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EXPLORING THE CONSTRUCT OF EXECUTIVE FUNCTIONS AND WORKING MEMORY IN PRESCHOOL CHILDREN

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ABSTRACT

Executive Functions (EF) are a set of higher-order cognitive processes that enable the implementation of goal-directed behaviours. In adulthood, studies have identified at least three distinct but interrelated EF: inhibition, shifting, and updating (Miyake et al., 2000). While it is established that these functions are distinct in adults, there is no consensus in the literature on their structure in developmental ages, especially in the preschool period. Specifically, there is still little clarity regarding the multicomponent nature of the construct and the relationship between its components. Specifically, one debated aspect concerns the relationship between EF and Working Memory (WM), which is often considered a single construct along with the updating function. Another aspect concerns the nature of the inhibition construct: in the literature, opposing positions consider inhibition on one hand as a unitary function, and on the other as a multifactorial construct; moreover, even within this second position, there is no agreement on the nature of the different components. These aspects are examined by the current project, which aims to identify the structure of EF in preschool age, with a specific focus on WM and inhibition.

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Introduction

Executive Functions (EF) and Working Memory (WM) are increasingly considered a fundamental component in the cognitive and social development of children; in particular, research conducted in recent decades has revealed how EFs are associated with aspects such as attention, behavioural regulation, academic learning, and socio-emotional functioning (Blair & Razza, 2007; Best, Miller, & Jones, 2009; Cameron et al., 2012; Carlson et al., 2014; Diamantopoulou, Rydell, Thorell, & Bohlin, 2007). These functions come into play daily, whenever we face new tasks and situations, activities that require some form of monitoring, or situations where acting impulsively is not advisable; they are essential even when we need to plan our actions, make decisions, or correct errors, as well as being relevant in the conscious control of thoughts and emotions.

EF and WM play a fundamental role from the early years of a child's life. In fact, although the development of these processes continues into adolescence, the most rapid progress is observed between the ages of 3 and 5 (Carlson, 2005); this promotes in children an organization of thought and behaviour characterized by greater flexibility, a decrease in impulsive responses, and the implementation of more self-regulated behaviours. Furthermore, the preschool development of EF and WM is associated with increased socio-emotional skills, including theory of mind, problem-solving ability, and school readiness (Blair & Razza, 2007; Hughes & Ensor, 2007; Senn, Espy, & Kaufmann, 2004).

Given their relevance to cognitive development, especially during this period of life, EF and WM have been extensively studied in the literature. However, there are still many issues that need to be clarified. One of these is the structure of EF in preschool age. A systematic review by Karr, Areshenkoff, Rast, Hofer, Iverson, and Garcia-Barrera (2018) highlighted how studies addressing this topic in this age group have found models with one or two factors. One of the possible factors contributing to this discrepancy is also an ongoing debate about whether to consider WM as a construct overlapping with that of updating (e.g., Diamond, 2013; Garon, Bryson, & Smith, 2008) or as two separate constructs (e.g., Panesi, Bandettini, Traverso, & Morra, 2022). Closely related to this, there is the issue of tasks, which in some cases are indiscriminately used to measure one or the other function. It is also worth noting, however, that tasks to measure updating in young children are indeed very few, so differentiation of tasks even in cases where WM and updating are considered as separate constructs is rather difficult.

Another open issue concerns one of the most studied EFs, inhibition, and particularly its latent structure. The position that inhibition is a multidimensional construct rather than unitary is quite widespread. This multidimensionality seems plausible when we consider that tasks measuring inhibition suggest the involvement of very different processes.

Our project aims to contribute to this debate, seeking to clarify issues on which there is still considerable inconsistency. Specifically, through two systematic reviews, we aim to analyse the literature regarding the EF construct and its latent structure in preschool children, with a particular focus on the relationship between WM and updating. Additionally, a critical paper will explore the construct of inhibition in relation to existing models and tasks. In the second part, through an experimental study conducted on a sample of preschoolers, we will investigate which models better describe the latent structures of (a) WM and updating; (b) inhibition; (c) EF.

The choice to focus our project on these constructs in this age group is primarily due to two reasons: firstly, we have observed how EF and WM greatly influence other socio-cognitive abilities, such as theory of mind or learning. A more precise understanding of the dimensions of EF and WM can be useful for a deeper comprehension of the functioning of these other abilities, with potentially interesting implications, for example, for enhancement possibilities. Secondly, cognitive development receives a significant boost in the preschool years, making it interesting to investigate more thoroughly how EF and WM are structured in such a sensitive age period.

References

Best, J.R., Miller, P.H., & Jones, L.L. (2009). Executive functions after age 5: Changes and correlates. Developmental Review, 29, 180–200. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Blair C, & Razza RP. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development. 78(2):647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Cameron, C.E., Brock, L.L., Murrah, W.M., Bell, L.H., Worzalla, S.L., Grissmer D., et al. (2012). Fine motor skills and executive function both contribute to kindergarten achievement. Child Development, 83(4):1229–1244. https://doi.org/10.1111/j.1467-8624.2012.01768.x

Carlson, S.M. (2005) Developmentally Sensitive Measures of Executive Function in Preschool Children. Developmental Neuropsychology, 28:2, 595-616. https://doi.org/10.1207/s15326942dn2802_3.

Carlson, S.M., White, R.E., & Davis-Ungera, A. (2014). Evidence for a relation between executive function and pretense representation in preschool children. Cognitive Development, 29. https://doi.org/10.1016/j.cogdev.2013.09.001.

Diamantopoulou, S., Rydell, A.M., Thorell, L.B., & Bohlin, G. (2007). Impact of executive functioning and symptoms of attention deficit hyperactivity disorder on children’s peer relations and school performance. Developmental Neuropsychology, 32(1), 521–542. https://doi.org/10.1080/87565640701360981

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Review, 134, 31–60. https://doi.org/10.1080/09297049.2013.857650.

Hughes, C., and Ensor, R. (2007). Executive function and theory of mind: predictive relations from ages 2- to 4-years. Dev. Psychol. 43, 1447–145. https://doi.org/10.1037/0012-1649.43.6.1447

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The Unity and Diversity of Executive Functions: A Systematic Review and Re-Analysis of Latent Variable Studies. Psychological Bulletin. https://doi.org/10.1037/bul0000160.

Panesi, S., Bandettini, A., Traverso, L., & Morra, S. (2022). On the Relation between the Development of Working Memory Updating and Working Memory Capacity in Preschoolers. Journal of Intelligence 10:5. https://doi.org/10.3390/jintelligence10010005.

Senn, T.E., Espy, K.A., & Kaufmann, P.M. (2004). Using path analysis to understand executive function organization in preschool children. Developmental Cognitive Neuroscience Laboratory - Faculty and Staff Publications. 8. https://doi.org/10.1207/s15326942dn2601_5.

Latent structure of executive function in preschoolers: a systematic review and meta-analysis

Abstract

In the last decades, an impressive amount of research demonstrated the importance of the early development of executive function for concurrent and subsequent psychological development and adjustment. Nevertheless, the structure of executive function in this age range is still a matter of debate. The present systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement and focused on studies that used confirmatory factor analysis with at least two indicators for identifying executive function components in preschool and toddler children. Both points of convergence and divergence, as well as issues with study design and operationalization of executive function are discussed (sample size, age range, type of indicators, relationship between indicators and latent variables). To move forward in understanding early executive function development, future research should benefit from taking into account some of the issues identified.

1. Introduction

The term Executive Function (EF) is often described as an "umbrella" term encompassing set of high-order cognitive abilities crucial for self-regulation and organizing complex, goal-directed behaviors. These abilities include initiating, planning, and organizing an action, shifting attention between different tasks; and suppressing prepotent responses to reach functional goals. These domain-general processes have an adaptive function, playing a crucial role when we are faced with new situations or problems where automatic or impulsive responses would be inadequate or ineffective (Diamond, 2013).

Despite a large number of studies, there is no consensus on the model that best describes the EF structure. Historically, models considered EF as a unitary factor. Baddeley (1986; 2003), for example, proposed a “Central Executive”, defined as an attentional system with limited capacity, involved in storing and processing information, focusing and shifting attention, reasoning and decision-making. The Central

Executive in turn refers to the Supervisory Attention System (SAS), defined by Norman and Shallice (1980; 1986) as an attentional control system related to individual differences in cognitive tasks that require planning and control skills. At the same time, dissociations among EF task performance observed in clinical context supported the emergence of multi-component models of EF (Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999; Stuss & Benson 1986; Tranel, Anderson, & Benton, 1994). In the discussion about the unitary versus multicomponent nature of EF, a fundamental contribution was given by the seminal paper of Miyake and colleagues (Miyake et al., 2000). These authors used confirmatory factor analysis (CFA) to assess the fit of several EF models in an adult sample. They compared a model positing a unitary central executive against another portraying the central executive as comprising various executive dimensions. Through CFA, Miyake and colleagues identified three interrelated but distinct EFs: inhibition—the ability to suppress task irrelevant cognitive processing and ignore salient yet irrelevant features of the environment (Miyake et al., 2000); shifting—the ability to switch between different operations or levels of processing (Miyake et al., 2000); and updating—the capacity to encode, hold and monitor incoming information in working memory (WM), replacing outdated information with new information (Morris & Jones, 1990). According to this perspective, EF appears to rely on WM, which involves the simultaneous maintenance and manipulation of information. Furthermore, EF seems to involve a common inhibitory component, which would explain why these functions are interrelated yet distinct.

While multiple EF models continue to exist (e.g., Zelazo, Carter, Reznick, & Frye, 1997), the three-component model identified by Miyake and colleagues has become the most widely accepted theoretical framework for understanding EF (Friedman & Miyake, 2018; Miyake & Friedman, 2012). However, consensus on the best model in adulthood does not necessarily extend to childhood, where findings are less consistent. Lehto, Juujarvi, Kooistra, and Pulkinnen (2003) found an executive structure similar to that proposed by Miyake et al. (2000) in children aged from 8–13 years, identifying three latent dimensions interpreted as inhibition, WM and shifting. In contrast, Huizinga, Dolan, and van der Molen (2006) and van der Sluis, de Jong, and van der Leij (2007) identified only two EF components, WM and shifting, and did not identify a separate inhibition factor, possibly due to an inappropriate selection of inhibition tasks. A two-factor model was also proposed by Shing, Lindenberg, Diamond, Li, and Davidson (2010), who identified only two dimensions (WM and inhibitory control), in children aged 10 – 15 years. Lee, Bull, and Ho (2013) also found a two-factor structure including an updating and a combined inhibition–switching factor in children aged 5 to 13 years.

The scenario among preschool children shows similarly discordant results. Some studies (e.g., Hughes, Ensor, Wilson, & Graham, 2010; Shing et al., 2010; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011) suggested that a single factor model best described the EF structure in preschoolers. Other research indicated that a two-factor model better represented the EF structure in this age group. Miller, Giesbrecht, Müller, McInerney, and Kerns (2012), for example, identified a two-factor model consisting of WM and inhibition in a sample of children aged 3 to 5 years. Similarly, Lerner and Lonigan (2014) claimed in favor of a model distinguishing between WM and inhibition in children aged from 3.5 to 5 years. This was confirmed by a latter study, performed by Usai, Viterbori, Traverso, and De Franchis (2014), also identifying a two-factor model in 5- and 6-year-old children. In this model inhibition was a separate factor, while WM and shifting were merged into a single factor (see also Monette, Bigras, & Lafrenière, 2015). Differently, Panesi and Morra (2020) reported a similar two-factor model, including a WM and a combined inhibition – shifting – updating factors.

A systematic review by Karr, Areshenkoff, Rast, Hofer, Iverson, and Garcia-Barrera (2018) revealed that most of the studies on preschool children identified one or two factors, whereas studies in older children more frequently identified two or three factors. The inconsistency in the developmental literature regarding the structure of EF can arise from several causes. First, it is important to note the variability in how WM and updating are conceptualized across different age groups. While in adult populations, there is a consensus that these are separate constructs (Himi, Bühner, & Hilbert, 2021), each contributing uniquely to the EF framework, in the developmental literature, the distinction between WM and updating is often blurred. For instance, Garon et al. (2008) in their review of EF in preschoolers, identified inhibition, shifting, and WM as key EFs, effectively equating WM with the broader updating processes described by Miyake et al. (2000). Similarly, Diamond (2013) considered inhibition, WM, and cognitive flexibility as core EFs that develop in early childhood, where WM often encompasses the functions of updating. This conflation can lead to confusion and inconsistencies in the measurement and interpretation of EFs in young children. The assumption that WM subsumes updating tasks not only impacts the theoretical structure of EF models but also affects the empirical findings regarding their development. Understanding these distinctions and their implications is crucial for accurately assessing cognitive development and tailoring educational strategies accordingly.

Another source of inconsistency in the developmental literature on EF pertains to the variability in constructs considered across different studies. For example, Panesi and Morra (2020) included tasks assessing WM, inhibition, shifting, and updating in their models of EF structure. In contrast, many studies focus more narrowly on a subset of constructs, typically assessing only WM and inhibition (e.g., Lerner & Lonigan, 2014; Wiebe et al., 2011). Nevertheless, it should be noted that EF include several higher-order cognitive processes such as reasoning, planning, and problem-solving (Diamond, 2013) which are less investigated. Additionally, distinctions made by authors like Zelazo and Müller (2002) between 'cool' EF and 'hot' EF further complicate the issue. These authors categorize cool EF to involve cognitive skills like inhibition and WM, whereas hot EF includes processes linked to emotional and motivational aspects, such as delay of gratification and affective decision-making. The EF considered influence the research design and, consequently, the results.

Inhibition, WM, and shifting are commonly investigated due to their central role in cognitive development. Additionally, they appear relatively circumscribed and, therefore, they seem easy to operationalize (see Miyake et al., 2000). Nevertheless, operationalize these EF for children is far from simple. EF task requires diverse knowledge and skills (i.e. impurity problem, Miyake et al., 2000), that children are acquiring (Hughes & Graham, 2002). In CFA, EF tasks should be very different and very basic in non-EF requests and very similar in the EF required. Nevertheless, some studies use tasks that seem characterized by a different level complexity.

Furthermore, the label "preschool" is used in the literature to encompasses different age ranges. For example, in some study, this term is used to refer to children from 3 to 6 (Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Völter et al., 2022); in others is used to refers to children from to 2 to 6 years (Wiebe et al., 2008). The inclusion of a broad age range in studies of preschool children's EF can pose significant challenges due to the rapid developmental changes of early childhood. Some reviews in fact documented substantial differences in EF task performance among children aged 2, 3, 4 and 5 years; these differences are likely reflective of distinct developmental trajectories (e.g., Carlson, 2005; Best & Miller, 2010).

Other problems rely on the use of different numbers of indicators to identify specific EF components in different studies. Some authors considered two or more indicators for each function considered (e.g., Usai et al., 2014); others employed a different number of indicators depending on the investigated function (Schoemaker et al., 2012); still others used less than two indicators (Garon, Smith, & Bryson, 2013) or use multiple indicators from a single task (Hughes, Ensor, Wilson, & Graham, 2009). This can be problematic, as using a limited number of indicators per factor might bias the results of latent factor models.

All these inconsistencies and methodological problems are a key factor contributing to the inconsistences observed in developmental studies of EF, particularly in the preschool years where cognitive abilities are rapidly developing. Although existing evidence points to both quantitative and qualitative changes in EF during early development, the exact nature of these functions remains somewhat elusive.

In light of these challenges, it is crucial to comprehensively review and understand the methodologies employed in these studies. Karr et al. (2018) included preschoolers in their systematic review but did not focus exclusively on this age group. Their research aimed to evaluate the empirical support for various EF models and to identify the best fitting models based on CFA results. Our study builds upon these foundations with a more focused examination of the methodologies, sample characteristics, and indicator features used in preschool EF research. By doing so, with the present systematic review we aim to uncover the reasons behind the observed inconsistencies and provide insights on how future research can be structured to better understand EF development in early childhood. Moreover, we also aimed to investigate the relationship between latent variables with a metanalysis.

To advance our understanding of EF structure during preschool years, examining systematically the methodologies and findings of previous studies is essential. Such efforts will not only clarify the developmental trajectory of EF but also enhance our understanding and help to develop future and more informed studies.

2. Systematic Review

The main aim of this systematic review is to critically examine the recent literature on the EF structure in preschool children. This review is structured around several key research questions: (a) which theoretical model received more empirical confirmation; (b) which models were compared and contrasted; (c) which latent variables are examined; (d) how the tasks employed were actually informative of the constructs they are intended to measure; (e) how the age range of participants affects the resulting model.

In this review we decided to focus on WM, inhibition, shifting, and updating as described by Miyake and colleagues (2000), as these factors are prominently used in the literature. Our review aims to not only to compare different EF models, but also to critically analyze the methodologies used to identify them. This examination will help in understanding how methodological inconsistencies can influence the outcomes of research in this area.

2.1. Method

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2009). The flowchart shown in Figure 1 outline the search and selection process.

2.1.1. Literature search

The literature search was conducted on 8th November 2022, including the following databases: PsycINFO, PsycArticles, Psychology and Behavioral Sciences Collection and Pubmed. To minimize the risk of publication bias, grey literature from ProQuest, which also includes dissertations, was also considered. The search was limited to publications in English. Keywords used across all databases included combinations of: "executive function*” or "cognitive flexibility" or "shifting" or "inhibition" or "inhibitory control" or "updating" AND "working memory" or "M capacity" or "attentional capacity" or "memory span" AND "confirmatory factor analysis" or "CFA" or "SEM" or "Structural Equation Model" or "model" or "factor" or "structure" AND "child*" or "preschool*" or "kindergarten". In PsycINFO, PsycArticles, and PubMed, the selected keywords could appear in any field; however, in ProQuest, these keywords were required to be present only in the abstract or summary text. Additionally, we restricted our search to publications in English.

