a school-based physical activity intervention in enhancing cognitive performance in adolescents. Results showed no benefits after intervention in inhibitory control. Besides, contrary to the authors predictions, an appreciably greater change in the interference score of the reaction time was found in favor of the control group (5.0 milliseconds (95% CI: 0 - 9). Thus, authors declared not to find evidence for the effectiveness of their 20-week multi-faceted school-based physical activity intervention for enhancing executive functioning compared to a control group even having positive results of the intervention in cardiorespiratory fitness in girls and BMI in boys.

Zhao et al. (2015) achieved significant improvements in the response inhibition ability of the participants training with an inhibitory game (“Wesley says”). The Stroop task performance analysis showed that the training intervention group performed significantly faster (shorter RT) than the control group on incongruent, congruent, and neutral trials after intervention. Moreover, this group also showed higher ACC on incongruent trials. Regarding the Go/No-Go performance, the intervention group reached a reduction in both commission and omission mistakes (the former related to inhibitory processes or impulsivity; the latter reflecting inattention symptoms) after intervention.

Supplementary information A9. Multilevel analysis accounting for dependency of effect sizes

Results of a three-level analysis:

- Level 1: sampling variance
- Level 2: variance within studies
- Level 3: variance between studies

Considering the results of this model, the general meta-analysis results are the following:

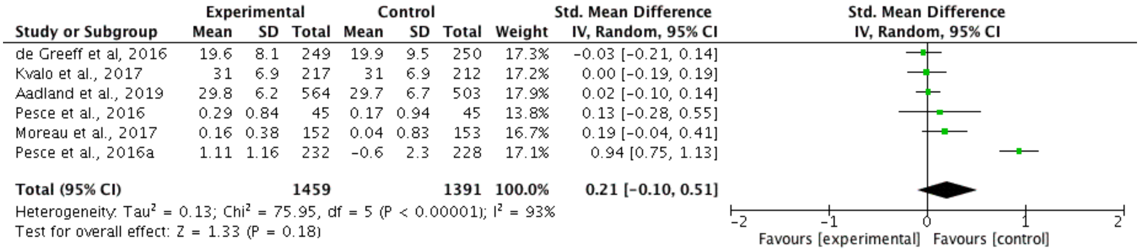
```
Multivariate Meta-Analysis Model (k = 20; method: REML)

 logLik   Deviance     AIC       BIC       AICc
 -9.996   19.992     25.992    28.825    27.592

Variance Components:

              estim      sqrt    nlvls   fixed       factor
sigma^2.1    0.016*     0.127     20      no      effectsizeID
sigma^2.2    0.076**     0.275     13      no         studyID

* variance within studies
** variance between studies

Test for Heterogeneity:
Q(df = 19) = 107.165, p-val < .001

Model Results:

estimate    se        tval     pval      ci.lb      ci.ub
0.124      0.094    1.326    0.201     -0.072     0.321
```

With these results, it can be concluded that the overall effect is 0.124 (Cohen's *d*), with a standard error of 0.094. However, this overall effect is non-significant (*t* (19) = 1.326, *p* = 0.201) and the interval confidence (IC) is -0.072 to 0.321. The IC ranges from an almost null effect to a small effect size.

According to Cohen's criteria (J. Cohen, 1992), who established that effect sizes starting from 0.20 are small, 0.50 are medium, and 0.80 are large the overall effect of 0.124 have to be regarded as below small - very small.

Supplementary information A10. Results of the traditional meta-analysis calculations (forest plots and combined funnel plot)

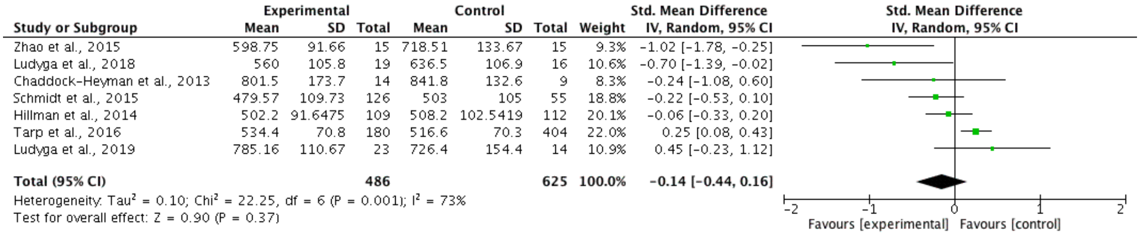
a. Single scores forest plot:



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
de Greeff et al, 2016	19.6	8.1	249	19.9	9.5	250	17.3%	-0.03 [-0.21, 0.14]
Kvalo et al., 2017	31	6.9	217	31	6.9	212	17.2%	0.00 [-0.19, 0.19]
Aadland et al., 2019	29.8	6.2	564	29.7	6.7	503	17.9%	0.02 [-0.10, 0.14]
Pesce et al., 2016	0.29	0.84	45	0.17	0.94	45	13.8%	0.13 [-0.28, 0.55]
Moreau et al., 2017	0.16	0.38	152	0.04	0.83	153	16.7%	0.19 [-0.04, 0.41]
Pesce et al., 2016a	1.11	1.16	232	-0.6	2.3	228	17.1%	0.94 [0.75, 1.13]
Total (95% CI)			**1459**			**1391**	**100.0%**	**0.21 [-0.10, 0.51]**

Heterogeneity: $\text{Tau}^2 = 0.13$; $\text{Chi}^2 = 75.95$, df = 5 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 1.33 (P = 0.18)

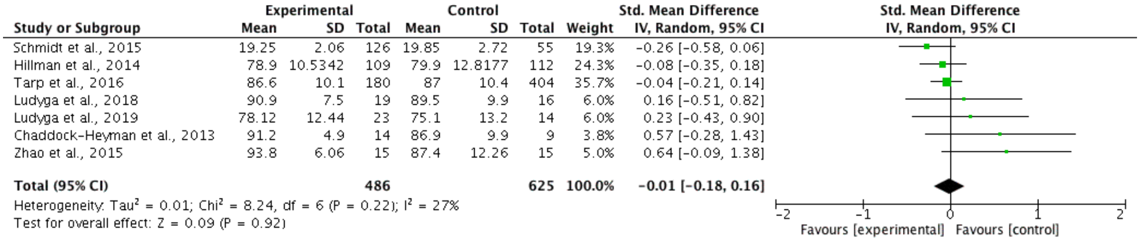
b. Reaction times forest plot:



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Zhao et al., 2015	598.75	91.66	15	718.51	133.67	15	9.3%	-1.02 [-1.78, -0.25]
Ludyga et al., 2018	560	105.8	19	636.5	106.9	16	10.6%	-0.70 [-1.39, -0.02]
Chaddock-Heyman et al., 2013	801.5	173.7	14	841.8	132.6	9	8.3%	-0.24 [-1.08, 0.60]
Schmidt et al., 2015	479.57	109.73	126	503	105	55	18.8%	-0.22 [-0.53, 0.10]
Hillman et al., 2014	502.2	91.6475	109	508.2	102.5419	112	20.1%	-0.06 [-0.33, 0.20]
Tarp et al., 2016	534.4	70.8	180	516.6	70.3	404	22.0%	0.25 [0.08, 0.43]
Ludyga et al., 2019	785.16	110.67	23	726.4	154.4	14	10.9%	0.45 [-0.23, 1.12]
Total (95% CI)			**486**			**625**	**100.0%**	**-0.14 [-0.44, 0.16]**

Heterogeneity: $\text{Tau}^2 = 0.10$; $\text{Chi}^2 = 22.25$, df = 6 ($P = 0.001$); $I^2 = 73\%$
Test for overall effect: Z = 0.90 (P = 0.37)

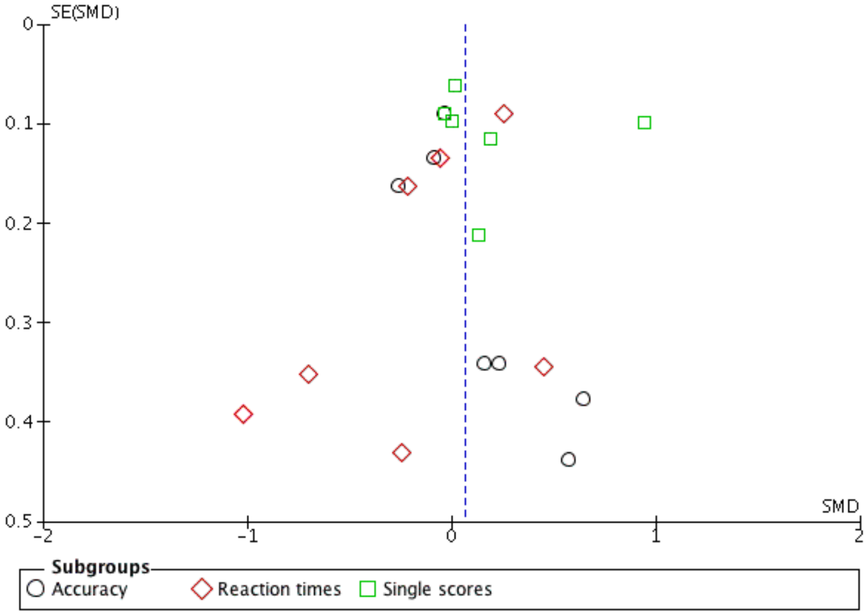
c. Accuracy forest plot:



Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Schmidt et al., 2015	19.25	2.06	126	19.85	2.72	55	19.3%	-0.26 [-0.58, 0.06]
Hillman et al., 2014	78.9	10.5342	109	79.9	12.8177	112	24.3%	-0.08 [-0.35, 0.18]
Tarp et al., 2016	86.6	10.1	180	87	10.4	404	35.7%	-0.04 [-0.21, 0.14]
Ludyga et al., 2018	90.9	7.5	19	89.5	9.9	16	6.0%	0.16 [-0.51, 0.82]
Ludyga et al., 2019	78.12	12.44	23	75.1	13.2	14	6.0%	0.23 [-0.43, 0.90]
Chaddock-Heyman et al., 2013	91.2	4.9	14	86.9	9.9	9	3.8%	0.57 [-0.28, 1.43]
Zhao et al., 2015	93.8	6.06	15	87.4	12.26	15	5.0%	0.64 [-0.09, 1.38]
Total (95% CI)			**486**			**625**	**100.0%**	**-0.01 [-0.18, 0.16]**

Heterogeneity: $\text{Tau}^2 = 0.01$; $\text{Chi}^2 = 8.24$, df = 6 ($P = 0.22$); $I^2 = 27\%$
Test for overall effect: Z = 0.09 (P = 0.92)

d. Combined funnel plot:



Note. SMD = Standard mean differences; SE = Standard error

Spanish summary A11. Resumen en castellano

El control inhibitorio es un componente central de las funciones ejecutivas, que juega un papel fundamental en la organización de varios procesos mentales para generar comportamientos dirigidos a objetivos específicos (Browne et al., 2016; Bugos & DeMarie, 2017; Diamond, 2013; Liu et al., 2015).