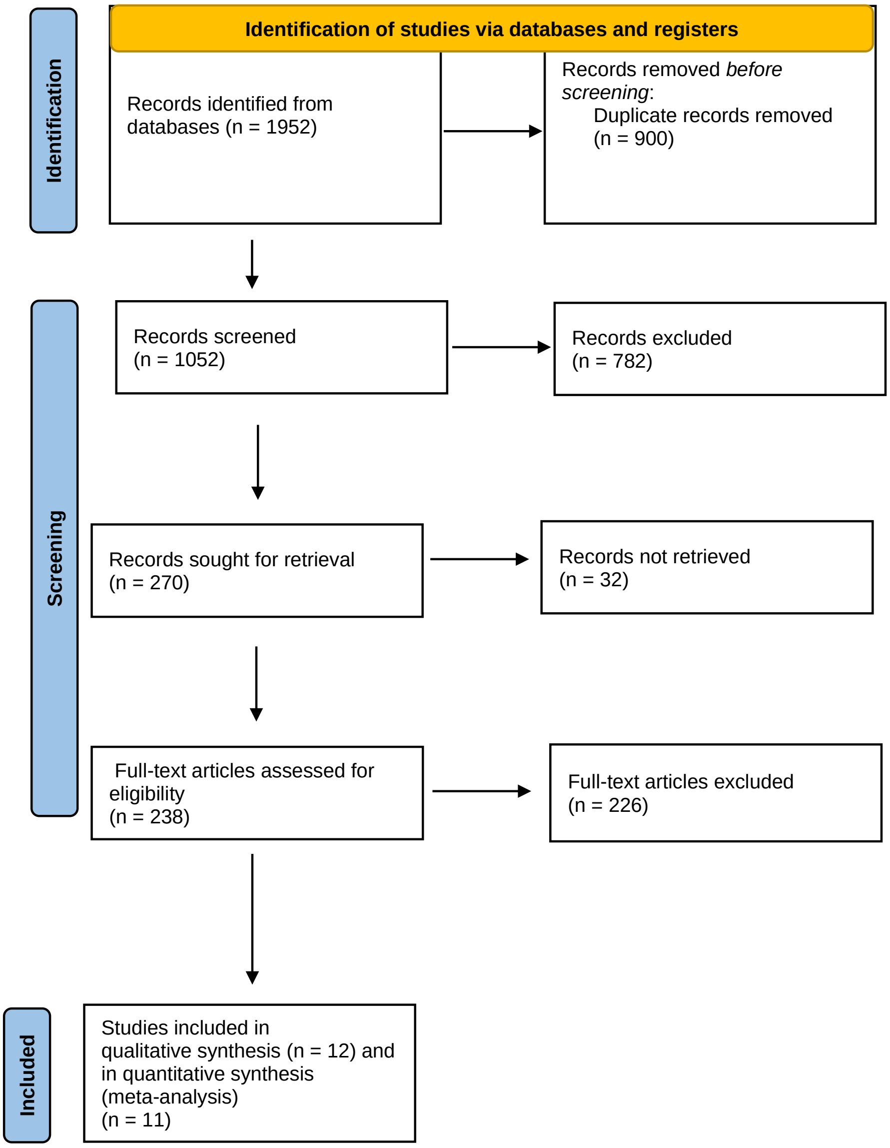
2.1.2. Abstract screening

From the initial search a total of 1952 abstracts were identified. After removing 900 duplicates, 1,052 papers remained. Two authors independently and blindly reviewed 263 articles, corresponding to 25% of total abstracts. Agreement between reviewers was 100%. Titles and abstracts were reviewed to identify the relevant articles. The selection process followed a set of inclusion criteria: (1) articles published on scientific journals or dissertations; (2) empirical studies; (3) participants were humans; (4) participants were children under 7 years old; (5) samples consisted of typically developing children; (6) EF and WM were assessed through performance-based tasks; (7) more than one EF were assessed. Articles that did not provide sufficient information to determine inclusion were carried forward to the full-text screening phase.

2.1.3. Full-text articles screening

A total of 270 references proceeded to full-text screening, from which 238 full-text articles were retrieved. For their assessment, we added three inclusion criteria: (1) CFA was used; (2) at least two models were compared; (3) each EF was measured by at least two tasks. Twelve papers met all inclusion criteria, corresponding to 14 studies as two articles included two studies each (Hume, 2015; Miller et al., 2012).

Figure 1. Search and selection process



2.2. Results

Table 1 summarizes the main characteristics of each study included in this review, including demographic, tested models, EF construct, and indicators. The studies are categorized into two broad groups: those supporting a unitary model and those supporting a two-factor model. This distinction is made to help readers better understand the key features that may influence the observed models.

Table 1. Characteristics of the study

(a) One-factor models

Unitary						
References	Hume (2015)	Miller et al. (2012)	Panesi & Morra (2021)	Völter et al. (2022)	Wiebe et al. (2008)	Wiebe et al. (2011)
Sample, N Age(range)	117 40.98 (36-45)	129 50.45 (36-68)	78 31.1 (25-37)	190 49.65 (36-72)	243 47 (28-72)	228 37 (/)
Compared Models	Unitary vs WM-Inhibition	Unitary vs WM-Inhibition	Unitary vs EF-WM	Nine factors Unitary factor WM/Shifting/Common factor WM/Shifting/inhibition WM/Shifting/inhibition (unrelated) WM-Shifting/Inhib. WM-Inhibition/Shift. Shifting-Inhib./WM	WM/Inhibition WM/Interference from distractors/ Proactive interference WM/Motor inhibition/Cognitive Inhibition General executive control	Unitary vs WM-Inhibition
Task	*WM* Word Span Reversed Listening Span Size Ordering Animal House *Inhibition* Day-Night Stroop Knock Tap Picture Imitation Bird & Dragon	*WM* Boxes Task BDS BWS *Inhibition* Boy-Girl Stroop Preschool CPT Go/No-Go Block 1	*WM* Imitation Sorting Task Memory Span Spin the Pots *Inhibition* Shape Stroop Circle Tracing Tower Building Reverse Categorization	*WM* WM Boxes WM Updating WM Grid *Inhibition* Inhibition Boxes Inhibition Cylinder Inhibition Grid *Shifting* Shifting Shelf Shifting Boxes Shifting Tray	*WM* Delayed Alternation task Six Boxes task Digit Span *Inhibition* Delayed Response task Whisper task NEPSY Statue NEPSY Visual Attention Shape School task Tower of Hanoi CPT	*WM* Nine Boxes Nebraska Barnyard Delayed Alternation *Inhibition* Big-Little Stroop Go/No-go Shape School-Inhibit Condition Snack Delay

(b) Two-factor models

	Two factors							
References	Hume (2015)	Lerner & Lonigan (2014)	Lonigan et al. (2016)	Miller et al. (2012)	Miller et al. (2013)	Monette et al. (2015)	Mulder et al. (2014)	Usai et al. (2014)
Sample, N Age(range)	120 52.42 (48-57)	289 55.74 (45-63)	241 54.23 (38-69)	129 50.45 (36-68)	129 50.04 (36-68)	275 68.43 (/)	2437 28 (20-37)	175 68.5 (63-76)
Compared Models	Unitary WM/Inhibition	WM/Inhibition WM-Response conflict/Int. supp. WM-Inib. Supp./Response conflict WM/In.supp./Response conflict	Unitary WM/Inhibition	Unitary WM/Inhib-shifting WM-shifting/Inhib. WM/Inhib./Shift.	Unitary WM/Inhibition WM/Inhibition (unrelated)	Unitary WM/Inhib-shifting WM-shifting/Inhib. WM/Inhib./Shift.	Cool/hot	Unitary Inhib./WM-shift Inhib/WM/Shift
Task	*WM* Word Span Reversed Listening Span Size Ordering Animal House *Inhibition* Day-Night Stroop Knock Tap Picture Imitation Bird & Dragon	*WM* Word Span Reversed Size Ordering Object Span Listening Span *Inhibition* Day-Night Stroop Bird and Dragon Luria's Hand Game Picture Imitation Block Sorting Knock Tap	*WM* Size Ordering Word Span Reversed Listening Span Animal Span *Inhibition* Day-Night Stroop Knock Tap Picture Imitation	*WM* Boxes Task BDS BWS Preschool CPT (omission errors) *Inhibition* Preschool CPT (commission error) Boy-Girl Stroop Go/No-Go Block Tower of Hanoi *Shifting* DCCS Go/No-Go Block 2 Go/No-Go Block 3	*WM* Boxes Task BDS BWS P-CPT *Inhibition* Boy-Girl Stroop Tower of Hanoi Go/No-Go	*WM* BWS Backward Block Span *Inhibition* Day-Night Stroop Fruit Stroop Hand Stroop *Shifting* Trails-P Card Sort Verbal Fluidity Shift Face Sort	*Cool EF* Visual search Six boxes Memory for location *Hot EF* Snack task Delay task	*WM* BDS Dual request selective task *Inhibition* Circle Drawing Tower of London *Shifting* Semantic fluency DCCS
Results	WM/Inhibition	WM/Inhibition	WM/Inhibition	WM-shifting/Inhibition	WM/Inhibition	Inhibition/WM-Shifting	Cool EF/hot EF	Inhibition/WM-Shifting

2.2.1 Which theoretical model received more empirical confirmation?

Table 1 outlines the models tested in the studies included in this systematic review alongside the models that were accepted based on fit indices. The results vary greatly among considered studies, with six studies supporting a one-factor model as the best fitting model (Hume, 2015; Miller et al., 2012; Panesi & Morra, 2021; Völter et al., 2022; Wiebe et al., 2008; Wiebe et al., 2011) and eight studies favouring a two-factor model (Hume, 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Mulder et al., 2014; Usai et al., 2014). These findings indicate that there is no consistent pattern across studies concerning the latent structure of EF, suggesting that methodological differences may explain the lack of a clear consensus.

2.2.2 How many and which models were analyzed?

The differences of models tested in the studies is notable. Five studies compared two models (Hume, 2015; Lonigan et al., 2016; Mulder et al., 2014; Panesi & Morra, 2021; Wiebe et al., 2011). Two studies evaluated three models (Miller et al., 2013; Usai et al., 2014), while Monette and colleagues (2015) assessed four models. Furthermore, four studies examined five or more models, exploring up to eight different alternative models (Lerner & Lonigan, 2014 tested five models; Miller et al., 2012 tested six models; Wiebe et al., 2008 tested seven models; Völter et al., 2022 tested eight models). This variety underscores the complexity of determining the most appropriate EF model and highlights the importance of considering multiple model configurations to fully understand the structure of EF.

A key aspect of the studies is the number of factors considered. One-factor and two-factor models were most frequently tested. Specifically, twelve studies evaluated a one-factor model (Hume, 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Mulder et al., 2014; Panesi & Morra, 2021; Usai et al., 2014; Völter et al., 2022; Wiebe et al., 2008; Wiebe et al., 2011), and an equal number investigated two-factor models (Hume, 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Monette et al., 2015; Mulder et al., 2014; Miller et al., 2013; Panesi & Morra, 2021; Usai et al., 2014; Völter et al., 2022; Wiebe et al., 2008; Wiebe et al., 2011). Of these, six studies explored more than one two-factor model (Lerner & Lonigan, 2014; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Völter et al., 2022; Wiebe et al., 2008). Additionally, the fit of three-factor models was analyzed in six studies (Lerner & Lonigan, 2014; Miller et al., 2012; Monette et al., 2015; Usai et al., 2014; Völter et al., 2022; Wiebe et al., 2008), with two of these studies examining alternative three-factor models (Völter et al., 2022; Wiebe et al., 2008). Remarkably, Völter and colleagues (2022) also tested a comprehensive nine-factor model, underscoring the complexity and breadth of their analytical approach.

It is noteworthy that among the studies supporting a unitary model, many only compared one-factor and two-factor models. Conversely, in the subset of research endorsing a two-factor model, four studies also evaluated three-factor models. This selective approach can potentially restrict the outcomes: CFA inherently depends on the range of models hypothesized by researchers. As such, the final model identified is intrinsically linked to the models included in the comparative analysis.

It is important to note that some studies investigating the validity of a three-factor model did not conceptualize three distinct EF (e.g., WM/updating, inhibition, and shifting); instead, they hypothesized that one function comprised multiple subcomponents for each EF. This approach was adopted for example by Wiebe and colleagues (2008) and Lerner and Lonigan (2014), both of whom considered various subcomponents of inhibition within their models. This suggests a nuanced understanding of EF, where single functions may have internal subdivisions that influence cognitive processing, but makes it hard to compare models from different manuscript because the number of tasks was often restricted making it hard to also test the presence of subcomponents within the three EF.

2.2.3 Which latent variables received more attention?

The majority of studies predominantly focused on WM and inhibition. WM was featured in eleven studies (Hume et al., 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Panesi & Morra, 2021; Usai et al., 2014; Völter et al., 2022; Wiebe et al., 2008; Wiebe et al., 2011), and inhibition was explored in ten (Hume et al., 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Usai et al., 2014; Völter et al., 2022;

Wiebe et al., 2008; Wiebe et al., 2011). Shifting, however, was considered in only four studies, always alongside WM and inhibition (Miller et al., 2012; Monette et al., 2015; Usai et al., 2014; Völter et al., 2022). One study examined a general EF factor independent of WM (Panesi & Morra, 2021), and another differentiated between 'Cool' and 'Hot' EFs (Mulder et al., 2014).

As previously discussed, the selection of latent variables models significantly influences the results of the CFA. Notably, few studies incorporated shifting into their hypothesized models, which complicates direct comparisons across different studies. Despite the impact of the type and number of latent variables on the model outcomes, these factors alone are insufficient for definitive conclusions. Eight studies focused exclusively on WM and inhibition, but not included shifting (Hume et al., 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Wiebe et al., 2008; Wiebe et al., 2011). Intriguingly, these studies resulted in both one-factor and two-factor models, suggesting that different study might yield different results.

2.2.4 How were the employed tasks informative of the constructs?

A significant issue that may account for the inconsistencies observed among studies concerning the latent structure of EF is the selection of tasks used for assessment. The type, number, and association of indicators can produce different results.

First of all, we can notice an extremely high variability in the tasks employed to measure the same latent variables: most measures were employed only in one study, with few exceptions: for example, the Backward Word Span (Miller et al., 2012; Miller et al., 2013; Monette et al., 2015) and the Stroop Day/Night Task (Hume, 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Monette et al.; 2015) were the tasks which were employed most often and consistently across different studies.

Analyzing the tasks used across studies is complicated by the frequent use of different names for very similar tasks. For instance, the task named "Word Span Reversed" by Lerner and Lonigan (2014) and Lonigan et al. (2016) is essentially the same as "Backward Word Span," despite the naming difference. Similarly, Panesi and Morra (2021) refer to an inhibitory task as "Circle Tracing," whereas Usai and colleagues (2014) call a comparable task "Circle Drawing Task." This pattern extends to Stroop tasks like the Day-Night, Knock Tap, and other variants, which all involve inhibiting a prepotent response in favor of an incongruent one but use different stimuli to elicit the Stroop effect. Furthermore, tasks that are based on the span process, such as Word Span Reverse, Listening Span, and others, require recalling an increasing number of elements. These tasks often employ different materials, adding another layer of complexity. Additionally, the format of the tests varies, with some conducted on paper and others computerized, which can influence the task outcomes. Moreover, even when the same task is used, most studies adopt different scoring procedures, making direct comparisons between tasks used in different studies even more challenging.

A significant methodological issue arises when the same task is employed to assess different EF factors across studies. For instance, the Preschool Continuous Performance Test (CPT) was used to evaluate both WM and inhibition; Miller et al. (2013) used it to measure WM, while Miller et al. (2012) and Wiebe et al. (2008) used it for assessing inhibition. Notably, Miller et al. (2012) used the Preschool CPT to indicate both WM and inhibition within the same study. Similarly, the Go-No Go Task was utilized by the same group to assess both shifting and inhibition. This issue extends to different EF factors being measured by the very same tasks. For example, Panesi and Morra (2021) used the Circle Tracing task to assess a generic EF factor, whereas Usai et al. (2014) used it specifically for inhibition. The Six Boxes task was another example, employed both to measure cool EF in the study by Mulder et al. (2014) and WM by Wiebe et al. (2008). Furthermore, the Snack Delay task was used to assess both hot EF and inhibition in different studies. Such practices can complicate the interpretation of results, as they may not only reflect the intended cognitive processes but also overlapping or unrelated cognitive demands.

Furthermore, some of the studies included in the present systematic review used tasks measuring abilities often different from those that they are traditionally intended to. For example, Miller and colleagues (2012; 2013) and Wiebe and colleagues (2008) employed the Tower of Hanoi, and Usai and colleagues (2014) used the Tower of London. These two tasks are generally used as a measure of planning, while in these cases they were employed as measures of inhibition. This may be due to the fact that young children performance in these tasks is significantly affected by children's ability to respect the rules, rather than their emerging planning ability (see also Bull, Espy, & Senn, 2004), This was suggested by other empirical evidence, like Lehto and colleagues (2003) and Senn, Espy and Kauffman (2004). This evidence suggest that children may approach to the task in different ways, making hard to understand how the use of certain tasks is informative of the constructs they would assess.

Table 1 illustrates that there are considerable differences in the number of indicators used to measure each latent variable in the studies reviewed. A few studies used only two indicators, the minimum required for inclusion in this review (Monette et al., 201; Mulder et al., 2014; Usai et al., 2014). Most studies employed three or four indicators (Hume, 2015; Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Monette et al., 2015; Mulder et al., 2014; Panesi & Morra, 2021; Völter et al., 2022; Wiebe et al., 2008; Wiebe et al., 2011). Notably, two studies used more than four indicators to measure EF, Lonigan and colleagues (2016) used six indicators and Wiebe et al. (2008) used seven indicators to assess inhibition. It is also worth noting that no study used the same number of indicators uniformly for each EF component. For instance, eight studies varied in the number of indicators for each EF component (Lerner & Lonigan, 2014; Lonigan et al., 2016; Miller et al., 2012; Monette et al., 2015; Mulder et al., 2014; Panesi & Morra, 2021; Wiebe et al., 2008; Wiebe et al., 2011), with Wiebe et al. (2008) presenting the widest range—three indicators for WM and as many as seven for measuring inhibition. Only four studies included in this review included a consistent number of indicators for each EF factor (Hume, 2015; Miller et al., 2013; Usai et al., 2014; Völter et al., 2022). This wide variability in the choice and number of indicators highlights the challenges in comparing results across different studies and emphasizes the need for more consistent methods for assessing EF.

2.2.5. How does the range of age affect the structure of EF?

Table 1 clearly shows that the age ranges of preschooler samples in the studies are not uniform. Four studies encompassed the entire preschool range of 3 to 6 years old (Lonigan et al., 2016; Miller et al., 2012; Miller et al., 2013; Völter et al., 2022), while Wiebe et al. (2008) extended their study to include children from 2 to 6 years old. Other studies targeted narrower age spans; for instance, Usai et al. (2014) focused on children between 5 and 6 years old, Lerner & Lonigan (2014) on 4 to 5-year-olds, and two studies (Mulder et al., 2014; Panesi & Morra, 2021) included children between 2 and 3 years old. Hume (2015) examined two distinct groups, one aged 3-4 years and another aged 4-5 years. Notably, Monette et al. (2015) did not specify the age range of their sample, whereas Wiebe et al. (2011) reported that children were assessed within three weeks of their third birthday.

It is evident from the review that all studies resulting in a one-factor model involved children up to four years old. Conversely, studies that identified a two-factor model generally included children aged four to five years. The only exception was the study by Mulder and colleagues (2014): in this particular paper the authors found a distinction between diverse EF in younger children, but this distinction was between cool and hot EF. In sum, among studies which used the same classification of EF seems clear that EF are a unique factor in 3-year-old children, and separated in two factors, which distinguish WM and inhibition, in 5-year-old children; four years may be considered as a transition age.

3. Metanalysis

With this paper we also aimed to investigate the relationship between latent variables with a metanalysis. As previously noted, WM and inhibition are probably the most assessed constructs across different studies. As we intended to include as many studies as possible, we decided to focus on these factors, investigating their latent correlations.

3.1. Method

From the set of studies that we included in the systematic review, we focused on the ones which investigated the functions of WM and inhibition calculating latent correlations between these two constructs. Therefore, we needed to exclude Mulder and colleagues' study (2014), since they classified EF as cool and hot and they did not take into account WM and inhibition. Furthermore, Hume's article (2015) included separate analysis for 3- and 4-year-old children. Finally, we decided to include Panesi and Morra's work (2021) because, they employed WM tasks, alongside with measures of Inhibition, even if they were considered tapping the same underlying EF factor in the original report.

Studies indicating a latent correlation of one or exceeding one were not included in our analysis (Hume, 2015 – 4-year-old children; Völter et al., 2022; Wiebe et al., 2008), since is not possible to calculate standard errors and variances under these circumstances. Furthermore, we every latent correlation in the meta-analysis was calculated based on the correlation matrix presented in the original report. The final dataset consisted in nine latent correlations between the inhibition and WM factors. Following the guidelines provided by Borenstein, Hedges, Higgins, and Rothstein (2009), the correlations were converted to Fisher's *z′* score, and then converted back to the correlation metric. A random effect model was used. Standard errors were calculated using the formula 1/(N-3). The "metafor" package for R (Viechtbauer, 2010) was used for the analyses.

3.2. Results

The meta-analytic estimate was r = 0.66, 95% CI [0.59, 0.71]) indicating that there was a strong positive relationship between inhibition and WM factors (Figure 2). There was significant variability among the effects, Q(8) = 33.67, p < 0.001. The funnel plot used to examine the effect of publication bias did not report asymmetry, as showed in Figure 3.

Figure 2. Forest plot. The correlation on the bottom row indicates the overall meta-analytic effect.

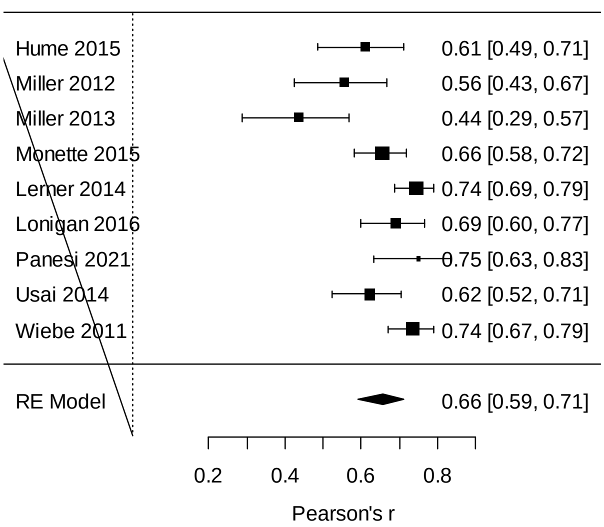
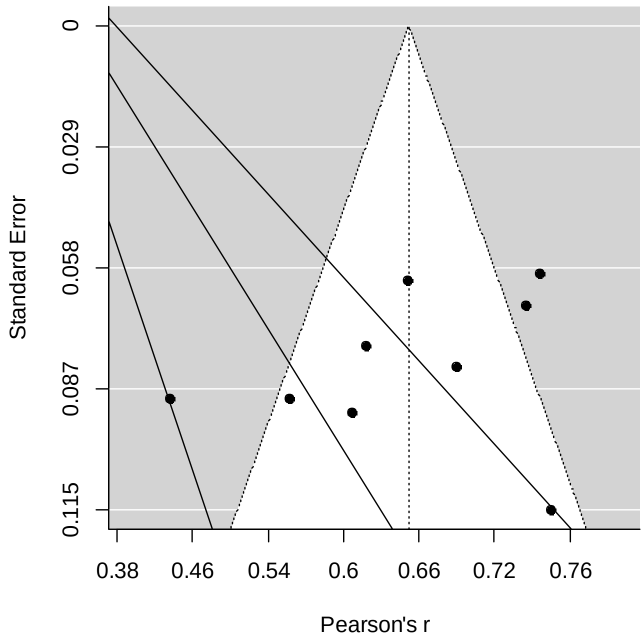


Figure 3. Funnell plot



4. General discussion

The structure of executive functions (EF) in adulthood is widely supported by the three-component model proposed by Miyake and colleagues, which has become well-established (Miyake et al., 2000; Miyake & Friedman, 2012). However, consensus on the EF structure during childhood remains elusive. Developmental studies yield conflicting results, particularly for preschool-aged children: some researchers advocate for a unitary structure of EF, while others support models with two distinct components, as highlighted by Karr et al., 2018. These authors conducted a systematic review of EF models across various age groups, including preschoolers, but did not focus exclusively on them. Their objective was to evaluate the empirical support for different EF models using confirmatory factor analysis (CFA) to determine which models best fit the data. The study synthesized findings from existing research to identify the most robust and accurate models of EF, contributing to a broader understanding of how EF is conceptualized and measured across diverse populations. Compared to this work, the present systematic review shares some objectives and adds new ones. Like Karr et al. (2018), our main goal was to critically examine the latent structure of EF in existing literature. However, unlike Karr et al. (2018), we decided to focus only on preschooler population. Furthermore, we aimed to elucidate the reasons for observed inconsistencies and offer guidance for structuring future research to better understand EF development. For this purpose, our analysis focuses on the factorial models analyzed, the EF components considered, the number and types of tasks used for assessment, and the age range of the study samples. Additionally, this review attempts to meta-analyze the latent correlations between WM and inhibition, aiming to clarify these relationships in early childhood.

As expected, our review uncovered several inconsistencies in the existing literature. Nearly half of the studies supported a one-factor model, while the rest advocated for a two-factor model. This division underscores the difficulty in identifying a universally accepted model, prompting a reflection on the caveats that significantly impact the outcomes of various studies. We noted substantial variations across studies, particularly in the type and number of models tested; there was a prevalent comparison between one- or two-factor models among studies favoring a single-factor model, and an introduction of three-factor models in those identifying a two-factor model. Regarding the choice of latent variables, there was more consensus: most studies included WM and inhibition, while a subset adhered to Miyake's classical model from 2000, also incorporating shifting. However, a minority of studies explored different operationalizations of EF, such as the distinction between cool EF and hot EF, following the framework proposed by Zelazo and Muller (2002).

A critical issue we observed is the high variability in the tasks employed to measure the same latent factors across different studies, often using very distinct tasks. This variability, coupled with ambiguities such as similar tests presented under different names, which can significantly affect the results. Furthermore, the use of tests far removed from their original intended purposes adds to this complexity (e.g., using a task originally intended to measure planning to measure inhibition). Another problem relies to the use of very similar tasks to measure the same factor. For example, Miller and colleagues (2013) assessed WM using both Backward Word Span and Backward Digit Span. The high correlation observed between these tasks—due to their shared nature as span tasks involving verbal inputs—may not truly reflect the underlying latent variable variance (Cole et al., 2007). This suggests that employing a broader variety of measures could mitigate such issues. Additionally, the problem of task impurity arises when tasks designed to measure specific cognitive processes inadvertently require multiple cognitive functions. This impurity can lead to skewed conclusions about the specific cognitive processes being examined. This issue is exacerbated in studies like those by Miller et al. (2012), Miller et al. (2013), and Monette et al. (2015), which utilize the same tasks but different scoring methods in studies. The highly correlated errors from these indices can complicate result interpretation (Kline, 2015). Additionally, problems arise when tasks are allowed to load on different latent factors, as seen in Monette et al. (2015) and Miller et al. (2012), where indicators from the same tasks are loaded onto different latent variables. This method can obscure the distinction between EF factors.

Given the aforementioned issues, it is important to consider whether CFA is always the appropriate for identifying the latent structure of EF, if the measures included are two strongly correlated or pertaining the very same task, for example. CFA starts with a theoretical model that highlights the relationships among the variables in a given model, commonly referred to as the measurement model. This model is then compared against the observed data to evaluate the model's fit; this involves assessing how well the covariance matrix, as estimated from the available data, replicates the observed covariance matrix. However, if there are methodological biases related to the choice of indicators or variables, the results from CFA might not be entirely reliable. These biases could significantly influence the model, and by extension, the interpretations drawn about the latent structures of EF. This question is highlighted by Miller et al. (2012): in their study, they tested two different sets of models: firstly, they tried to replicate the structure found by Wiebe et al. in 2008, administering WM and inhibition tasks; in this case, they accepted a one-factor model. Secondly, they added some performance indicators to distinctly measure WM, shifting, and inhibition factors. As result, a two-factor model consisting of a WM-shifting factor and an inhibition one fit the data better than a single-factor model. Thanks to these findings, the authors suggested that the structure of EF in preschoolers that emerges from CFA was influenced by task and performance indicator selection.

Concerning the age range, we observed that the age range was very heterogeneous across different studies. Our review indicates that studies with samples of children under four years old typically identified a one-factor model, whereas those with children older than four years found two-factor models. These results imply that EFs may differentiate as children develop, with the age around four and a half years potentially marking a critical transition stage from a unitary to a bifurcated EF structure.

The results of our meta-analysis provide additional insights into the structure of EF in preschool children, particularly through an analysis of the correlations between inhibition and WM at the latent level. A significant correlation of .66 was observed, underscoring a strong relationship between these two EF components. This finding corroborates the observations by Panesi and colleagues (2020), who noted a particularly strong link between WM and inhibition. This correlation might be explained by the theoretical model proposed by Im-Bolter and colleagues (2006), which posits that WM and inhibition are overarching resources that develop concurrently and interactively throughout childhood. Additionally, this result supports Miyake and colleagues' (2000) hypothesis that all EF components are, to some extent, dependent on WM. Recent studies, including those by Lerner and Lonigan (2014), further validate this relationship, indicating that preschoolers with lower WM capacities tend to perform less proficiently on tasks requiring inhibition, highlighting the crucial role of WM in preschool children.

While this study has yielded important insights, it also highlights several areas for improvement in future research. To broaden our understanding of EF in preschoolers, it is crucial to expand beyond primarily measuring inhibition and WM. Including tasks that assess shifting—a component seldom explored in this age group—could provide a more comprehensive view of EF. The choice of tasks used in CFA is critical. Future studies should avoid using tasks that are intrinsically highly correlated or employing different scores from the same task within their models, as this can complicate the interpretation of the CFA. Although using two indicators per latent factor is common, this can lead to problems in the estimation of the latent variables for these factors (Kline, 2015). A more extensive array of tasks, ideally with a consistent number of indicators for each latent factor, would enhance model reliability and validity. Moreover, employing more than two indicators for each latent variable and avoiding similar tasks could improve the robustness of the findings.

Careful consideration of the age range of participants is also essential; employing a large, comprehensive battery of tests across a broad cohort of children for each individual age can significantly aid in understanding the nuanced structure of EF in preschoolers. Finally, as developmental changes are continually occurring, conducting longitudinal studies would be invaluable. These studies could identify when and how relationships between factors changes, and pinpoint critical periods in the development of EF.

It also important to highlight some limits of the current review. Regrettably our review was limited by the paucity of research on this area yielding to a small number of studies considered. Our inclusion criteria were intentionally stringent to ensure a reasonably homogeneous set of studies. We specifically focused on research that examines the latent structure of EF using CFA, widely regarded as the most effective method for confirming the structure of EF (Miyake et al., 2000). However, a different approach may have allowed to consider other studies on EF structure form both white and grey literature. In this regard, it is important to acknowledge that alternative conceptualizations of EF exist, along with different analytic strategies for exploring their nature (e.g., Camerota, Willoughby, and Blair, 2020; Doebel, 2020; Willoughby, Holochwost, Blanton, & Blair, 2014). Future reviews should consider including studies that address these broader perspectives to provide a more comprehensive understanding of EF across various age groups and theoretical frameworks. The meta-analysis conducted was based on a limited number of studies, which is not ideal. We recommend that future meta-analyses include a larger pool of studies to enhance the robustness of the findings. However, the availability of a more extensive dataset is contingent upon the publication of additional research focused on preschool children, which is currently sparse. It is also important to note that the small sample size in our analysis precluded the testing for potential moderators (e.g., age).

In conclusion, this systematic review has highlighted the complex and multifaceted nature of EF in preschool children. Our findings reveal significant variability in the conceptualization and measurement of

EF, influenced heavily by the choice of tasks, the models employed, and the age of the participants. Therefore, although Some studies suggest a unitary structure of EF among younger preschoolers and others point towards a differentiated model as children approach school age, future studies are needed to verify whether these results are confirmed even when different construct are included (e.g. inhibition, shifting, updating, WM) and diverse methodological approaches are employed. Additionally, our meta-analysis of the latent correlations between WM and inhibition contributes to a deeper understanding of these functions' interdependencies. As we move forward, it is crucial that future studies refine EF measurement strategies, expand the range of considered variables, and embrace longitudinal designs to track changes across time. By continuing these efforts, we aim to better understand the complex aspects of cognitive development that support children's learning and growth during these critical early years.

5. References

Baddeley, A. (1986). Oxford psychology series, No. 11. Working memory. New York, NY, US.

Baddeley, A. (2003). Working memory: looking back and looking forward. Nature reviews neuroscience, 4(10), 829.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. Child development, 81(6), 1641–1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2009). Introduction to meta-analysis. John Wiley & Sons, Ltd.

Camerota, M., Willoughby, M. T., & Blair, C. B. (2020). Measurement models for studying child executive functioning: Questioning the status quo. Developmental Psychology, 56(12), 2236. https://doi.org/10.1037/dev0001127

Carlson, S.M. (2005) Developmentally Sensitive Measures of Executive Function in Preschool Children. Developmental Neuropsychology, 28:2, 595-616. https://doi.org/10.1207/s15326942dn2802_3

Cole, D. A., Ciesla, J. A., & Steiger, J. H. (2007). The insidious effects of failing to include design-driven correlated residuals in latent-variable covariance structure analysis. Psychological methods, 12(4), 381–398. https://doi.org/10.1037/1082-989X.12.4.381

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168 https://doi.org/10.1146/annurev-psych-113011-143750

Doebel, S. (2020). Rethinking executive function and its development. Perspectives on Psychological Science, 15(4), 942-956. https://doi.org/10.1177/1745691620904771

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Review, 134, 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Garon, N., Smith, I. M., & Bryson, S. E. (2014). A novel executive function battery for preschoolers: Sensitivity to age differences. Child Neuropsychology, 20(6), 713-736. https://doi.org/10.1080/09297049.2013.857650

Godefroy O, Cabaret M, Petit-Chenal V, Pruvo JP, Rousseaux M. Control functions of the frontal lobes. Modularity of the central-supervisory system? Cortex. 1999 Feb;35(1):1-20. doi: 10.1016/s0010-9452(08)70782-2

Himi, S. A., Bühner, M., & Hilbert, S. (2021). Advancing the understanding of the factor structure of executive functioning. Journal of Intelligence, 9(1), 16. https://doi.org/10.3390/jintelligence9010016

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2009). Tracking executive function across the transition to school: A latent variable approach. Developmental Neuropsychology, 35(1), 20-36. https://doi.org/10.1080/87565640903325691

Hughes, C., & Graham, A. (2002). Measuring executive functions in childhood: Problems and solutions?. Child and adolescent mental health, 7(3), 131-142. https://doi.org/10.1111/1475-3588.00024

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variables analysis. Neuropshychologia, 44, 2017–2036. https://doi.org/10.1016/j.neuropsychologia.2006.01.010

Hume, L. E. (2015). The Structure and Nature of Executive Functions in 3- and 4-Year-Old Children. Retrieved from http://purl.flvc.org/fsu/fd/FSU_migr_etd-9617

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. Child Development, 77, 1822–1841. https://doi.org/10.1111/j.1467-8624.2006.00976.x

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The unity and diversity of executive functions: A systematic review and re-analysis of latent variable studies. Psychological Bulletin, 144(11), 1147–1185. https://doi.org/10.1037/bul0000160

Kline, R. B. (2015). Principles and Practice of Structural Equation Modeling, 4th edition. New York: Guilford Press

Lee, K., Bull, R., & Ho, R. M. H. (2013). Developmental changes in executive functioning. Child Development, 84, 1933–1953. https://doi.org/10.1111/cdev.12096