Las funciones ejecutivas son consideradas funciones cognitivas de orden superior. Estas funciones forman parte de un constructo multidimensional que tiene un papel indispensable en la gestión de las emociones, la atención, la memoria, y la regulación de comportamientos, y nos permiten controlar y autorregular nuestra propia conducta (Filippetti & Richaud de Minzi, 2012; Guillén, 2017; Miyake et al., 2000).

Para entender la estructura de estas funciones, Guillén (2017) sugirió pensar en un sistema de gestión que controla toda la información de nuestro cerebro. Este sistema es el encargado de facilitar un rendimiento eficiente en diferentes tareas y situaciones, basado en toda la información disponible hasta el momento.

La mayoría de los investigadores asumen la existencia de tres funciones ejecutivas principales: el control inhibitorio, la memoria de trabajo y la flexibilidad cognitiva (Alesi et al., 2016; Diamond, 2013).

De acuerdo con Barkley (1997), el control inhibitorio es clave dentro de las funciones ejecutivas, porque un déficit en este dominio puede causar un efecto cascada en el resto de funciones. Este hecho sitúa al control inhibitorio como una capacidad esencial para el correcto desarrollo del resto de funciones ejecutivas, así como de los procesos superiores que necesitan el trabajo conjunto de dichas funciones (comportamientos, pensamientos o emociones).

El control inhibitorio gobierna la capacidad de inhibir respuestas prepotentes (dominantes o más automatizadas), en favor de otra respuesta o en favor de la ausencia de respuestas (Alesi et al., 2016; Wu et al., 2011), y la capacidad para resistir interferencias (distracciones o hábitos) para mantener el foco en el objetivo primario cuando la situación lo requiere (Hillman et al., 2014; Nigg, 2000; Schmidt et al., 2015). Es por ello que control inhibitorio es entendido como una familia de funciones diferentes pero relacionadas, que gobiernan procesos diferentes pero interrelacionados (Friedman & Miyake, 2004).

El córtex prefrontal parece ser la “torre de control” no sólo del control inhibitorio, sino también de la memoria de trabajo y de la flexibilidad cognitiva. Sin embargo, el control inhibitorio es posible no solo gracias al córtex prefrontal, sino también a todas las complejas conexiones que éste establece con diferentes regiones corticales y subcorticales (ganglios basales, tálamo, e ínsula entre otras) (Forstmann & Alkemade, 2017).

El desarrollo de nuevas técnicas de imagen como la Imagen por Resonancia Magnética Funcional (fMRI en sus siglas en inglés), o la Electroencefalografía (EEG) que permiten, respectivamente, mostrar en imágenes las regiones cerebrales activadas y registrar la actividad bioeléctrica cerebral, han permitido delimitar mejor las estructuras cerebrales activadas en tareas que requieren control inhibitorio. No obstante, Forstmann and Alkemade (2017) advirtieron de la necesidad de más investigación debido a que las técnicas de neuroimagen disponibles podrían no detectar todas las pequeñas estructuras que contribuyen en los complejos procesos de inhibición.

Es sabido que un buen control inhibitorio favorece el éxito en procesos relacionados con el pensamiento y el aprendizaje, con la salud física y mental, con el desarrollo cognitivo, el éxito académico, la competencia social, y el funcionamiento psicológico general (Benson et al., 2012; Blair & Razza, 2007; Browne et al., 2016; X. Chen et al., 2009).

En contraposición, un déficit en el control inhibitorio nos deja a la merced de nuestros impulsos internos, de nuestras respuestas automáticas y de la influencia de los estímulos que nos rodean (Diamond, 2013). La presencia de problemas en el control inhibitorio se ha relacionado con desórdenes de alto impacto a nivel social, como desórdenes alimenticios, abuso de sustancias, problemas académicos, comportamientos antisociales, Trastorno por Déficit de Atención con Hiperactividad (TDAH), esquizofrenia, etc. (Alderson et al., 2007; Alesi et al., 2016; Brocki et al., 2007; Chamorro et al., 2012; X. Chen et al., 2009; Grandjean & Collette, 2011; Houben & Wiers, 2009; Jasinska et al., 2012; Raust et al., 2007; Young et al., 2009; P. D. Zelazo & Carlson, 2012). Además, varios autores han apuntado a que la impulsividad podría estar causada por una falta de control inhibitorio (Enticott et al., 2006; Jasinska et al., 2012; Lawrence et al., 2009; Logan et al., 1997; Perales et al., 2009).

Sin embargo, en los últimos años se han estudiado numerosas alternativas de intervención para entrenar el control inhibitorio. De todas las posibilidades de intervención cabe destacar, dado su extendido uso, los programas de entrenamiento con ordenador, intervenciones musicales, entrenamiento con sesiones de mindfulness, yoga o artes marciales, intervenciones individuales de ejercicio físico (agudas) e intervenciones de ejercicio físico con un diseño longitudinal.

En el presente trabajo, tras la introducción teórica del control inhibitorio, y el análisis del estado del arte en el que se subrayan cuestiones como las principales líneas de investigación relacionadas con el control inhibitorio, los diferentes tipos de intervención utilizados para su entrenamiento, la falta de datos normativos para la detección de déficits mediante diferentes tareas comportamentales, y su estudio llevado a cabo principalmente dentro del conjunto de las funciones ejecutivas, se han presentado tres estudios.