Lehto, J. E., Juujarvi, P., Kooistra, L., & Pulkinnen, L. (2003). Dimensions of executive functioning: Evidence from children. British Journal of Developmental Psychology, 21, 59–80. https://doi.org/10.1348/026151003321164627

Lerner, M. D., & Lonigan, C. J. (2014). Executive function among preschool children: Unitary versus distinct abilities. Journal of Psychopathology and Behavioral Assessment, 36, 626–639. https://doi.org/10.1007/s10862-014-9424-3

Lonigan, C. J., Lerner, M. D., Goodrich, J. M., Farrington, A. L., & Allan, D. M. (2016). Executive function of Spanish-speaking language-minority preschoolers: Structure and relations with early literacy skills and behavioral outcomes. Journal of Experimental Child Psychology, 144, 46–65. https://doi.org/10.1016/j.jecp.2015.11.003

Miller, M. R., Giesbrecht, G. F., Muller, U., McInerney, R. J., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. Journal of Cognition and Development, 13, 395–423. https://doi.org/10.1080/15248372.2011.585478

Miller, M. R., Müller, U., Giesbrecht, G. F., Carpendale, J. I., & Kerns, K. A. (2013). The contribution of executive function and social understanding to preschoolers’ letter and math skills. Cognitive Development, 28(4), 331–349. https://doi.org/10.1016/j.cogdev.2012.10.005

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. Current directions in psychological science, 21(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N.P., Emerson, M.J.; Witzki, A.H., HoWMrter, A. & Wager, T.D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. Cognitive Psychology, 41:1, 49-100 https://doi.org/10.1006/cogp.1999.0734

Monette, S., Bigras, M., & Lafrenière, M. A. (2015). Structure of executive functions in typically developing kindergartners. Journal of Experimental Child Psychology, 140, 120–139. https://doi.org/10.1016/j.jecp.2015.07.005

Morra, S., Panesi, S., Traverso, L., & Usai, M.C. (2018). Which tasks measure what? Reflections on executive function development and a commentary on Podjarny, Kamawar, and Andrews 2017. Journal of Experimental Child Psychology 167: 246–58. https://doi.org/10.1016/j.jecp.2017.11.004

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. British Journal of Psychology, 81, 111–121. https://doi.org/10.1111/j.2044-8295.1990.tb02349.x

Mulder, H., Hoofs, H., Verhagen, J., van der Veen, I., & Leseman, P. P. (2014). Psychometric properties and convergent and predictive validity of an executive function test battery for two-year-olds. Frontiers in Psychology, 5, 733. https://doi.org/10.3389/fpsyg.2014.00733

Norman D.A., & Shallice T. (1980). Attention to action: Willed and automatic control of behavior. Center for Human Information Processing, University of California, San Diego: Technical report n. 99.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In Consciousness and self-regulation: Advances in research and theory volume 4 (pp. 1-18). Boston, MA: Springer US.

Panesi, S. and Morra S (2021). Executive Function, Language, and the Toddler's Discovery of Representational Drawing. Frontiers in Psychology, 12:659569. https://doi.org/10.3389/fpsyg.2021.659569

Panesi, S., Bandettini, A., Traverso, L., & Morra, S. (2022). On the Relation between the Development of Working Memory Updating and Working Memory Capacity in Preschoolers. Journal of Intelligence 10: 5. https://doi.org/10.3390/jintelligence10010005.

Panesi, S. & Morra, S. (2020). Executive Functions and Mental Attentional Capacity in Preschoolers. Journal of Cognition and Development, 21:1, 72-91. https://doi.org/10.1080/15248372.2019.1685525

Senn, T.E., Espy, K.A., & Kaufmann, P.M. (2004). Using path analysis to understand executive function organization in preschool children. Dev Neuropsychol., 26(1):445-64. https://doi.org/10.1207/s15326942dn2601_5. PMID: 15276904.

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S. C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. Developmental neuropsychology, 35(6), 679–697. https://doi.org/10.1080/87565641.2010.508546

Shreffler J, Huecker MR. Type I and Type II Errors and Statistical Power. [Updated 2023 Mar 13]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK557530/

Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. Psychological bulletin, 95(1), 3. https://doi.org/10.1037/0033-2909.95.1.3

Tranel, D., Anderson, S. W., and Benton, A. (1994). Development of the concept of "executive function" and its relationship to the frontal lobes. In: Boller, F. and Grafman, J. (Eds.), Handbook of Neuropsychology (Vol. 9, pp. 125–148). Amsterdam: Elsevier.

Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in five-and six-year-old children: A longitudinal study. European Journal of Developmental Psychology, 11, 447–462. https://doi.org/10.1080/17405629.2013.840578

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. Intelligence, 35, 427–449. doi:10.1016/j.intell.2006.09.001

Viechtbauer, W. (2010). Conducting Meta-Analyses in R with the metafor Package. Journal of Statistical Software, 36(3). https://doi.org/10.18637/jss.v036.i03

Völter, C. J., Reindl, E., Felsche, E., Civelek, Z., Whalen, A., Lugosi, Z., Duncan, L., Herrmann, E., Call, J., & Seed, A. M. (2022). The structure of executive functions in preschool children and chimpanzees. Scientific reports, 12(1), 6456. https://doi.org/10.1038/s41598-022-08406-7

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. Developmental Psychology, 44(2), 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Wiebe, S., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. Journal of Experimental Child Psychology, 108, 436–452. https://doi.org/10.1016/j.jecp.2010.08.008

Willoughby, M., Holochwost, S. J., Blanton, Z. E., & Blair, C. B. (2014). Executive functions: Formative versus reflective measurement. Measurement: Interdisciplinary Research & Perspectives, 12(3), 69-95. https://doi.org/10.1080/15366367.2014.929453

Zelazo, P. D., Carter, A., Reznick, J. S., & Frye, D. (1997). Early development of executive function: A problem-solving framework. Review of General Psychology, 1(2), 198-226. https://doi.org/10.1037/1089-2680.1.2.198

Zelazo, P. D., & Muller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), Handbook of childhood cognitive development (pp. 445–470). Oxford, UK: Blackwell Publising.

WM and Updating in Preschoolers: Synonymous or Distinct Constructs? A Systematic Review

Abstract

Executive Functions (EF) are a set of higher-order cognitive processes that enable the implementation of goal-directed behaviours. While it is established that these functions are distinct in adults, there is no consensus in the literature on their structure in developmental ages, especially in the preschool period. Specifically, one debated aspect concerns the relationship between EF and Working Memory (WM), which is often considered a single construct along with the updating function. The present systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement and focused on studies which took into account WM and updating functions in preschool children. The relationship between WM and updating, the theoretical models to support the position of authors towards this relationship and the tasks employed to assess these constructs are discussed.

1. Introduction

When we talk about Executive Functions (EF) we refer to a set of higher-order cognitive processes, which are fundamental for self-regulation and for the implementation of goal-oriented behaviours, as they are responsible for monitoring and controlling thoughts, emotions and action. These processes, considered as domain-general, have a highly adaptive function and their contribution is very important, especially when we are faced with new situations or problems in which the implementation of automatic or impulsive responses would be inadequate or not sufficiently effective (Diamond, 2013). Miyake, Friedman, Emerson, Witzki, Howerter et al. (2000) identified three EF: shifting, inhibition, and updating. Specifically, shifting is defined as the ability to move attention from one task to another or from one operation to another; inhibition is defined as the ability to consciously inhibit dominant, automatic or overbearing responses when necessary and to process irrelevant or misleading information; updating is the monitoring and coding incoming information for relevance to the task at hand and then appropriately revising the items held in working memory (WM) by replacing old, no longer relevant information with newer, more relevant information. According to this perspective, EF seem to rely on WM, which can be defined as a system able to store and process information at the same time. In other words, WM keeps mental representations available so that they can be processed, selected, integrated, or transformed (Engle, Cantor & Carullo, 1992; Oberauer, Farrell, Jarrold, & Lewandowsky, 2016). Currently, the three-component model empirically identified by Miyake and colleagues (Friedman & Miyake, 2017; Miyake & Friedman, 2012) has become the most widely used theoretical model of EF in adulthood.

In the last few years, studies about the differentiation of EF proliferated in developmental literature, too. However, results on children are often not consistent with each other, especially in preschoolers. Some studies among this population, in fact, proposed a single factor for all executive functioning (e.g., Hughes, Ensor, Wilson, & Graham, 2010; Shing et al., 2010; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011), while other studies proposed a two-factor model (e.g., Lerner &; Lonigan, 2014; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Usai, Viterbori, Traverso, & De Franchis, 2014).

In relation to the difficulty in identifying the EF structure in a unique way, there are some open questions. One of the most debated concerns the relationship between WM and updating. Specifically, in literature there are contrasting claims about the overlapping or differentiation of these two constructs.

In adult research, WM and updating are considered as two different functions. As previously explained, Miyake et al. (2000) considered updating as an EF, relying on WM. Based on this model, several researchers considered updating as an EF in the service of WM. For example, a differentiation was confirmed by Himi, Bühner and Hilber (2021) thanks to a confirmatory factor analysis (CFA), from which updating and WM turned out to be separated but correlate latent variables in adults. Overall, most experimental and correlational studies suggest a relatively weak relationship between WM and updating (e.g., Kane, Brown, McVay, Silvia, Myin-Germeys, &. Kwapil., 2007). Redick and Lindsey in 2013 published a meta-analysis of 26 studies on n-back and complex span tasks in adults. Although both these tasks require maintaining and elaborate information, the underlying processes may be different. In the N-Back, one must report whether the item being presented matches that presented n items back, possibly updating the information. Differently, in complex span tasks subjects recall some items while also performing a secondary processing task. Redick and Lindsey's results indicated that the correlations between the complex span measures and n-back tasks were weaker than what would be expected for measures assessing the same underlying WM construct.

However, in developmental literature, WM and updating are often considered as synonyms. For instance, Garon, Bryson, and Smith (2008) conducted a review focusing on EF in preschoolers. They identified inhibition, shifting, and WM as key EF. Similarly, Diamond (2013) regarded inhibition, WM, and cognitive flexibility as EF that develop in young children. In these influential articles, WM is viewed as an EF, supplanting updating in Miyake' s model (2000).

On the other hand, there is another current of development researchers who emphasise the importance of verifying whether it could be useful to consider updating and WM as separate functions even in preschool children as it is for adults (see Morra, Panesi, Traverso, & Usai, 2018). Their belief has its roots in more recent WM models, which emphasize the role of attentional resources in keeping task-relevant information activated. Im-Bolter, Johnson, and Pascual-Leone (2006) conceptualized a two-level, four-component model. According to this model, in fact, there is a first underlying level which includes two general resources, which are inhibition and WM, while the second level includes the actual EF, which are shifting and updating. According to this theory, therefore, WM and inhibition are general mental resources, while shifting and updating skills are considered executive schemes that contribute to the control and coordination of both mental resources. Consequently, it is possible to identify a clear distinction between the constructs of WM and updating, which within this theoretical framework cannot be considered synonymous.

The distinction between WM and updating is also supported by empirical evidence. Traverso, Viterbori, and Usai (2015) used an adapted version of the Keep Track, which in 5-year-old children correlated mainly with inhibition measures and less with WM measures. Similarly, Panesi, and Morra (2017) created an updating test, the Magic House, which correlates more strongly with inhibition tests than with WM tests. In 2020, Panesi and Morra published a study whose results are consistent with the theory of Im-Bolter et al. (2006): the authors, in fact, identified a distinction between WM and inhibition measures; furthermore, it emerged that the shifting and updating measures were more correlated with inhibition than WM. In 2022 Panesi, Bandettini, Traverso, and Morra investigated the relationship between WM and updating in preschoolers through the administration of differentiated tests for the two constructs, noting how updating skills in this age group depend on WM but do not coincide with it.

This confusion between updating and WM in the literature on developmental age is partly justified by the fact that few tasks are available for children, especially for preschoolers. Miyake et al. (2000) choose three tasks to assess updating function in adulthood: Keep Track Task, Tone Monitoring Task, and Letter memory task. In all these tasks, the requirement was to update information in WM based on the goal of the task, storing new information and discarding those no longer relevant. These tasks were adapted for use with older children. For example, Agostino, Johnson, and Pascual-Leone (2010) adapted the Letter Memory task for 8- to 13-year-olds; van der Ven, Kroesbergen, Boom, and Leseman (2012) created a version for schoolchildren of the Keep Track Task; Sharma (2019, cited in Köder, Sharma, Cameron, & Garraffa,, 2022) developed the Animal Sounds Monitoring Task for children between 5 and 11, based on Tone Monitoring Task. However, it is difficult to find adaptation for younger children. In Italian landscape, Usai, Traverso, Gandolfi, and Viterbori (2017) published a battery to assess EF in preschoolers (FE-PS 2-6), which included a version of the Keep Track task for 4-6-year-old, adapted from Vander Sluis, de Jong and van der Leij (2007) and van der Ven and colleagues (2012). The task involved 20 figures from 5 categories, and children had to pay attention to specified categories before naming figures presented in sets of 6. Finally, the children had to repeat the last element relating to each chosen category. In 2017 the same year, Panesi and Morra developed an updating task for preschool children, called Magic House. In this task, each item shown to the child featured three, four or five toy animals placed sequentially left to right in a cardboard house. Subsequently, the child was required to recall the last two animals in the house. A special mention is deserved by N-back task, recognized as one of the most well-known updating tasks. As reported above, it involves presenting sequences of items to participants and prompting them to determine whether the current item matches the one displayed n steps earlier. To accomplish this, they must consistently retrieve items kept beyond their focus of attention, and subsequently replace the oldest item with the most recently presented one. In developmental literature it is frequently used to assess updating in children from school age (e.g., Duan, Wei, Wang & Shi, 2010; Im-Bolter et al., 2006). However, in other cases N-back is employed as a measure of WM. For example, Grey and colleague (2017) administered N-back auditory task and N-back visual task to a sample of 7 to 9 years olds to assess Central Executive, following the WM multicomponential model proposed my Baddeley (1992). Similarly, Zhang, Chang, Chen, Ma, and Zhou (2018) used the 2-back task to assess WM in a sample of children aged 10–13 years; even in this case, the theoretical background of the study followed Baddeley's model (1992).

Regarding the use of N-back in pre-schoolers, there are very few references in the literature and most of them treated it as a WM task. Mou, Berteletti, and Hyde (2018), for example, administered a revised version of the classic N-back task, in which children were presented with sequential images of objects (e.g., table, coat, umbrella) and required to determine whether a picture matched any previously viewed pictures (''same'') or differed from them (''different''). Images were reiterated either immediately (1-back) or after the introduction of one new picture (2-back). Another task adapted from adult literature is the Self-Ordered Pointing Task (SOPT, Petrides & Milner, 1982). In this task, the child must point to images in an array, one at a time, without pointing to the same image twice. The location of the images changes after each point. This task is usually used to measure WM (Cragg & Nation, 2007), although the task procedure seems to predominantly solicit the updating process.

In sum, there is a lot of confusion about the relationship between WM and updating, both from a theoretical and empirical point of view. Moreover, the ambiguity in terminology inevitably affects the choice of measurement tools. Studies treating updating and WM interchangeably employ tasks associated with both constructs indiscriminately. Conversely, researchers distinguishing these functions as separate skills utilize distinct tasks for their measurement.

The aim of the present systematic review was to contribute to clarity about this issue: we critically examined studies which took into account WM and updating functions in preschool children, with a specific focus on the tasks employed to assess these constructs. Specifically, our goals were to: (a) investigate the relationship between WM and updating in preschool literature; (b) investigate the theoretical models to support the position of authors towards this relationship; (c) analyse the tasks employed to assess these constructs.

2. Method

In developmental literature, the difference between the constructs of WM and updating still represents an important open question. For this reason, we considered both studies which considered WM and updating as synonymous and studies which considered them two different functions, as well as we included both studies which considered WM as an EF and those which considered it as a separate cognitive ability.

The present systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2009). The flow chart shown in Figure 1 explains the search and selection process, which lead to the final set of articles included in this review.

2.1 Literature Research

Literature search was conducted on 15th January 2022 in the following databases: PsycINFO, PsycArticles, Pubmed. Furthermore, we included the so-called grey literature from ProQuest, in order to reduce the effect of publication bias. In particular, we chose to include thesis dissertations. For all the databases, the following keyword have been used: “updating” or “update” or "keep track" or "n-back" or "self order pointing task" or "Magic House" AND “working memory” or “M capacity” or “attentional capacity” or “memory span” AND “child*” or “presch*”. In PsycINFO, PsycArticles and Pubmed, these keywords could be present in all fields; however, in ProQuest they must be present only in the abstract, in order to better identify the studies we interested for our review. Finally, no filters were applied regarding the publication period; the search included all articles ever published.

2.2. Abstract screening

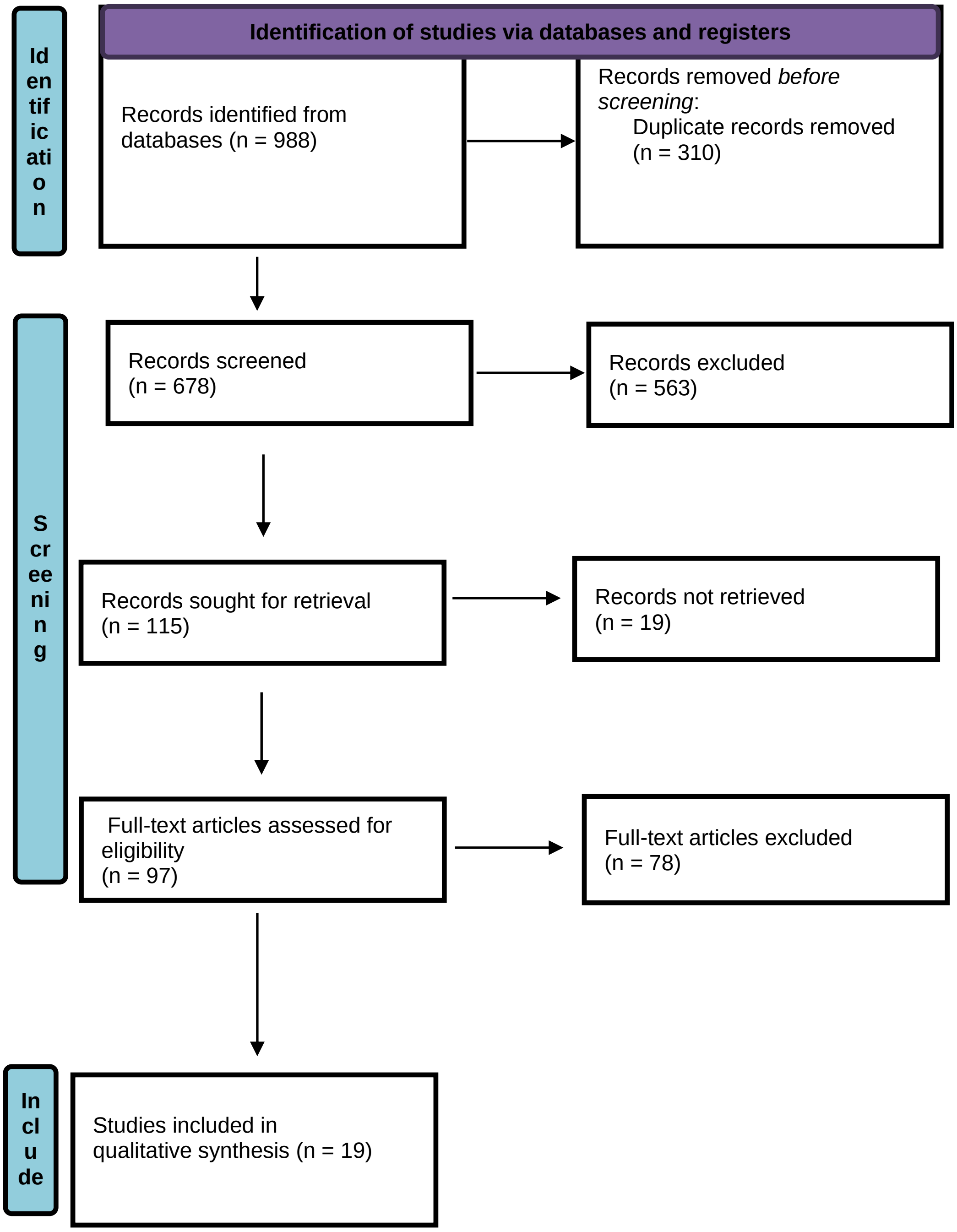
At the end of the search process, a total of 988 abstract were identified. After removing duplicates, 678 papers remained. Two authors independently and blindly reviewed 247 articles, corresponding to 25% of total abstracts. Agreement between reviewers was 100%. The selection process followed a set of inclusion criteria: (1) articles published on scientific journals or thesis; (2) English language; (3) participants were children under 7 years old; (4) samples consisted of typically developing children; (4) participants were humans; (5) empirical studies; (6) updating and/or WM were assessed; (7) performance-based tasks were used to assess these functions.

We decided to focus our review only on studies that recruited typically developing samples, as differences in EF and WM often occur in atypical developing children furthermore, we chose to include only studies that included performance-based measures of updating and WM, excluding articles in which only questionnaire-based assessment of EF was used, as questionnaire-based and performance-based assessment of EF seem to be poorly correlated (Conklin, Salorio, & Slomine, 2008; McAuley, Chen., Goos, Schachar, & Crosbie, 2010; Sølsnes, Skranes, Brubakk & Løhaugen, 2014). If the abstracts did not provide enough information to determine inclusion or exclusion, the articles were included in the phase for full text screening.

2.3 Full-text screening

At the end of the abstract screening, 115 references were included for the next phase. However, only 97 full-text articles were retrieved. We continued the selection with the same inclusion criteria used for screening the abstracts. This phase resulted in 19 studies which met the inclusion criteria.

Figure 1. Search and selection process



3. Results

3.1. Demographic characteristics

Table 1. *Demographic characteristic*

Authors	N	Age (Mean)	Age range	%F
Abeles & Morton (2000)	180	-	36-48	-
Belacchi et al. (2010)	23	59.21	-	52
Dauvier et al. (2012)	79	70.8	65–77	54
Di Lieto et al. (2020)	187	-	66-78	48
Hartstein et al. (2018)	45	36.2	33-39	-
Kolkman et al. (2013)	47	71.28	-	47
Lee & Bull (2016)	-	68.64	-	-
Mou et al. (2018)	131	46	43-51	-
Panesi & Morra (2016)	123	53.1	36–73	47
Stadtmiller et al. (2021)	57	63	60–67	51
Traverso et al. (2015)	75	68.6	62 - 76	53
Traverso et al. (2020)	90	68	62–76	54
Troller-Renfree et al. (2020)	40	64.2	-	54
Verswijveren et al. (2020)	100	43.92	30.12–60	54
Voigt et al. (2014)	33	-	60-72	-
Webster et al. (1997)	15	45.20	-	-
Whitely et al. (2013)	21	70.8	-	-
Willoughby et al. (2019)	6040	67.4	-	-
Zeytinoglu et al. (2017)	278	48	-	-

Note: Age (mean) and age range are expressed in months.

Demographic characteristics for each sample included in the present systematic review are reported in Table 1. It is possible to notice a high heterogeneity of sample sizes, which varies between 15 and 6040 subjects. Moreover, the age ranges differ from each other: some studies are focused on younger preschoolers (Abeles & Morton, 2000; Belacchi et al., 2010; Hartstein et al., 2018; Mou et al., 2018; Webster et al., 1997). Others focused on older preschoolers (Dauvier et al., 2012; Di Lieto et al., 2020; Kolkman et al., 2013; Lee & Bull, 2016; Stadtmiller et al., 2021; Traverso et al., 2015; Traverso et al., 2020; Troller-Renfree et al., 2020; Voigt et al., 2014; Whitely et al., 2013; Willoughby et al., 2019; Zeytinoglu et al., 2017). Finally, some samples covered the whole preschool range of age (Panesi & Morra, 2016; Verswijveren et al., 2020).

3.2. Construct

Table 2. *Differentiation or overlapping of WM and Updating*

Authors	WM-Updating	Theoretical model
Abeles & Morton (2000)	One	Baddeley (1992)
Belacchi et al. (2010)	Different	Miyake et al. (2000)
Dauvier et al. (2012)	One	-
Di Lieto et al. (2020)	One	Diamond (2013)
Hartstein et al. (2018)	One	-
Kolkman et al. (2013)	Different	Miyake et al. (2000); Baddeley (2000)
Lee & Bull (2016)	Not clear	-
Mou et al. (2018)	One	-
Panesi & Morra (2016)	Different	Miyake et al. (2000); Im-Bolter et al. (2006)
Stadtmiller et al. (2021)	One	Baddeley (1992)
Traverso et al. (2015)	Different	Miyake et al. (2000)
Traverso et al. (2020)	Different	Miyake et al. (2000)
Troller-Renfree et al. (2020)	One	-
Verswijveren et al. (2020)	One	-
Voigt et al. (2014)	One	Baddeley (1992)
Webster et al. (1997)	One	Baddeley (1992)
Whitely et al. (2013)	One	-
Willoughby et al. (2019)	One	Diamond (2013)
Zeytinoglu et al. (2017)	One	Diamond (2013)

As previously explained, in developmental literature there is no agreement about the relationship between WM and updating: some authors consider them as separated functions (see Morra et al., 2018), while others see an overlap between them (e.g., Garon et al., 2008; Diamond, 2013). The present study managed to portray the lack of agreement on this issue, as we can observe in Table 2, which shows the theoretical approach to these constructs in each paper included.

As we can notice, most studies did not make a distinction between WM and updating explicit: on the contrary, they contemplated the existence of a single construct, generally called WM, which usually included the characteristics of updating. In these studies, a unique set of tasks assessed this unique function. The overlapping between WM and updating was proposed by Abeles and Morton (2000), Dauvier and colleagues (2012), Di Lieto and colleagues (2020), Hartstein and colleagues (2018), Mou and colleagues (2018), Stadtmiller and colleagues (2021), Troller-Renfree (2020), Verswijveren and colleagues (2020), Voigt and colleagues (2014), Webster and colleagues (1997), Whitely and colleagues (2013) and Willoughby and colleagues (2019). Among them, some authors overtly classify memory WM as an EF (Di Lieto et al., 2020; Hartstein et al., 2018; Mou et al., 2018; Troller-Renfree et al., 2020; Willoughby et al., 2019).

Furthermore, in the studies in which it is made explicit, the reference model is not always the same. Some studies stated that they used Diamond's model (Diamond, 2013), which, starting from EF Miyake's model, replaced updating with WM in children. As a result, WM is treated as an EF (Di Lieto et al., 2020; Willoughby et al., 2019; Zeytinoglu et al., 2017). Other studies (Abeles & Morton, 2000; Stadtmiller et al., 2021; Voigt et al., 2014; Webster et al., 1997) referred to Baddeley's model (Baddeley, 1992), according to which WM is composed by a Central Executive component that regulates and coordinates the flow of information between the Executive and two slave systems: the Phonological Loop, which retains verbal information in a speech based code, and the Visuospatial Sketchpad, which is specialized in retaining visual or spatial information.

Finally, as mentioned above, some papers highlighted that updating is a feature of WM, which is defined as the ability to storage and update information (Dauvier et al., 2012; Hartstein et al., 2018; Voigt et al., 2014; Whitely et al., 2013). In these cases, we cannot talk about a total overlapping between the two constructs, but updating was considered as sort of a sub-component. This difference did not emerge from the use of tasks.

On the other hand, a minority of studies named both WM and updating separately, treating them as two distinct functions, assessed by two different sets of tasks. It is the case of Belacchi et al. (2010), Kolkman et al. (2013), Panesi and Morra (2016), Traverso et al. (2015) and Traverso et al. (2020). A peculiarity of Kolkman and colleagues' paper is that the authors distinguished updating and WM from a theoretical point of view, but they assessed only the function of updating, to pursue the aim of their research. All the studies mentioned above rely on Miyake's model (Miyake et al., 2000), which identifies three separated but correlated EF (inhibition, shifting, and updating) which seem to rely on WM, underlining a differentiation between WM and updating. Moreover, other models were taken into account in some of these papers: Kolkman and colleagues referred to Baddeley's Central Executive (Baddeley, 1996, 2000), which is responsible for control and regulation of cognitive processes in which EF are involved; Panesi and Morra (2016) cited also the model proposed by Im-Bolter, Johnson, and Pascual-Leone (2006), according to which WM and inhibition are general resources, while shifting and updating are executive abilities that partly rely on WM and inhibition. Even in this case, the difference between WM and updating is highlighted.

Finally, there is one study where the differentiation or the overlapping between WM and updating was not clear. Lee and Bull (2016) theoretically referred to these constructs as separated functions, as well as they used different tasks; however, for the purpose of their study, they did statistical analysis generating a latent factor which included measures of both WM and updating, thus cancelling the difference between them.

3.3. Tasks

As we said, one of the consequences of this inconsistency about the differentiation or the overlapping of WM and updating regards the choice of the tasks to assess these functions. Table 3 shows the diverse measures employed by the studies included in the present systematic review. They have been classified according to the construct they meant to assess: WM, updating or a unique function which not distinguishes the other two.

Table 3. *Tasks used to assess WM, updating or a unique function.*

Tasks	Only WM	Only Updating	Unique function
Backward Corsi Block Tapping			1
BDS			1
BWS	4		
Delayed Recognition Span Task			1
DFT	1		
Digit Span			1
Dual task manipulation			1
Dual task word span	1		
Forward Word Span	1		
Keep Track		2	
List Sorting Working Memory			1
Listening Recall task	1	1	
Magic House		1	
Matrix Path			1
Mr Cucumber	3		
Mr. X	1		
N-Back			3
Nebraska Barnyard task			1
Numbers reversed			2
Pictorial Updating		1	
Selective Word Span	1		
Sentence Imitation			1
Updating word span		1	

We can observe a quite huge variety of tasks. As expected, the majority of tasks were used to assess a unique function, with a slight increase in frequency of use of Number Reverved and N-Back. On the other hand, in studies which considered WM and updating as separated constructs we can notice that more tests are used to assess WM than updating. WM was measured by eight different tasks, with a more frequency of Mr Cucumber and Backward Word Span; updating was assessed by five tasks; there is a slight increase in frequency of Keep Track, but it may be due to the fact that it was used by the same research group in different studies. Moreover, a sign of the lack of clarity on tasks is given by the fact that the same measure (Listening Recall Task) is used to assess both WM and updating, in two studies that considered these functions as separated constructs.

4. Discussion

As previously explained, the relationship between WM and updating is an important open question in developmental literature. While in research on adults (see for example Himi, Bühner and Hilbert, 2021) updating is considered an EF at service of WM, according to Miyake and colleagues (2000), there is no such clarity in developmental literature. In fact, there some authors who consider WM and updating as overlapping constructs and use these terms as synonymous to refer to the same function. (e.g., Diamond, 2013; Garon et al., 2008). In this situation, also the tasks could be used interchangeably. On the other hand, other authors see the possibility that the terms WM and updating may refer to two different processes and that they are measurable through different tests (see Morra et al., 2018). Understanding whether it is functional to consider updating as distinct from WM capacity in young children, as it seems to be for adults, is relevant for acquiring more information regarding cognitive functioning during the preschool years. Nevertheless, in the literature this question is not always clearly addressed. Having information on how the developmental literature addresses this question can be useful for setting up new research. Overall, this review has identified 19 studies in which the terms “updating” or tasks requiring updating information in memory and tasks involving the term “working memory” in preschool age were used. Overall, it was observed that, despite an evident inconsistency in preschool literature, the predominant position regarding the relationship between WM and updating is that which sees the existence of a single construct (WM) that can also encompass the characteristics of updating. In some cases, this general function represents an EF, according to the models proposed by Diamond (2013). Overall, the most shared model among the studies supporting a unique construct seems to be the one proposed by Baddeley (2000). On the other hand, many studies supporting the distinction between WM and updating based their claims on Miyake’s model (2000). However, a substantial number of studies did not report their theoretical framework, making hard to understand the reason behind the formulation of their constructs. A clear overview of the theoretical frameworks can help to better understand the rationale of the existing positions regarding the relationship between WM and updating.

Finally, we explained above that one of the possible reasons behind this confusion about WM and updating may be the lack of measures to adequately assess these functions in children, especially in preschoolers. At the same time, however, this confusion regarding WM and updating risks generating further confusion about the choice of tasks to use. Indeed, studies that rely on theoretical models positing WM and updating as a single construct tend to indiscriminately use tasks designed to measure these functions. In the present systematic review, we classified the tasks reported in the studies according to the function for which they were employed. In doing so, we wanted to highlight the potential confusion in the choice of tasks, which fortunately was limited: only one test was used to measure both WM and updating. In other cases, it seems that the function of the different tests was well-defined, despite the inconsistency in the adopted theoretical models. Additionally, we emphasized the measures recognized purely for the evaluation of updating, which turned out to be particularly Keep Track, Magic House, Pictorial Updating and Updating Word Span.

This systematic review represents a novelty in literature. To our knowledge, no existing articles provide such a comprehensive systematization of studies on the relationship between working memory (WM) and updating in preschoolers, with a particular focus on the tasks employed to assess these constructs. Our work offers a crucial resource for researchers grappling with ongoing debates in developmental literature and seeking clarity in the application of tasks for evaluating WM and, notably, updating.

5. References

Abeles, P., & Morton, J. (2000). Keeping track: the function of the Current State Buffer. Cognition, 75, 179-208. https://doi.org/10.1016/s0010-0277(00)00061-5

Agostino, A., Johnson, J., & Pascual-Leone, J. (2010). Executive functions underlying multiplicative reasoning: Problem type matters. Journal of Experimental Child Psychology, 105, 286–305. https://doi.org/10.1016/j.jecp.2009.09.006

Baddeley, A. D. (1992). Working memory. Science, 255, 556–559. https://doi.org/10.1126/science.1736359

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? Trends in Cognitive Sciences, 4:11, 417-423. https://doi.org/10.1016/s1364-6613(00)01538-2.

Belacchi, C., Carretti, B., & Cornoldi, C. (2010). The role of working memory and updating in Coloured Raven Matrices performance in typically developing children. European Journal of Cognitive Psychology, 22: 7, 1010-1020. https://doi.org/10.1080/09541440903184617.

Conklin, H. M., Salorio, C. F., & Slomine, B. S. (2008). Working memory performance following paediatric traumatic brain injury. Brain Injury, 22(11), 847–857. https://doi.org/10.1080/02699050802403565.

Cragg, L., & Nation, K. (2007). Self-ordered pointing as a test of working memory in typically developing children. Memory, 15(5), 526–535. https://doi.org/10.1080/09658210701390750.

Dauvier, B., Chevalier, N., & Blayec, A. (2012). Using finite mixture of GLMs to explore variability in children's flexibility in a task-switching paradigm. Cognitive Development, 27, 440– 454. https://doi.org/10.1016/j.cogdev.2012.07.004.

Di Lieto, M.C., Pecini, C., Castro, E., Inguaggiato, E., Cecchi, F., Dario, P., Cioni, G., & Sgandurra, G. (2020) Empowering Executive Functions in 5-and 6-Year-Old Typically Developing Children Through Educational Robotics: An RCT Study. Front. Psychol. 10:3084. https://doi.org/10.3389/fpsyg.2019.03084.

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12-yearold children. Psychological Test and Assessment Modeling, 52(4), 419-431.

Engle, R.W., Kane, M.J., & Tuholski, S.W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In Models of Working Memory. Edited by Akira Miyake and Priti Shah. Cambridge: Cambridge University Press, pp. 102–30. https://doi.org/10.1017/CBO9781139174909.007.

Friedman, N.P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. Cortex, 86, 186-204. https://doi.org/10.1016/j.cortex.2016.04.023.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Bulletin, 134(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31.