Los estudios se han diseñado con el fin de clarificar varios aspectos teóricos relativos al control inhibitorio. Además de favorecer un mejor conocimiento del constructo y de su relación con la impulsividad, se han estudiado las posibilidades reales que suponen diferentes tipos de intervención con ejercicio físico (intervenciones agudas de ejercicio físico, y estudios longitudinales con intervenciones de ejercicio físico) para la mejora del control inhibitorio en muestras con un desarrollo normal (sin ningún tipo de desorden previamente diagnosticado).

El primer estudio (Estudio I) presenta un doble objetivo. En primer lugar, esclarecer los aspectos teóricos de la relación entre los constructos control inhibitorio e impulsividad, y, en segundo lugar, analizar las diferencias de estos dos constructos en una muestra de escolares con desarrollo normal.

Dada la variabilidad detectada en el control inhibitorio de escolares con un desarrollo normal, y dado que se ha probado la relación de déficits en este constructo con la presencia de diferentes desórdenes de alto impacto a nivel social, se han analizado las posibilidades de mejora del control inhibitorio mediante intervenciones de ejercicio físico.

Surge así el segundo estudio (Estudio II) que forma parte de este trabajo. El estudio incluye una revisión sistemática y meta-análisis sobre los efectos que diferentes intervenciones de ejercicio físico llevadas a cabo en estudios independientes con diseños longitudinales tienen en el control inhibitorio de niños y adolescentes con un desarrollo normal.

Además del cálculo del efecto (llevado a cabo mediante dos métodos estadísticos diferentes) que este tipo de intervenciones de ejercicio tienen en el control inhibitorio, la revisión de literatura permitió observar otra alternativa de intervención, también basada en ejercicio físico, que podría causar beneficios en el control inhibitorio de niños, adolescentes y adultos. Hablamos de las intervenciones agudas de ejercicio físico. A diferencia de las intervenciones con un diseño longitudinal (o de "larga duración") propuestas por los diferentes estudios incluidos en la revisión sistemática y meta-análisis, las intervenciones agudas de ejercicio físico se basan en la premisa de que una sola intervención de ejercicio físico puede causar cambios a nivel cognitivo de forma inmediata.

Dado que los resultados de los cálculos meta-analíticos del Estudio II no mostraron beneficios estadísticamente significativos en la muestra estudiada tras su participación en intervenciones de ejercicio con un diseño longitudinal, y dada la existencia de literatura que apuntan a la presencia de beneficios en el control inhibitorio tras intervenciones con un diseño corto (intervenciones agudas de ejercicio), el tercer estudio (Estudio III) surgió con el fin de investigar la viabilidad de este tipo de intervenciones cortas con ejercicio llevadas a cabo para la mejora del control inhibitorio en el ámbito educativo.

El Estudio III incluyó dos tareas de entrenamiento con ejercicio y una tarea control (sin ejercicio). Una de las tareas con ejercicio (Go/No-Go motriz) fue específicamente diseñada para demandar la capacidad de control inhibitorio. La otra tarea de entrenamiento con ejercicio incluyó un circuito de ejercicio aeróbico, sin un requerimiento específico del control inhibitorio. El grupo control realizó una tarea de lecto-escritura, que, a pesar de contar también con un componente cognitivo, no demandaba la capacidad de control inhibitorio.

A continuación, se presentan los resúmenes de los resultados de los tres estudios:

En el Estudio I *"Inhibitory control and impulsivity in a schoolers sample"*, se recabaron y analizaron los datos de 102 niños y niñas de entre 10 y 12 años (*M* = 10.97; *SD* = 0.67) de la ciudad de A Coruña (Galicia). En este estudio se evaluaron dos componentes del control inhibitorio (inhibición de respuestas y control de interferencias), y dos componentes del constructo impulsividad (estilo cognitivo reflexividad-impulsividad y capacidad de retraso de gratificación). Para la evaluación de los componentes de cada constructo se utilizó una batería de tareas de evaluación específicas. La tarea Go/No-Go para evaluar la inhibición de respuestas, la prueba de Stroop para el control de interferencias, la Escala Magallanes de Impulsividad Computarizada (EMIC) para evaluar el estilo cognitivo reflexividad-impulsividad, y una tarea de retraso de gratificación para evaluar la capacidad de retrasar recompensas. En definitiva, se han seleccionado cuatro tipos de tareas que requieren diferente grado de control voluntario.

Los resultados de los análisis de correlaciones mostraron que los componentes estudiados del control inhibitorio presentaron correlaciones significativas entre sí, apuntando a la existencia de conexiones subyacentes entre ambos. Este hecho respalda la teoría de Friedman and Miyake (2004) que define el CI como una familia de funciones interrelacionadas. Estos autores apuntan a que el principal mecanismo común entre la inhibición de respuestas y el control de interferencias podría ser la capacidad de mantener activa la información crítica relacionada con la consecución de objetivos.

Sin embargo, no se encontraron correlaciones significativas entre los componentes de impulsividad estudiados, ni entre los componentes de ambos constructos entre sí (control inhibitorio e impulsividad). Bickel et al. (2012), tampoco encontraron un componente de las funciones ejecutivas que se pudiese entender como antagónico a la reflexividad-impulsividad (componente del constructo impulsividad).

No obstante, cuando el análisis se hizo sobre las variables: tiempos de reacción y errores (precisión de respuesta), sí que hubo correlaciones significativas entre todos los componentes estudiados de ambos constructos (menos con la tarea de retraso de gratificación debido a su diferente naturaleza). Este hecho puede ser entendido en base a dos explicaciones. La primera, que las piedras angulares de los componentes de ambos constructos sean estas variables: tiempos de reacción y precisión. La segunda, que ambos constructos estén definidos en su base por una forma personal y específica, propia de cada individuo, de proceder ante este tipo de tareas, que se mantiene prácticamente invariable en la ejecución de todas ellas.

En cualquier caso, se descubrieron grandes diferencias a nivel individual en el desempeño de dichas tareas, lo que demuestra que a pesar de la falta de datos normativos que hablen de “déficits”, sí que hay niños y niñas con un desarrollo normal, que, dentro de una misma muestra, tienen más o menos problemas para inhibir respuestas y controlar las interferencias. De la misma forma, estos niños y niñas presentan un estilo cognitivo más o menos impulsivos o reflexivo y tienen o no dificultad para retrasar recompensas. En este estudio, sólo un niño no fue capaz de esperar para recibir la recompensa que no era inmediata.

El análisis de las diferencias entre géneros mostró que en la mayoría de las tareas los niños fueron menos precisos en sus repuestas y más rápidos a la hora de darlas que las niñas. Sin embargo, salvo en la variable precisión de la prueba de Stroop en la que sí que hubo diferencias estadísticamente significativas entre niños y niñas (t (77.94) = -2.223, p = 0.029), apuntando a que las niñas fueron significativamente más precisas que los niños, en el resto de las variables de estudio no hubo diferencias significativas.

La literatura previa también apunta a la existencia de diferencias en el constructo impulsividad en relación con el género (Cross et al., 2011; Else-Quest et al., 2006; Weafer & de Wit, 2014). Además, diferentes estudios previos determinaron que los participantes con género masculino eran más propensos que las participantes con género femenino a presentar problemas relacionados con la impulsividad y la falta de control inhibitorio, como la toma de riesgos (Byrnes et al., 1999); el comportamiento antisocial (Moffitt et al., 2001); y problemas de comportamiento en general (Calvete & Cardenoso, 2005) entre otros.

Con el fin de estudiar las posibilidades de mejora del control inhibitorio mediante intervenciones de ejercicio, en el estudio II "*Effects of exercise interventions on the inhibitory control of children and adolescents: A systematic review and meta-analysis",* se llevó a cabo una revisión sistemática de literatura con meta-análisis sobre los efectos de intervenciones de ejercicio físico con un diseño longitudinal en el control inhibitorio de niños y escolares con desarrollo normal. El protocolo de este trabajo fue registrado el 30 de enero de 2019 en PROSPERO (International prospective register of systematic reviews) bajo el siguiente código identificativo: CRD42019118820.

La búsqueda de literatura se llevó a cabo en las siguientes bases de datos: PubMed, PsycINFO, Medline, Eric, SPORTDiscuss, y PsycARTICLES. La estrategia electrónica de búsqueda tuvo la combinación de las siguientes palabras clave: ((exercise OR physical activity OR physical education OR sport OR fitness) AND (inhibitory control OR inhibition OR cognitive control) AND (training OR intervention) AND (children OR adolescents)). La búsqueda no estuvo limitada a un periodo específico de publicación, y todos los estudios debían estar publicados en inglés para poder ser incluidos.

Los criterios de inclusión fueron los siguientes:

1. Población: niños o adolescentes; masculino / femenino; sin ninguna patología

previamente diagnosticada (muestras con pequeño porcentaje de niños con patología fueron incluidas, las muestras compuestas por poblaciones patológicas específicas fueron excluidas); edad hasta los 18 años;

2. Intervención: los participantes debían atender algún tipo de intervención de ejercicio; con diseño longitudinal; pudiendo incluir uno o varios brazos de intervención relacionados con ejercicio físico;

3. Control: todos los estudios debían incluir un grupo control; grupos control de lista de espera o participando en actividades sin demanda de control inhibitorio;

4. Resultados: los estudios debían incluir un análisis de los beneficios que la intervención tuvo en el control inhibitorio;

5. Diseño del estudio: ensayos controlados aleatorizados (en inglés Randomized Controlled Trials (RCTs)) o ensayos controlados aleatorizados grupales (en inglés Cluster Randomized Controlled Trials); que incluyesen un diseño longitudinal o crónico, (entendiendo longitudinal o crónico como términos intercambiables).

La selección de los estudios relevantes fue realizada por dos investigadores independientes. Cuando la información en el resumen del estudio no fue suficiente para tomar una decisión, se examinaron los textos completos. Cualquier divergencia entre los investigadores fue solventada con la ayuda de un tercer investigador. La calidad metodológica de los estudios incluidos fue evaluada con la Lista Delphi (Delphi List; (Verhagen et al., 1998)), por dos investigadores.

La búsqueda de literatura reportó un total de 2735 artículos identificados mediante las bases de datos previamente comentadas. Tras remover los duplicados, un total de 2197 artículos fueron revisados por título o por título y resumen. Un total de 82 artículos fueron seleccionados en la primera ronda de selección. Además, tras examinar sus referencias, otros 6 posibles artículos fueron seleccionados. En total, 88 artículos fueron revisados a texto completo. Finalmente, sólo 13 estudios cumplieron con los criterios de inclusión establecidos, y fueron, por lo tanto, incluidos en la revisión sistemática con meta-análisis. Todo el proceso de selección se puede ver en el Diagrama de Flujo (Flow Diagram en inglés) en la Figura 4. Además, la Tabla 4 incluye las características generales de cada uno de los estudios.

El cálculo del tamaño del efecto se llevó a cabo mediante dos análisis estadísticos diferentes, un modelo de análisis de efectos aleatorios y un meta-análisis siguiendo el método tradicional. El modelo más extendido para calcular el tamaño del efecto de una intervención específica sigue siendo hoy en día el análisis tradicional, sin embargo, el análisis multinivel ha surgido como una posibilidad interesante para tratar la dependencia de los tamaños del efecto. En el estudio actual, se implementaron ambos métodos con el fin de explorar si existían resultados notablemente diferentes entre ellos.