Gray, S., Green, S., Alt, M., Hogan, T., Kuo, T., Brinkley, S., & Cowan, N. (2017). The structure of working memory in young children and its relation to intelligence. Journal of Memory and Language, 92, 183-201. https://doi.org/10.1016/j.jml.2016.06.004

Hartstein, L.E., & Berthier, N.E. (2017). Transition to success on the model room task: the importance of improvements in working memory. Developmental science, 21(2). https://doi.org/10.1111/desc.12538

Himi, Samsad A., Markus Bühner, and Sven Hilbert. 2021. Advancing the understanding of the factor structure of executive functioning. Journal of Intelligence 9: 16. https://doi.org/10.3390/jintelligence9010016.

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: A latent variable approach. Developmental Neuropsychology, 35, 20–36. https://doi.org/10.1080/87565640903325691.

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. Child Development, 77, 1822–1841. https://doi.org/10.1111/j.1467-8624.2006.00976.x.

Kane, M.J., Brown, L.H., McVay, J.C., Silvia, P.J., Myin-Germeys, I., & Kwapil, T.R. (2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. Psychological Science 18: 614–21. https://doi.org/10.1111/j.1467-9280.2007.01948.x.

Köder, F., Sharma, C., Cameron, S., & Garraffa, M. (2022) The effects of bilingualism on cognition and behaviour in individuals with attention deficits: A scoping review. Front. Psychol. 13:1057501. https://doi.org/10.3389/fpsyg.2022.1057501.

Kolkman, M. E., Hoijtink, H. J. A., Kroesbergen, E. H., & Leseman, P. P. M. (2013). The role of executive functions in numerical magnitude skills. Learning and Individual Differences, 24, 145–151. https://doi.org/10.1016/j.lindif.2013.01.004.

Lee, K., & Bull, R. (2016). Developmental changes in working memory, updating, and math achievement. Journal of Educational Psychology, 108(6), 869–882. https://doi.org/10.1111/cdev.12096.

Lerner, M. D., & Lonigan, C. J. (2014). Executive function among preschool children: Unitary versus distinct abilities. Journal of Psychopathology and Behavioral Assessment, 36, 626–639. https://doi.org/10.1016/j.jecp.2015.11.003.

McAuley, T., Chen, S., Goos, L., Schachar, R., & Crosbie, J. (2010). Is the behavior rating inventory of executive function more strongly associated with measures of impairment or executive function? Journal of the International Neuropsychological Society: JINS, 16(3), 495. https://doi.org/10.1017/S1355617710000093.

Miller, M. R., Giesbrecht, G. F., Muller, U., McInerney, R. J., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. Journal of Cognition and Development, 13, 395–423. https://doi.org/10.1080/15248372.2011.585478

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. Current directions in psychological science, 21(1), 8–14. https://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N.P., Emerson, M.J.; Witzki, A.H., HoWMrter, A. & Wager, T.D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. Cognitive Psychology, 41:1, 49-100. https://doi.org/10.1006/cogp.1999.0734.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Medicine, 6(7), e1000097.

Morra, S., Panesi, S., Traverso L., & Usai MC. (2018). Which tasks measure what? Reflections on executive function development and a commentary on Podjarny, Kamawar, and Andrews. Journal of Experimental Child Psychology, 167, 246-258. https://doi.org/10.1016/j.jecp.2017.11.004

Mou, Y., Berteletti, I., & Hyde, D.C. (2018). What counts in preschool number knowledge? A Bayes factor analytic approach toward theoretical model development. Journal of Experimental Child Psychology, 166, 116–133. https://doi.org/10.1016/j.jecp.2017.07.016

Oberauer, Klaus. 2009. Design for a working memory. Psychology of Learning and Motivation 51: 45–100. https://doi.org/10.1016/S0079-7421(09)51002-X.

Panesi, S., & Morra, S. (2016). Drawing a dog: The role of working memory and executive function. Journal of experimental child psychology, 152, 1–11. https://doi.org/10.1016/j.jecp.2016.06.015.

Panesi, S., & Morra, S. (2017). La Casetta Magica. Un nuovo strumento per indagare l'aggiornamento (updating) della memoria di lavoro in età prescolare [The Magic House: A new measure of updating for preschoolers]. Psicologia Clinica Dello Sviluppo, 21(3), 443-462.

Panesi, S., & Morra, S. (2020). Executive Functions and Mental Attentional Capacity in Preschoolers. Journal of Cognition and Development, 21(1), 72-91. https://doi.org/10.1080/15248372.2019.1685525.

Panesi, S., Bandettini, A., Traverso, L., & Morra, S. (2022). On the Relation between the Development of Working Memory Updating and Working Memory Capacity in Preschoolers. Journal of Intelligence 10:5. https://doi.org/10.3390/jintelligence10010005.

Petrides, M. & Milner, B. (1982). Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. Neuropsychologia, 20:3, 249-262. https://doi.org/10.1016/0028-3932(82)90100-2

Redick, Thomas S., and Dakota R. B. Lindsey. 2013. Complex span and n-back measures of working memory: A meta-analysis. Psychonomic Bulletin & Review 20: 1102–13. https://doi.org/10.3758/s13423-013-0453-9

Sharma, C. J. M. (2019). The effect of bilingualism on Attention Deficit Hyperactivity Disorder (ADHD)-related behaviour, ADHD symptoms, and executive functions in a general primary school population [Unpublished doctoral dissertation]. Cambridge, UK: University of Cambridge.

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S. C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. Developmental neuropsychology, 35(6), 679–697. https://doi.org/10.1080/87565641.2010.508546.

Sølsnes, A. E., Skranes, J., Brubakk, A. M., & Løhaugen, G. C. (2014). Executive functions in very-low-birth-weight young adults: A comparison between self-report and neuropsychological test results. Journal of the International Neuropsychological Society: JINS, 20(5), 506. https://doi.org/10.1017/S1355617714000332.

Stadtmiller, E., Lindner, K., Süss, A., & Gagarina, N. (2022). Russian-German five-year-olds: What omissions in sentence repetition tell us about linguistic knowledge, memory skills and their interrelation. Journal of child language, 49(5), 869–896. https://doi.org/10.1017/S0305000921000325.

Traverso, L., Viterbori, P., & Usai, M.C. (2015). Improving executive function in childhood: Evaluation of a training intervention for 5-year-old children. Frontiers in Psychology, 6, 525. https://doi.org/10.3389/fpsyg.2015.00525

Traverso, L., Viterbori, P., Malagoli, C., & Usai M.C. (2020). Distinct inhibition dimensions differentially account for working memory performance in 5-year-old children. Cognitive Development, 55:100909. https://doi.org/10.1016/j.cogdev.2020.100909

Troller-Renfree, S. V., Buzzell, G. A., & Fox, N. A. (2020). Changes in working memory influence the transition from reactive to proactive cognitive control during childhood. Developmental science, 23(6), e12959. https://doi.org/10.1111/desc.12959

Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in five-and six-year-old children: A longitudinal study. European Journal of Developmental Psychology, 11, 447–462. https://doi.org/10.1080/17405629.2013.840578

Usai, M.C., Traverso, L., Gandolfi, E., & Viterbori, P. (2017). Batteria per la valutazione delle funzioni esecutive in età prescolare (FE-PS 2-6). Erickson.

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. Intelligence, 35, 427–449. https://doi.org/10.1016/j.intell.2006.09.001.

van der Ven, S. H., Kroesbergen, E. H., Boom, J., & Leseman, P. P. (2013). The structure of executive functions in children: A closer examination of inhibition, shifting, and updating. British Journal of Developmental Psychology, 31, 70–87. https://doi.org/10.1111/j.2044-835X.2012.02079.x

Verswijveren, S. J. J. M., Wiebe, S. A., Rahman, A. A., Kuzik, N., & Carson, V. (2020). Longitudinal associations of sedentary time and physical activity duration and patterns with cognitive development in early childhood. Mental Health and Physical Activity, 19, 100340. https://doi.org/10.1016/j.mhpa.2020.100340

Voigt, B., Mahy, C. E. V., Ellis, J., Schnitzspahn, K., Krause, I., Altgassen, M., & Kliegel, M. (2014). The Development of Time-Based Prospective Memory in Childhood: The Role of Working Memory Updating. Developmental Psychology. https://doi.org/10.1037/a0037491

Webster, P. E., Plante, A. S., & Couvillion, L. M. (1997). Phonologic impairment and prereading: update on a longitudinal study. Journal of learning disabilities, 30(4), 365–375. https://doi.org/10.1177/002221949703000402.

Whitely, C., & Colozzo, P. (2013). Who's Who? Memory updating and character reference in children's narratives. Journal of speech, language, and hearing research: JSLHR, 56(5), 1625–1636. https://doi.org/10.1044/1092-4388(2013/12-0176)

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. Developmental Psychology, 44(2), 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Wiebe, S., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. Journal of Experimental Child Psychology, 108, 436–452. https://doi.org/10.1016/j.jecp.2010.08.008

Willoughby, M. T., Wylie, A. C., & Little, M. H. (2019). Testing longitudinal associations between executive function and academic achievement. Developmental psychology, 55(4), 767–779. https://doi.org/10.1037/dev0000664

Zeytinoglu, S., Calkins, S. D., Swingler, M. M., & Leerkes, E. M. (2017). Pathways from maternal effortful control to child self-regulation: The role of maternal emotional support. Journal of family psychology: JFP: journal of the Division of Family Psychology of the American Psychological Association (Division 43), 31(2), 170–180. https://doi.org/10.1037/fam0000271.

Zhang, H., Chang, L., Chen, X., Ma, L., & Zhou, R. (2018). Working Memory Updating Training Improves Mathematics Perf.ormance in Middle School Students With Learning Difficulties. Frontiers In Human Neuroscience, 12. https://doi.org/10.3389/fnhum.2018.00154

Inhibition: should we stop considering diverse inhibitory tasks?

Abstract

Inhibitory control is a key executive function allowing individuals to regulate attention, behaviour, thoughts, and emotions, and to override dominant responses when necessary. This ability is critical for successful social, academic, and emotional development, especially in preschool children. The present paper examines the complexity of inhibitory control by exploring the variety of tasks used to measure it and the implications of such diversity on understanding inhibition as a cognitive construct.

1. Introduction

Inhibitory control entails the capacity to regulate attention, behaviours, thoughts, and emotions, thereby overriding strong internal predispositions or external temptations. It enables individuals to prioritize actions that are more appropriate or required in a given context. In absence of inhibitory control, we would be susceptible to impulses, entrenched habits, or environmental stimuli dictating our actions. It involves intentionally suppressing dominant, automatic, or prepotent responses when circumstances demand it (Diamond, 2013; Miyake et al., 2000).

Although it is one of the most studied constructs in cognitive psychology, its definition is not straightforward. A debated issue in the literature, for instance, concerns the taxonomy that best represents this construct and its complexity. Dempster (1993) identifies domain-specific inhibitions (motor, linguistic, perceptual), while Nigg (2000) differentiates effortful inhibition (of motor or cognitive responses) and automatic inhibition (of attention). Inhibition is also seen as comprising response inhibition (suppressing dominant but inappropriate responses) and interference inhibition (preventing distraction from competing stimuli; Nigg, 2000; Diamond, 2013; Friedman & Miyake, 2004). Furthermore, inhibition can be divided into intentional (conscious) and automatic (preconscious) processes (Harnishfeger, 1995; Johnson, Im-Bolter, & Pascual-Leone, 2003). Garon et al. (2008) categorize inhibition tasks into simple (low working memory demand) and complex (high working memory load), suggesting that complex inhibition tasks build on the skills required for simple ones. Inhibitory tasks also vary significantly depending on the specific inhibitory process or response type engaged, such as Stroop-like tasks that suppress dominant responses in favour of less automatic ones, Go/No-Go tasks that involve withholding responses, and tasks requiring sustained motor control. These variations imply that inhibition encompasses multiple dimensions, leading to a lack of consensus on its precise definition.

Taking inspiration from Rey-Mermet, Gade, & Oberauer (2018) we chose to give this provocative title to the present work precisely to draw attention to the fact that the reason for this difficulty may lie in the types of measures we use to evaluate it. Specifically, our main objective is to reflect on the existence of different dimensions of the inhibition construct, which can explain performance in tasks classified generically as inhibitory, but which seem to be based on different processes. For example, responding with less automaticity versus withholding a response in the presence of a specific stimulus.

2. Inhibition and other constructs

The preschool years mark a critical period when children are rapidly developing their cognitive abilities. Inhibition, alongside other executive functions (EF) and working memory (WM) plays a crucial role in this developmental journey. From resisting temptations to waiting for a turn, preschoolers encounter numerous situations that call upon their burgeoning inhibitory control. In their review, Best and Miller (2010) showed that substantial development of inhibitory processes takes place during the preschool years. By age 4, children demonstrate signs of successful performance in both response inhibition tasks and complex inhibition tasks, which necessitate the involvement of WM. Inhibition continues to enhance, especially from ages 5 to 8, particularly for tasks that integrate inhibition and WM.

Moreover, this pivotal skill influences various aspects of a child's life. From literature, in fact, it emerges that inhibition is closely related to different domains of child functioning, affecting their development. For example, inhibitory control seems to be related to academic achievement in preschool and beyond. Children who exhibit better inhibitory control tend to perform better in tasks that require sustained attention, such as listening to instructions, following classroom rules, and completing assignments. The ability to inhibit distractions allows children to stay focused on learning tasks, leading to improved performance in areas such as literacy, mathematics, and problem-solving. In this regard, Allan, Hume, Allan, Farrington, and Lonigan (2014) conducted a metanalysis summarizing results from 75 studies of preschool and kindergarten children. Results showed a modest relation between inhibition and academic skills. Specifically, a stronger association resulted with behaviour tasks rather than with parent-questionnaire measures, but less than teacher-questionnaire measures, suggesting the importance of adopting both type of measures. Moreover, inhibitory control in general was more strongly associated with early math skills than with early literacy skills.

Another aspect of child functioning that inhibition resulted to impact is the field of social skills. Preschoolers with well-developed inhibitory control are more capable of taking turns, sharing, and cooperating with peers. These children are better equipped to inhibit impulsive reactions during conflicts, leading to more positive social interactions. Specifically, inhibition is involved in Theory of Mind (ToM), which is the cognitive ability to understand that others have beliefs, desires, intentions, and perspectives that are different from one's own. In a systematic review, Osterhaus and Bosacki (2022), among other goals, investigated the cognitive antecedents of Advanced ToM (AToM) in 208 studies of children aged from 5 years. They found a small yet significant association between AToM and the ability to inhibit or regulate one’s responses. Moreover, it has been suggested that improving executive functions, and inhibition as part of them, may aid in the development of AToM skills.

Inhibition plays a vital role also in emotional regulation, the ability to manage and control one's emotions. Preschool children with stronger inhibitory control are more adept at regulating their emotional responses to situations. They can suppress negative emotions such as anger or frustration, leading to better coping mechanisms and reduced likelihood of behavioural problems (Carlson and Wang, 2007).

Furthermore, inhibitory control seems to be associated with maladaptive behaviour across early childhood. A meta-analysis by Berger and Buttelmann (2022) with 22 studies on typically developing children aged 2-8 years revealed a small but robust correlation between inhibitory control and the prevalence of externalizing behaviour problems in typically developing children, although this correlation is weakened in non-clinical settings compared to clinical populations emerged from a previous meta-analysis conducted by Schoemaker, Mulder, Deković & Matthys (2013), which included studies focused on ADHD and ODD samples. On the other hand, Berger and Buttelmann (2022) did not find a significant linear association between inhibitory control and internalizing behaviour problems.

In sum, the importance of studying the construct of inhibition in the context of child development is evident. The ability to control impulses, regulate emotions, and maintain attention are fundamental for children's social, academic, and emotional success. A healthy development of inhibition helps children manage challenging situations, adapt to new environments, and interact constructively with others. Furthermore, good inhibition is often associated with better learning outcomes and more appropriate and respectful behaviour towards others.

Notably, despite what was reported above, the construct of inhibition has not yet been fully understood. In fact, regarding this construct and the way it is studied in literature, there are some open and unclear questions, which this article aims to critically analyse.

Increasing our understanding of the cognitive processes underline inhibitory tasks and increasing our comprehension of inhibition is relevant for several developmental domains. It seems essential to develop interventions and educational strategies aimed at supporting children's growth. Educators and parents can implement activities and techniques that promote the development of inhibitory control, such as games that require turn-taking, practicing waiting in line, or teaching relaxation techniques for emotional regulation. By fostering strong inhibition in preschoolers, we lay a solid foundation for their future success in various aspects of life. But to do this is essential to understand the nature of the cognitive processes behind the different behaviours.

3. How many tasks?

An aspect that immediately stands out is the wide variety of tasks used to measure inhibition, even in preschool-age children. Specifically, under the label of inhibition measures, there are tasks that differ in characteristics, structure, complexity, and type of indicator.

As for the characteristics, inhibition measures can be grouped in several categories. A common group of tasks is that of Stroop tasks. The original Stroop task (Stroop, 1935) involves the presentation of colour names printed in coloured ink that does not match the colour name. Individuals must say the colour of the ink, ignoring the word's name. This task requires inhibiting the automatic response to the word's name and focusing on the colour characteristic, which can be challenging and require cognitive effort. In developmental literature, tasks thus designated exhibit a prominent feature that elicits a predominant response, which must be suppressed in favour of another less automatic response, typically related to an opposite characteristic. Day/Night Stroop Task (Gerstadt, Hong, & Diamond, 1994) and Grass/Snow (Carlson & Moses, 2001) are examples of this kind of stroop tasks for children.

Another type of inhibition task includes the go/no go tasks, which require a different process than Stroop-like tasks. During a go/no go task, participants are presented with various stimuli and must respond quickly (by pressing a button or performing an action) only when a specific "go" stimulus appears, while they must refrain from responding when a "no go" stimulus appears. Bear and Dragon (Reed, Pien, & Rothbart, 1984) and Simon Says (Strommen, 1973), for example, require children a go/no go process. Stop-signal tasks show a similar procedure, although their inhibitory requirement is quite different: in these tasks, the go signal is presented on every trial; however, on a small number of trials, just as the subject is about to respond to the go signal, a stop signal (typically a sound) appears, signalling that the button should not be pressed on that trial.