El modelo de análisis de efectos aleatorios se seleccionó para reducir el sesgo potencial asociado a la heterogeneidad entre los estudios (The Cochrane Collaboration, 2011), basado en la suposición de diferentes tamaños de efectos verdaderos (Borenstein et al., 2009; Petitti, 2000; Xue et al., 2019). Su resultado (d = 0.124, 95% CI -0.072 to 0.321, p = 0.201) muestra un tamaño de efecto pequeño, pero no puede asumirse como estadísticamente significativo porque el valor p es mayor que 0.05 y los valores del intervalo de confianza (CI) cruzan el valor nulo.

El meta-análisis tradicional, en el que se calcularon las diferencias de medias estandarizadas (en inglés SMD) de la intervención (pre-post), muestra una situación similar. Ninguno de los tres cálculos del tamaño del efecto puede considerarse estadísticamente significativo, debido a que todos presentan valores p no significativos y a que los valores CI cruzan de nuevo el efecto nulo. Puntuaciones independientes (d = 0.21, IC del 95%: -0.10 a 0.51, p = 0.18), tiempos de reacción (d = -0.14, IC del 95%: -

0.44 a 0.16, $p = 0.37$), y precisión ($d = -0.01$, IC del 95%: -0.20 a 0.17, $p = 0.92$). Por lo tanto, a pesar de que dos de los tamaños del efecto son pequeños de acuerdo con los criterios de Cohen (J. Cohen, 1992) para las variables de tiempos de reacción y puntuaciones independientes, se puede concluir que el efecto general de las intervenciones estudiadas no es significativo en el control inhibitorio de la muestra estudiada de niños y adolescentes de acuerdo con ambos procedimientos estadísticos.

Este estudio es el primer meta-análisis centrado específicamente en los efectos que las intervenciones de ejercicio físico con un diseño longitudinal tienen en el control inhibitorio de niños y adolescentes con un desarrollo normal. De la misma manera, es el primer meta-análisis llevado a cabo mediante dos métodos estadísticos diferentes. Esto hace que las comparaciones con meta-análisis previos no sea posible. Sin embargo, dado que el control inhibitorio es ampliamente estudiado bajo el termino de las funciones ejecutivas, hay varios estudios relacionados que no pueden ser ignorados. Existen meta-análisis centrados en los beneficios obtenidos con programas de ejercicio en las funciones ejecutivas (Wilke et al., 2019; Xue et al., 2019), que también reportan los resultados específicos obtenidos en el control inhibitorio.

Xue et al. (2019) realizaron un meta-análisis sobre los efectos de las intervenciones de ejercicio con un diseño longitudinal en las FE en niños y adolescentes y descubrieron mejoras significativas en dichas funciones ($SMD = 0.20$, 95% CI 0.09 to 0.30, $p < 0.05$). Los resultados relativos al control inhibitorio reportado por estos autores fueron también positivos, además de estadísticamente significativos ($SMD = 0.26$, 95% CI 0.08 to 0.45, $p < 0.05$). Sin embargo, un meta-análisis previo en el que se incluyeron diferentes tipos de intervenciones con ejercicio y una muestra compuesta por niños, adolescentes y adultos jóvenes (Verburgh et al., 2013), no encontró beneficios generales estadísticamente significativos en las FE ($d = 0.14$, 95% CI -0.04 to 0.32, $p = 0.19$). Estos datos coinciden con los resultados obtenidos en el presente estudio.

Verburgh et al. (2013) también analizaron los beneficios de intervenciones agudas de ejercicio. En este caso, y a diferencia de los resultados que obtuvieron con intervenciones de ejercicio con un diseño longitudinal, los resultados mostraron un tamaño del efecto medio (de acuerdo con los criterios de J. Cohen (1992)) y estadísticamente significativo ($d = 0.46$, 95% CI 0.33 to 0.60, $p < 0.001$). Lo que declaró la obtención de beneficios relevantes en las FE después de participar en este tipo de intervenciones con ejercicio.

Otro meta-análisis centrado en los en los efectos de intervenciones agudas de ejercicio de resistencia sobre la función cognitiva (Wilke et al., 2019), mostró resultados positivos en el control inhibitorio de adultos sanos después de este tipo de intervenciones con ejercicios de resistencia ($SMD = 0.73$, 95% CI 0.21 to 1.26, $p = 0.01$). Por su parte, Chang et al. (2012), descubrieron un efecto general positivo (aunque pequeño) de este tipo de intervenciones agudas de ejercicio en el rendimiento cognitivo de una muestra que abarcaba todo el rango de edades ($g = 0.097$).

Sin embargo, la existencia de estudios en los que no se han demostrado mejoras en el CI tanto después de intervenciones de ejercicio físico agudas como con un diseño longitudinal (de Greeff et al., 2016; Kvalo et al., 2017; Ludyga et al., 2019; Schmidt et al., 2015; Tarp et al., 2016), no debe ser olvidada. Según una revisión sistemática reciente llevada a cabo por un panel de expertos (Singh et al., 2018), no existe evidencia concluyente de los efectos beneficiosos de este tipo de intervenciones sobre el rendimiento cognitivo en niños. Además, señalaron la necesidad de más investigación de alta calidad para aclarar las dudas en este ámbito de investigación.

Dado que los resultados del meta-análisis no mostraron una mejora estadísticamente significativa en el control inhibitorio tras la participación en intervenciones de ejercicio con un diseño longitudinal, y a que en la búsqueda de literatura se detectó la existencia de intervenciones de ejercicio físico con otro tipo de diseño (individual/ aguda) que reportaban beneficios a nivel cognitivo, en el tercer estudio se optó por diseñar una intervención de ejercicio físico de este tipo para ver su capacidad para optimizar el control inhibitorio.

El estudio III *"Effects of different acute exercise interventions in inhibitory control in schoolers",* está compuesto por una intervención aguda de ejercicio físico, con diferentes diseños de entrenamiento, para analizar los beneficios de dichas intervenciones en el control inhibitorio de una muestra de escolares con desarrollo normal. Un total de 59 niños y niñas de entre 10 y 12 años ($M = 10.97$; $SD = 0.742$) participaron en el estudio.

Este tipo de intervenciones individuales de ejercicio físico están específicamente diseñadas para ser llevadas a cabo una sola vez, con una duración aproximada que suele variar entre 10 y 40 minutos (Verburgh et al., 2013). Sus beneficios se calculan extrayendo la diferencia entre los datos del post-test (evaluación tras la intervención) y el pre-test (evaluación previa a la intervención) en base a los diferentes grupos de intervención; generalmente grupo(s) de intervención y grupo control.

Con el objetivo de examinar los beneficios de este tipo de intervenciones de ejercicio en entornos más "naturales" como fue sugerido por Jäger et al. (2015), la intervención de ejercicio físico que viene recogida en el Estudio III se llevó a cabo en un centro escolar de la provincia de Navarra.

Cada uno de los participantes asistió a dos sesiones. En la primera sesión se evaluó la condición física de los escolares con la prueba de 20 metros de ida y vuelta (20 m Shuttle Run test; SRT en inglés) de Leger et al. (1988). En la segunda sesión se llevó a cabo la evaluación del control inhibitorio previa a la intervención (pre-test), la intervención formando parte de uno de los tres grupos de intervención (grupo de ejercicio aeróbico, grupo de ejercicio con una tarea Go/No-Go motora, o grupo control con una tarea de lecto-escritura), y finalmente la evaluación del control inhibitorio posterior a la intervención (post-test). Todas las intervenciones se llevaron a cabo a la vez y tuvieron la misma duración (10 minutos). La participación se realizó en grupos de tres participantes. Cada uno de los tres participantes que participaron a la vez fue asignado de forma aleatoria a un grupo específico de intervención.

Las tareas de evaluación del control inhibitorio, tanto para el pre-test como para el post-test fueron todas computarizadas: Go/No-Go, Stroop, y Tarea de Flancos.

El grupo control estuvo los 10 minutos de intervención leyendo un libro y escribiendo unas frases a modo de resumen de su lectura. La intervención llevada a cabo por el grupo de ejercicio aeróbico estuvo compuesta por un circuito de carrera delimitado con conos dispuestos en zigzag, en el que el objetivo era realizar un ejercicio aeróbico continuo a una frecuencia cardiaca predeterminada hasta que el investigador daba la señal de stop. Aunque ambas tareas también incluyen un componente cognitivo, en ninguno de los dos casos se demanda la capacidad de control inhibitorio.

El diseño de la tarea Go/No-Go motriz incluyó tres características teóricamente relevantes para el entrenamiento del control inhibitorio: incluyó un componente lúdico y novedoso, estuvo específicamente dirigida a trabajar el control inhibitorio (demanda de control inhibitorio), e incluyó un alto componente motor. En esta actividad los participantes tenían que recorrer el espacio delimitado entre dos líneas (situadas a 12,5 metros) y lo tenían que hacer en base a los estímulos sonoros que recibían del ordenador. Había dos estímulos sonoros distintos, el sonido de un gato (No-Go), y el sonido de una vaca (Go). Los participantes tenían que actuar en base a los sonidos que escuchaban, de forma que tenían que correr hasta la línea situada en frente cuando aparecía el estímulo Go, y evitar salir corriendo cuando escuchaban el sonido No-Go.

Los dos grupos de intervención con ejercicio participaron a una intensidad moderada (entre el 60% y el 70% de su frecuencia cardiaca máxima) debido a la existencia de literatura previa que establece que esta intensidad es la más recomendable para producir beneficios a nivel cognitivo (Chang et al., 2011; Chang & Etnier, 2009; A. G. Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009). Esta intensidad equivalía, dependiendo de las características personales de cada participante, a un trote suave o a un caminar ligero. Todos los participantes tanto del grupo de ejercicio aeróbico como del grupo Go/No-Go llevaron pulsómetros para no exceder los límites de frecuencia cardiaca previamente establecida.

Los resultados no mostraron diferencias significativas en el control inhibitorio al comparar entre intervenciones. Además, con los resultados obtenidos, no se pudo asumir que las intervenciones de ejercicio implementadas causasen beneficios observables en este dominio. En conclusión, este tipo de intervenciones de ejercicio podrían mejorar el control inhibitorio, pero en el presente estudio dichas mejoras no fueron observables. En futuros estudios, además de implementar otros métodos de evaluación con neuroimagen que podrían complementar y ayudar a esclarecer la presencia de cambios inmediatos causados por este tipo de intervenciones de ejercicio, varios moderadores deben estudiarse más y ajustarse mejor con el fin de producir mayores beneficios en el control inhibitorio de escolares con un desarrollo normal.