In Flanker task, participants are instructed to focus on the centrally presented stimulus while disregarding the flanking stimuli surrounding it. In incompatible trials, where the flanking stimuli are mapped to the opposite response from the central stimulus, individuals respond more slowly due to the requirement of exerting top-down control (Eriksen & Eriksen, 1974). Adaptations of this test for children use images as stimuli, such as in the Flanker Fish Task (Viterbori, Gandolfi, & Usai, 2012).

In Antisaccade tasks (Roberts, Hager, & Heron, 1994), participants are instructed to look away from a suddenly appearing visual stimulus to a mirror position on the opposite side. This requires the participant to suppress the natural, reflexive urge to glance towards the new stimulus (prosaccade) and instead make a voluntary eye movement in the opposite direction (antisaccade).

Moreover, several inhibition tasks involve an affective engagement in decision-making. They are often based on the delay of gratification, in situations where children are required to wait before eating a snack (Snack Delay: Kochanska, Murray, & Harlan, 2000) or unpacking a wrapped gift (Gift Delay: Kochanska et al., 2000).

These tasks are carefully designed to be developmentally appropriate for preschool-aged children, often incorporating colourful stimuli, simple instructions, and engaging elements to make them fun and engaging.

In addition to the diverse demands of inhibitory tasks, it is also noteworthy that they require responses in different domains, even when the requirement is the same. Tasks that involve suppressing a dominant response in favour of a less automatic one, for instance, might call for a verbal response, as in the Day/Night Stroop Task (Gerstadt et al.,1994). In this task, children are instructed to say "night" when shown a card depicting the sun, and "day" when shown a card depicting the moon. Conversely, other tasks require a motor response to the same process, such as in the Knock Tap (Korkman et al., 1998), where children must perform the opposite hand movement to what the experimenter shows (knock or tap).

Moreover, even when the same paradigm is employed, not always the same variable is used. Often, inhibitory tasks allow for the collection of various measurements, such as time or accuracy (i.e., the number of correct responses), which can then be used as variables in data analyses depending on the study's objectives. In Day/Night Stroop Task, for example, possible indices that can be employed are the number of errors, the accuracy or the time took by the chid to complete the task. Likewise, in Flanker Task the researcher can register the time of reaction for each item or the number of correct responses. Circle Drawing Task reveals the time took by the child to trace the circle with his/her finger and the number of mistakes. Additionally, in these tasks, different variable from different phases are available, and it is possible to use variable from a single phase or to compute a composite score. In the Stroop task, for example, it is possible to refer to the stroop phase variables or even subtract accuracy and response time from the control phase.

The structure of the diverse tasks is not always the same. Some tasks are composed of a single phase, in which inhibitory control is required from the outset and maintained at the same level of difficulty throughout. Other tasks are composed of a control phase and an inhibitory one (e.g., Day/Night Task, Knock Tap, Luria's Hand Game), and still others are composed of two or more phases which correspond to increasing difficulty of the task (e.g., Simon Says).

Moreover, the number of items or trials is not always the same among tasks with the same title. For example, some Flanker tasks include one single block while others may include multiple blocks, requiring a child a higher cognitive effort.

Finally, another issue is the involvement of other cognitive functions. Indeed, inhibitory task may vary in the WM demands: Garon, Bryson, and Smith (2008) distinguished between simple and complex inhibition tasks according to WM demands. Examples of simple inhibition tasks are the Delay Gratification or the Antisaccade, while Knock Tap and Flanker as examples of complex inhibition tasks. Likewise, some tasks seem to require inhibition but even shifting ability. This is the case of Dots (Diamond et al., 2007), which requires to shift from a rule to another, suppressing the interference from the previous one.

4. Correlations and reliability

In the previous paragraph, we distinguished the different processes they are based on, the different procedures, and the different indicators that are used. Now let's see how they behave with each other. In evaluating this aspect, there are several aspects to consider.

The first is the correlation between the tasks. In fact, one of the key aspects highlighted in the literature is that inhibition tasks often show low correlation with each other. This suggests that, despite being classified under the general label of "inhibition," they may actually measure distinct processes. For example, tasks requiring the inhibition of prepotent responses (such as the Stroop task or the Stop-Signal task) may not correlate closely with tasks measuring resistance to distractor interference (such as the Flanker task). Rey-Mermet and colleagues (2017) published an article with a provocative title: “Should We Stop Thinking About Inhibition? Searching for Individual and Age Differences in Inhibition Ability”. In this article, the authors expressed among their goals to determine the psychometric structure of cognitive inhibition in adults, through the administration of eleven tasks for assessing inhibition of prepotent responses and resistance to distractor interference in a sample of adults. Specifically, they administered the antisaccade, the stop-signal, the colour Stroop, the Simon, the local and the negative compatibility tasks for the inhibition of prepotent responses and the arrow and letter flanker, the number Stroop, and the positive compatibility tasks as well as the n-2 repetition costs for the resistance to distractor interference. The reason behind the choice of the title is due to the fact that the results yielded that the inhibition measures showed good reliabilities but low correlations with each other. Bayesian hypothesis testing suggested a model with two correlated inhibition factors (inhibition of prepotent response and resistance to distracter interference). However, several issues challenge this interpretation, including low factor loadings, dominance of single measures within each factor, and ambiguous evidence regarding factor correlations. Consequently, the authors suggested that caution is needed when generalizing findings from studies using single laboratory paradigms to assess inhibition. They suggest that we should perhaps stop thinking about inhibition as a generic cognitive construct and consider that performance in inhibitory tasks may be very task specific.

Another issue regarding the tasks concerns the test-retest reliability. Willoughby, Blair, and The Family Life Project Investigators (2015), and later Willoughby, Kuhn, Blair, Samek and List (2017), investigated the test–retest reliability of a battery of EF, including inhibitory tasks, in a sample of preschool children. In both cases, their findings were in line with the ones of Rey-Mermet et al. (2018): despite their expectations, correlations between the measures were quite modest. However, differently from Rey-Mermet et al. (2018), these authors found modest levels of test–retest reliability, underlying the importance of administering multiple tasks and aggregating performance across these tasks in order to improve precision of measurement.

5. How many inhibitions?

Several theoretical models exist to explain inhibition and its role in cognitive processes. These models provide frameworks for understanding how inhibition operates in the brain and influences behaviour. However, as we'll highlight with the models below, there are various perspectives regarding the essence of the inhibition construct.

In recent years, literature has increasingly recognized inhibition as a multidimensional construct made up of various components. This view is supported by models that propose distinct automatic and controlled inhibitory functions (Howard, Johnson, & Pascual-Leone, 2014) as well as domain-specific inhibitions (e.g., perceptual, motor, linguistic, Dempster, 1993) and variations in inhibition at the levels of thought and behaviour (Harnishfeger, 1995).

Nigg (2000; 2017) distinguished between two types of inhibition: effortful inhibition of a motor or cognitive response and automatic inhibition of attention. He categorized effortful inhibition into four types: (a) interference control, which involves preventing interference due to resource or stimulus competition; (b) cognitive inhibition, which entails suppressing non-pertinent thoughts to prioritize other processes such as working memory or attention; (c) behavioural inhibition, which refers to overcoming a prepotent or socially inappropriate response; and (d) oculomotor inhibition, which involves suppressing a reflexive saccade.

Diamond (2013) theorized that inhibitory control can be distinguished into three main components: cognitive inhibition, which operates at the level of thoughts and memories; executive attention, which functions at the level of attention; response inhibition, which acts at the level of behaviour. Both cognitive inhibition and executive attention are involved in controlling interference. This process entails the ability to suppress interfering or dominant mental representations, as well as the capacity to disregard certain stimuli in order to focus on others, based on one's goals or intentions.

Another conceptualization of inhibition was proposed by the neo-Piagetian perspective: according to the Theory of Constructive Operators' (TCO; Johnson et al., 2003; Pascual-Leone, 1984) there is a distinction between effortful and automatic inhibition. The first one is defined as the intentional suppression of task-incompatible mental operations. The latter spontaneously and effortlessly deactivates mental operations outside the focus of controlled effortful attention.

These theoretical models offer different perspectives on the nature of inhibition providing frameworks for empirical studies which allowed other studies to propose empirically based models. There are, however, not many studies investigating the latent structure of inhibition. Friedman and Miyake (2004), for example, verify the goodness of fit o f a model including three main types of inhibition in adults through a latent variable analysis: (a) inhibition of prepotent responses, defined as the ability to intentionally prevent a dominant, automatic or prepotent response; to assess this dimension of inhibition, the authors used Antisaccade Task (adapted from Roberts et al., 1994), Stop-Signal Task (Logan, 1994) and Stroop Task (Stroop, 1935). (b) Resistance to distractor interference, which is the ability to overcome an interference that is external to the individual and irrelevant to the current task. It was investigated using Flanker task (Eriksen & Eriksen, 1974), Word naming task (Kane et al., 1994) and Shape matching Task (DeSchepper & Treisman, 1996). (c) Resistance to proactive interference, which was defined as the ability to control interference from previous tasks. It was assessed by Brown–Peterson variant (adapted from Kane & Engle, 2000), AB–AC–AD (adapted from Rosen and Engle, 1998) and Cued recall (Tolan & Tehan, 1999). Results suggested that the best fitting model was two factor model with an inhibition of prepotent response and resistance to distractor Interference factor and resistance to proactive interference factor. This model highlights that different tasks tap into different aspects of inhibition.

However, the number of studies focusing on developmental age is quite limited, resulting in a restricted understanding of how the construct of inhibition is organized in children. Gandolfi, Viterbori, Traverso, and Usai (2014) investigate the nature of inhibition processes in day-care center children aged 24–32 months and in preschool children aged 36–48 months. They found that for the younger sample, the data best fit a model with a single, undifferentiated inhibition factor. In older children, a two-factor model, where response inhibition was differentiated from interference suppression, was identified. These results were confirmed also by Traverso, Viterbori, Gandolfi, Zanobini, Usai (2022), in which CFA conducted on a sample of typically developing children from 4 to 5 years of age yielded a two-factor model, differentiating a response inhibition and an interference suppression dimension.

6. Conclusion and open questions

As we expose in the present paper, inhibition is an extensively studied construct in the literature, although there is still little clarity about its nature. As we mentioned before, the development of inhibition receives a significant boost in the preschool years, especially around the age of four (Best & Miller, 2010). These results are consistent with those observed by Gandolfi et al. (2014), who noted an increase in complexity in the models describing the latent structure of inhibition in preschoolers compared to toddlers.

Furthermore, from the literature, it emerges that inhibition seems to have predictive value on the development of other abilities. Indeed, significant correlations emerged with academic achievements, especially with early math skills (for a review, see Allan et al., 2014); with social skills, particularly with Theory of Mind (for a review, see Osterhaus et al., 2022); with emotion regulation (Carlson & Wang, 2007); and with externalizing behaviours, both in typically developing children (for a review, see Berger & Buttelmann, 2022) and in atypical development (Schoemaker et al., 2013).

Exactly, when we say that inhibition is predictive of other constructs, we mean that it is the performance in various inhibitory tasks that is concurrently or longitudinally related to these constructs. However, as we have seen, there are numerous different tasks to assess inhibition, which are based on very different inhibitory control demands. Some tasks require suppressing a dominant response in favour of a less automatic one (e.g., Stroop-like tasks); others involve withholding a verbal or motor response in the presence of a specific stimulus (e.g., go/no go tasks, stop-signal tasks); still others involve resisting cognitive conflict potentially generated by the presence of distractors. Moreover, we have observed that often the measures used can vary, even for the same tasks. For example, some studies might use the accuracy, others the time of reaction. All this can make it difficult to accurately compare different tests, especially in terms of their correlations with other constructs. The use of one test or index over another could also impact the results of studies, as well as differences in stimulus presentation mode, allowed response times, or error definitions.

In summary, while inhibition tasks are widely used to assess inhibitory control, the behaviour among these tasks highlights the complexity of the construct and the potential specificity of the processes that each of them intends to measure. This variety in results and correlations underscores the importance of carefully selecting tasks and assessment methods based on specific research goals and study populations.

In order to reflect on these methodological aspects, a systematic review of the literature on inhibitory tasks would be useful. This review should also investigate the correlations with other constructs and how different tasks and indicators behave when included in a factor analysis. This approach would systematize the tasks, aiding other researchers in selecting the most efficient tasks and indicators for their objectives.

Moreover, once the best tasks have been identified, it would be beneficial to investigate which dimension of inhibition they measure. As highlighted above, various inhibitory tasks may be based on processes that are quite different from one another, raising the question of whether there might actually be multiple types of inhibition.

One aspect that can be seen as a limitation of the existing models in the literature regarding the nature of inhibition is that many of them are theoretical constructs (e.g., Diamond, 2013; Nigg, 2000). Only a minority of studies have developed models based on factor analysis of the latent variables that make up the construct of inhibition. One of the most well-known models is that of Friedman and Miyake (2004), which identified two components of inhibition. This model was tested on a sample of adults. As for developmental age, the literature on the nature of the inhibition construct is rather sparse, especially for preschoolers. To our knowledge, Gandolfi and colleagues (2014) and Traverso and colleagues (2022) are among the few studies that have focused on this age group, identifying a two-factor model (response inhibition versus interference suppression). Future studies should therefore delve deeper into the investigation of the inhibition construct in young children. In this regard, to the best of our knowledge no studies investigate the possibility to identify other possible inhibition dimensions in preschool years.

In sum, this article has reviewed some of the challenges associated with studying the inhibitory construct. As we have discussed, these challenges are linked both to the need for better investigation of the construct, particularly in preschool-aged children, and to methodological aspects, such as the choice of tests and indicators to analyse performance. Greater collaboration among researchers regarding the methodologies used, as well as studies that more accurately systematize the existing tests in the literature, would be beneficial.

7. References

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: a meta-analysis. *Developmental psychology*, 50(10), 2368. https://doi.org/10.1037/a0037493

Berger, P., & Buttelmann, D. (2022). A meta-analytic approach to the association between inhibitory control and parent-reported behavioral adjustment in typically-developing children: Differentiating externalizing and internalizing behavior problems. *Developmental science*, 25(1), e13141.

Berger, P., & Buttelmann, D. (2022). A meta-analytic approach to the association between inhibitory control and parent-reported behavioral adjustment in typically-developing children: Differentiating externalizing and internalizing behavior problems. *Developmental science*, 25(1), e13141. https://doi.org/10.1111/desc.13141

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child development*, 81(6), 1641-1660. https://doi.org/10.1111/j.1467-8624.2010.01499.x

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child development*, 72(4), 1032-1053.

Carlson, S. M., & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development*, 22(4), 489-510. https://doi.org/10.1016/j.cogdev.2007.08.002

Dempster, F. N. (1993). Resistance to interference: Developmental changes in a basic processing mechanism. In Emerging themes in cognitive development: Volume I: Foundations (pp. 3-27). New York, NY: Springer New York.

DeSchepper, B., & Treisman, A. (1996). Visual memory for novel shapes: Implicit coding without attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22(1), 27–47. https://doi.org/10.1037/0278-7393.22.1.27

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. Science, 318(5855), 1387-1388. https://doi.org/10.1126/science.1151148

Diamond, A. (2013). Executive functions. *Annual review of psychology*, 64, 135-168. https://doi.org/10.1146/annurev-psych-113011-143750

Eriksen, B.A., and Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target letter in a non search task. *Percept. Psychophys.* 16,143–149. https://doi.org/10.3758/BF03203267

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interfer- ence control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, 133 (1), 101–135. https://doi.org/10.1037/0096-3445.133.1.101 .

Gandolfi, E., Viterbori, P., Traverso, L., & Usai, M. C. (2014). Inhibitory processes in toddlers: A latent-variable approach. *Frontiers in Psychology*, 5 , 381. https://doi.org/10.3389/fpsyg.2014.00381 .

Garon, N., Bryson, S., and Smith,I. (2008).Executive function in preschoolers: are view using an integrative framework. *Psychological Bulettin*. 134, 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: performance of children 312–7 years old on a stroop-like day-night test. *Cognition*, 53(2), 129-153. https://doi.org/10.1016/0010-0277(94)90068-X

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In Interference and inhibition in cognition (pp. 175-204). Academic Press. https://doi.org/10.1016/B978-012208930-5/50007-6

Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*, 31, 1-21. https://doi.org/10.1016/j.cogdev.2014.03.001

Johnson J., Im-Bolter N., Pascual-Leone J. (2003). Development of mental attention in gifted and mainstream children: The role of mental capacity, inhibition, and speed of processing. *Child Development*. Vol. 74. No. 6. P. 1594 – 1614. https://doi.org/10.1046/j.1467-8624.2003.00626.x

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. Journal of Experimental Psychology: Learning, Memory, and *Cognition*, 26(2), 336–358. https://doi.org/10.1037/0278-7393.26.2.336

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: continuity and change, antecedents, and implications for social development. *Developmental psychology*, 36(2), 220. https://doi.org/10.1037/0012-1649.36.2.220

Korkman, M., Autti-Rämö, I., Koivulehto, H., & Granström, M. L. (1998). Neuropsychological Effects at Early School Age of Fetal Alcohol Exposure of Varying Duration. *Child Neuropsychology*, 4(3), 199–212. https://doi.org/10.1076/chin.4.3.199.3171

Logan, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds.), Inhibitory processes in attention, memory, and language (pp. 189–239). Academic Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive psychology*, 41(1), 49-100. https://doi.org/10.1006/cogp.1999.0734

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathol- ogy: Views from cognitive and personality psychology and a working inhibition taxonomy. Psychological Bulletin, 126 (2), 220–246. https://doi.org/10.1037/ 0033-2909.126.2.220 .