La falta de beneficios estadísticamente significativos del presente estudio no está en línea con la literatura previa (A. G. Chen et al., 2014; Chu et al., 2015; Hillman et al., 2009; Jäger et al., 2014; Verburgh et al., 2013) que asegura encontrar tales beneficios tanto en el conjunto de las funciones ejecutivas como en el control inhibitorio. Sin embargo, también hay estudios independientes que no han encontrado beneficios con este tipo de intervenciones de ejercicio en ninguno de los dominios de los que se ha hablado previamente (Jäger et al., 2015; Stein et al., 2017; Stroth et al., 2009).

Cabe destacar que las ventajas de este tipo de intervención son su corta duración, su diseño generalmente ecológico y el requerimiento de materiales fáciles de conseguir y asequibles en cuanto a su precio. En consecuencia, se trata de intervenciones fáciles de implementar en el ámbito educativo, por lo que su éxito podría reportar un alto beneficio en el día a día de los escolares, con consecuencias relevantes no solo en su presente sino también en su futuro.

Si bien es cierto que los resultados obtenidos hasta ahora parecen ser no concluyentes, algunos autores como A. G. Chen et al. (2014) también han remarcado la falta de estudios en este campo con muestras escolares. Jäger et al. (2015) igualmente insistieron en que la mayoría de los estudios que investigan los efectos de intervenciones individuales de ejercicio físico se conducen en entornos de laboratorio e incluyendo intervenciones de ejercicio muy estandarizados, como caminar en cinta (Drollette et al., 2014; Hillman et al., 2009) o ejercicio en bicicleta estática (Stroth et al., 2009).

En cualquier caso, más investigación parece ser necesaria para esclarecer la aplicabilidad de este tipo de intervenciones de ejercicio para la mejora del control inhibitorio.

Las conclusiones generales alcanzadas tras realización del presente trabajo se exponen a continuación:

- El control inhibitorio y la impulsividad pueden ser entendidos conceptualmente como polos opuestos de la misma dimensión (inhibición-desinhibición), sin embargo, las tareas de evaluación de cada uno de estos constructos varían en su naturaleza y, requieren, por lo tanto, la participación de diferentes procesos cognitivos, así como de diferentes niveles de control voluntario.

- Los componentes del control inhibitorio estudiados, inhibición de respuestas y control de interferencias, mostraron correlaciones, lo que subraya la existencia de conexiones comunes subyacentes entre ellos.
- No se encontraron correlaciones entre los componentes de impulsividad (reflexividad-impulsividad e impulsividad temporal), ni de estos con los componentes del control inhibitorio, lo que destaca la independencia entre los dos constructos (control inhibitorio e impulsividad) al analizar las variables de estudio establecidas.
- Cuando se analizaron las variables de precisión y tiempo de respuesta, se encontraron grandes diferencias en la tendencia individual de los participantes a dar una respuesta.
- En resumen, independientemente de cómo se evalúa cada componente (la fórmula establecida), la tendencia de respuesta de cada participante (más o menos rápida y precisa) parece permanecer invariable en una muestra de escolares con un desarrollo típico.
- De acuerdo con la literatura previa, la implementación de intervenciones de ejercicio físico, con diseños tanto longitudinales como agudos, podría producir cambios en el control inhibitorio y en el resto de las funciones ejecutivas.
- Los resultados obtenidos en el meta-análisis realizado (Estudio II) no mostraron beneficios estadísticamente significativos en el control inhibitorio de niños y adolescentes con un desarrollo normal, tras su participación en intervenciones de ejercicio físico con un diseño longitudinal.
- Como la mayoría de las intervenciones de ejercicio incluidas en los estudios individuales se centraron en el objetivo general de causar beneficios en las FE, la falta de especificidad en su diseño para producir cambios en el CI podría ser la causa de la inexistencia de resultados significativos.
- En la intervención de ejercicio agudo propuesta en este trabajo (Estudio III), ninguno

de los diseños de intervención con ejercicio propuestos ha obtenido beneficios estadísticos significativos en el control inhibitorio.

- A pesar de haber diseñado una tarea específica para entrenar explícitamente la demanda de control inhibitorio, los resultados de esta intervención no han obtenido diferencias estadísticamente significativas en comparación con los otros dos diseños de intervención.
- Ninguno de los grupos de intervención con ejercicio ha mostrado diferencias estadísticamente significativas en comparación con el grupo control en sus resultados de control inhibitorio inmediatamente después de la intervención.

Futuras líneas de investigación

- La falta de datos normativos debe ser abordada para facilitar la detección de problemas y déficits, lo que acelerará el proceso de prevención de problemas futuros relacionados.
- Para evitar malentendidos, los componentes del CI deben diferenciarse mejor, y los resultados de los estudios deben especificar el componente específico del CI que han evaluado, en lugar de extrapolar sus resultados al constructo general del CI.
- Dentro del campo de la psicología, existen varias técnicas de control inhibitorio disponibles para fomentar comportamientos más conscientes y menos automáticos (como la aplicación de retroalimentación inmediata (Keith y Frese, 2005; Leidinger y Perels, 2012)). Sin embargo, para implementar tales técnicas, los componentes específicos que producen la falta de control inhibitorio deberían ser detectados previamente. Las intervenciones futuras deben dirigirse a trabajar sobre los componentes específicos que están fallando.
- Varios moderadores de beneficios (intensidad, duración, componente cognitivo, etc.)

deben estudiarse más y ajustarse mejor para diseñar intervenciones de ejercicio que puedan causar mayores beneficios en el control inhibitorio y en el resto de las funciones ejecutivas.

- La inclusión de otros métodos de evaluación (como las técnicas de neuroimagen) podría complementar los resultados obtenidos a través de tareas conductuales de evaluación.