Osterhaus, C., & Bosacki, S. L. (2022). Looking for the lighthouse: A systematic review of advanced theory-of-mind tests beyond preschool. *Developmental Review*, 64, 101021. ttps://doi.org/10.1016/j.dr.2022.101021

Pascual-Leone J. (1987). Organismic processes for neo-Piagetian theories: A dialectical causal account of cognitive development. *International Journal of Psychology*. Vol. 22. No. 5 – 6. P. 531 – 570. doi:10.1080/00207598708246795

Reed, M., Pien, D.L., and Rothbart, M.K. (1984). Inhibitory self-controling preschool children. Merrill.Palmer.Q. 30, 131–147.

Rey-Mermet, A., Gade, M., & Oberauer, K. (2018). Should we stop thinking about inhibition? Searching for individual and age differences in inhibition ability. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 44(4), 501. https://doi.org/10.1037/xlm0000450

Roberts, R. J., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General*, 123(4), 374. https://doi.org/10.1037/0096-3445.123.4.374

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of memory and language,* 39(3), 418-436. https://doi.org/10.1006/jmla.1998.2590

Schoemaker, K., Mulder, H., Deković, M., & Matthys, W. (2013). Executive functions in preschool children with externalizing behavior problems: A meta-analysis. *Journal of abnormal child psychology*, 41, 457-471. https://doi.org/10.1007/s10802-012-9684-x

Strommen, E. A. (1973). Verbal self-regulation in a children's game: impulsive errors on" Simon Says". *Child Development,* 849-853. https://www.jstor.org/stable/1127737

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18(6), 643–662. https://doi.org/10.1037/h0054651

Tolan, G. A., & Tehan, G. (1999). Determinants of short-term forgetting: Decay, retroactive interference, or proactive interference?. *International Journal of Psychology*, 34(5-6), 285-292. https://doi.org/10.1080/002075999399585

Traverso, L., Viterbori, P., Gandolfi, E., Zanobini, M., & Usai, M. C. (2022). The contribution of inhibitory control to early literacy skills in 4-to 5-year-old children. *Early Childhood Research Quarterly*, 59, 265-286. https://doi.org/10.1016/j.ecresq.2021.11.010

Viterbori, P., Gandolfi, E., & Usai, M. C. (2012). Executive skills and early language development. *Journal of Applied Psycholinguistics,* 3, 17-32.

Willoughby, M. T., Blair, C. B., & The Family Life Project Investigators (2015, June 29). Measuring Executive Function in Early Childhood: A Case for Formative Measurement. *Psychological Assessment*. Advance online publication. http://dx.doi.org/10.1037/pas0000152

Willoughby, M. T., Kuhn, L. J., Blair, C. B., Samek, A., & List, J. A. (2017). The test–retest reliability of the latent construct of executive function depends on whether tasks are represented as formative or reflective indicators. *Child Neuropsychology*, 23(7), 822-837. https://doi.org/10.1080/09297049.2016.1205009

Latent Structure of Executive Functions in Preschool Children

Abstract

Executive Functions (EF) are higher-order cognitive processes essential for executing goal-directed actions. In adults, research identifies three distinct but interrelated EF components: inhibition, shifting, and updating (Miyake et al., 2000). Although these functions are distinct in adults, their structure during developmental stages, particularly in preschool children, remains unresolved. There is ongoing debate about the multicomponent nature of EF and how its components interrelate. The present study analyses the structure of EF in preschool children, using Confirmatory Factor Analysis (CFA). The best fit to the data was a two-factor model in which inhibition was distinguished, while working memory, updating and shifting emerged as a unitary component.

1. Introduction

Executive Functions (EF) can be defined as a set of top-down cognitive processes that enable the execution of goal-directed behaviors, as well as the monitoring and control of thoughts, emotions, and actions, when going on automatic or relying on instinct or intuition would be ill-advised. (Diamond, 2013). Together with the working memory (WM), a system able to store and process information at the same time, they play a fundamental role from the first years of a child's life. Indeed, although the development of these processes continues until adolescence, the most rapid progress is observed between the ages of 3 and 5 years (Carlson, 2005); this promotes the organization of thought and behavior in children, characterized by greater flexibility, a decrease in impulsive responses and the implementation of more self-regulated behaviors. Furthermore, the preschool development of EF and WM is associated with the increase in social emotional skills, including theory of mind, ability in problem solving and academic prerequisites (Hughes & Ensor, 2007; Senn, Espy, & Kaufmann, 2004; Blair & Razza, 2007).

Despite the existence of a rich literature regarding these processes, there is still no clarity about their structure, especially in young children. One of the most validated models in adulthood is the three-factor model proposed by Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000), according to which there are three differentiated but correlated EF: inhibition, which is the ability to consciously inhibit dominant, automatic or overbearing responses when necessary and to process irrelevant or misleading information; updating, which is the monitoring and coding incoming information for relevance to the task at hand and then appropriately revising the items held in working memory by replacing old, no longer relevant information with newer, more relevant information; shifting, which is the ability to move attention from one task to another or from one operation to another. According to this perspective, these three processes rely on WM.

In the last few years, studies about the differentiation of EF proliferated in developmental literature, too. However, results on children are often not consistent with one other, especially in preschoolers. Some studies have obtained supportive results of a monofactorial model (e.g. Hughes, Ensor, Wilson, & Graham, 2010; Shing, Lindenberger, Diamond, Li, & Davidson, 2010; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011). Others claimed that a two-factor model is most appropriate for describing the EF latent structure in preschoolers. For example, Lerner and Lonigan (2014) found a model in which WM and inhibition resulted as two separate functions in children whose age ranged from 3.5 and 5 years. Furthermore, Usai, Viterbori, Traverso, and De Franchis (2014) identified a two-factor model in 5- and 6-year-old children, in which inhibition was distinguished, while WM and shifting were merged into a single component. Different results were found by Panesi and Morra (2020), who identified a two factor-model comprised of a WM and a combined inhibition – shifting – updating factor. A peculiarity of this study of this study is that updating was included in the analysis of the latent structure of EF. Indeed, the authors followed the neo-Piagetian approach, trying to apply it on preschoolers: according to Pascual-Leone's Theory of Constructive Operators (TCO; Pascual-Leone, 1970, 1987), WM is a limited domain-general resource for activating task-relevant schemes that matures during childhood. Building on this theory, Im-Bolter, Johnson, and Pascual-Leone (2006) and Im-Bolter, Johnson, Ling, and Pascual- Leone (2015), proposed a model with two layers: the first layer includes general resources like inhibition and WM, while the second layer comprises executive functions like shifting and updating, which rely on these basic resources. This perspective suggests that general resources and executive functions are part of an integrated system.

However, the difficulty in identifying the structure of EF in unambiguous manner is not the only open question. Closely linked to this topic, there are other two issues which are object of debate in developmental literature, that we will illustrate below. The first one concerns the distinction or overlap between the constructs of WM and updating. The second one concerns the nature of the inhibition construct and how it interacts with the other EF.

Regarding the relationship between WM and updating, in literature there are contrasting claims about the overlapping or differentiation of these two constructs. While in adult research WM and updating are considered as two different functions (e.g., Kane, Brown, McVay, Silvia, Myin-Germeys & Kwapil, 2007; Miyake et al., 2000; Redick & Lindsey 2013), in the developmental literature WM and updating are often considered as synonyms. Some authors (e.g., Diamond, 2013; Garon, Bryson & Smith, 2008) identified inhibition, shifting (or cognitive flexibility) and WM as EF. According to this perspective, WM supplanted updating in Miyake's model (2000). On the other hand, another current of development researchers claimed that in adults there is a substantial distinction between the constructs of WM and updating that should be investigated in children (e.g. Morra, Panesi, Traverso, & Usai., 2018). The distinction between WM and updating is based on more recent WM models which emphasize the role of attentional resources in maintenance activate information relevant to the task (e.g., Im-Bolter, Johnson, & Pascual-Leone, 2006). Besides from a theoretical point of view, the distinction between the constructs of WM and updating is also supported from empirical evidence. For example, Panesi, Bandettini, Traverso, and Morra (2022) investigated the relationship between WM and Updating in preschoolers through the administration of differentiated tests for the two constructs, noting how updating skills in this age group depend on WM but do not coincide with it. This inconsistency about the relationship between updating and WM in the developmental literature may be partly justified by the fact that few tasks are actually available for preschool children.

As mentioned above, another important open question is linked to the construct of inhibition: some studies, in fact, argue that inhibition should not be considered as one unitary function but as a multicomponential construct that includes several dimensions useful to perform different tasks. The nature of such a multifactorial model, however, is debated in literature: there are in fact different taxonomies in this regard. Dempster (1993), for example, distinguishes different domain-specific inhibitions, i.e. motor, linguistic and perceptual inhibition. Nigg (2000) distinguished between two types of inhibition: effortful inhibition of a motor or cognitive response and automatic inhibition of attention. Other authors proposed that inhibition included response inhibition, i.e., the ability to suppress a dominant but inappropriate response by preventing a behaviour impulsive (Nigg, 2000), and interference inhibition, defined as the ability to prevent interference coming from competing stimuli (Diamond, 2013; Friedman and Miyake, 2004; Nigg, 2000). A further distinction is that between intentional inhibition, based on conscious processes, and automatic, based on preconscious processes (e.g., Harnishfeger 1995; Johnson, Im-Bolter & Pascual-Leone, 2003). Garon et al. (2008) distinguishes inhibition tasks into simple and complex: simple tasks are those that involve minimal WM demand, while complex tasks are those that require a greater WM load. Based on this model, complex inhibition tasks are built on the skills required by simple inhibition tasks.

Moreover, inhibitory tasks can vary greatly depending on the specific inhibitory process engaged or the type of response required. Stroop-like tasks, for example, require suppressing a dominant response in favour of a less automatic one. Go/no go tasks involve withholding a verbal or motor response in the presence of a specific stimulus. Other tasks, like Circle Drawing Task or Statue, involve the motor control for the entire duration of the task, independently from the presence of a specific stimulus. Furthermore, they involve responses across different domains, even when the underlying requirement remains consistent. For example, tasks that entail suppressing a dominant response in favour of a less automatic one may necessitate verbal responses (e.g., Day/Night Stroop Task) or motor response (e.g., Knock Tap). This might suggest that beneath the umbrella term of inhibition, there could be different dimensions. Therefore, there is no clarity on the nature of the inhibition construct.

As mentioned above, another EF described by Miyake is shifting, which allows for switching from one task to another or from one rule to another. It is also included in the model of Im-Bolter et al. (2006; 2015) as a complex function that, along with updating, relies on WM and inhibition, considered as general resources. In developmental literature, it seems established that this function has not yet emerged in preschool age, while it begins to differentiate from school age onwards (for a systematic review, see Karr et al., 2018). The execution of tasks designed to measure shifting, therefore, would require other processes in young children. Even in these cases, the results are inconsistent: we have seen that in Usai et al. (2014) it seems to be explained by the same ability that underlies working memory, while in Panesi et al. (2020) it seems to be assimilated to tasks of inhibition and updating.

1.1 This study

In summary, several unresolved issues regarding executive functions (EF) in preschool children have emerged from the literature. Firstly, there is no consensus on the best model to represent EF: some studies have identified a single-factor model (e.g., Hughes, Ensor, Wilson & Graham, 2010; Shing et al., 2010; Wiebe, Espy, & Charak, 2008; Wiebe, Sheffield, Nelson, Clark, Chevalier, & Espy, 2011), while others support a two-factor model. It is interesting to note that most studies have included WM or inhibition in their models (e.g., Lerner & Lonigan, 2014), or WM, inhibition, and shifting (e.g., Usai et al., 2014). Panesi and Morra (2020) were the first to also include updating in a study on preschoolers. However, the introduction of updating is associated with a critical issue, as there are few measures of this function for young children. For this reason, the authors analysed the model with only one updating task.

The scarcity of updating tasks designed for young children also ties into the unresolved issue of whether WM and updating overlap or differentiate. This leads to the use of WM tasks to measure both, resulting in confusion regarding the relationship between the two constructs.

Finally, in developmental literature there is still little consensus regarding the model that best represents the nature of inhibition. Moreover, a wide range of tasks exists, that seem to rely on different inhibitory dimensions, as they appear to elicit processes that differ from one another.

The goal of the present study was to fit into this debate, contributing to provide greater clarity. In fact, we aimed to identify the structure of the EF and the WM in preschool age, investigating the relationship between inhibition, shifting, updating and WM, as well as the nature of the inhibition construct. Specifically, the main goals were: (a) to investigate the relationship between WM and updating; (b) to analyse the best fit model for the structure of inhibition; (c) to investigate the latent structure of EF, including inhibition, WM, updating, and shifting tasks. For these purposes, we used Confirmatory Factor Analysis (CFA), which is considered the most appropriate technique for studying latent cognitive structures. As far as we know, this is the first study to investigate all the Executive Functions (EFs) from Miyake's model (2000), along with Working Memory (WM), through a comprehensive battery of tests. Indeed, we used at least three measures for each construct, including updating. We choose this number of indicators following the suggestion of Kline (2015), who claimed that a lower number can lead to problems in the estimation of the latent variables. Moreover, we selected a higher number of inhibitory tasks that would represent various sub-dimensions suggested in the literature. Furthermore,

In general, we used tasks widely employed in the literature, such as some presented by Carlson (2005).

2. Method

2.1 Participants

In total, 311 children's families were reached out. Of these, 232 provided informed consent, while 79 (25%) denied it. Most of the refusals to consent occurred in two schools due to internal difficulties related to organization and communication. Among children authorized to participate in our study, 5 had formal diagnosis of disability, language impairment, or behaviour disorder and 13 had a difficulty in understanding Italian language: they performed the activities for ethical reasons, but we did not analyse their data for this study. Finally, 6 children did not complete the assessment. Therefore, the final sample had 208 participants (age range: 50-76; M = 63.31; SD = 6.82; 46% female) that took part in this study. All participants were typically developing preschoolers, recruited in five public preschool education services located in a northern region in Italy. Bilingual children were included in the sample, as long as they showed a good understanding of Italian language in Peabody Picture Vocabulary Test, (Stella, Pizzoli, & Tressoldi, 2000), excluding children with scores below the 25th percentile.

The study was conducted conforming to the ethical standards established by the Italian Psychology Association and the principles expressed in the Declaration of Helsinki; moreover, it was submitted to the ethics committee of Genoa University (CERA), that gave approval (n. 2022.03). Parents signed informed consent to authorize their children's participation in this study.

2.2 Measures

2.2.1 WM tasks

The following tasks were used to assess WM.

Mr. Cucumber (Case, 1985). The outline of an extra-terrestrial figure, to which coloured stickers had been attached, was displayed for 5 secs per item. The child was then presented with a simple outline, without coloured stickers, and had to indicate the positions of the stickers. There were three items at each level, featuring from 1 to 8 stickers. The test was discontinued whenever a child failed all three items at a given level. One point was given for each consecutive level at which a subject got at least two items correct, and one-third of a point for each correct item above that level (Mr. Cucumber, range of possible scores: 0 – 8). Cronbach's alpha calculated on a sample of 125 children (M = 53.02 months, SD = 9.55) was .65 (Panesi & Morra, 2020).

Backward Word Span (Morra, 1994). The child was required to repeat lists of words in reverse order. There were three lists at each level, comprising from 2 to 7 words. The test was discontinued whenever a child failed all three lists at one level. One point was given for each consecutive level at which a subject got at least two items correct (including level 1 which cannot exist, because it is not possible to reverse the order of a single word, and was therefore granted as correct by default), and one third of a point for each correct item above that level (BWS, range: 1– 7). Cronbach's alpha calculated on a sample of 125 children (M = 53.02 months, SD = 9.55) was .79 (Panesi & Morra, 2020).

Direction Following Task (Pascual-Leone & Johnson, 2005). This task requires children to follow oral directions of increasing complexity. We used a modified version for preschoolers, using cards showing figures of different shapes (bicycle and boat), colors (white, yellow, green, blue, and red) and sizes (large and small) to be placed in boxes of different color and size. We presented items expressed by simple syntactic constructions. There were three levels of increasing complexity, including five items each (e.g., level 1: "place a large boat in a red box"; level 2: "place a small yellow boat in a green box"; level 3: "place a large green boat in a little yellow box"). The scoring rules for the Italian version of the test (see Morra, Camba, Calvini & Bracco, 2013) were followed, adapting them for this shorter version. The score, based on a theory-guided task analysis, is assumed to represent a child's WM capacity (see Pascual-Leone & Johnson, 2011). 0 points were given if fewer than three responses at each level were correct; 1 point if at least three responses out of five were correct at the first level but fewer than three at the second and third levels; 2 points if at least four responses at the first level and at least three responses at the second level were correct, but fewer than three were correct in the third level, or if at least eight items were correct in total; 3 points if at least four responses at the first level, at least four responses at the second level, and at least three responses at the third and/or the fourth level were correct; 4 points if at least four responses at the first level, at least four responses at the second level, and at least four responses at the third or the fourth level were correct, as long as the last two levels were completed with at least three items correct (DFT, range: 0 – 4). Cronbach's alpha calculated on a sample of 125 children (M = 53.02 months, SD = 9.55) was .85 (Panesi & Morra, 2020).

2.2.2 Inhibition Tasks

The following tasks were used to assess Inhibition.

Pippo Says (adapted from "Simon Says", Strommen, 1973). It was a go/no-go task, which required withholding a motor response. In fact, children were required to comply with an instruction only when preceded by the verbal cue "Simon Says" and to inhibit the response when the cue was missing. More specifically, in this task the researcher gave a command, for example "raise your hands" or "touch your nose", and the children had to execute it only when the instruction was preceded by the phrase "Pippo says". This task was divided in two phases composed of 10 items each. In the first phase there was the simple inhibition of the voice command. The second phase required the researcher to execute the same movements expressed in the sentence, regardless of whether he/she said "Pippo says" or not; in this case, children had not only to inhibit verbal commands, but also refrain from imitating the researcher's movement. Each item was scored 2, 1 or 0: 2 if the response was correct, 1 in case of self-correction and 0 if the response was wrong. The total score of the go and the no-go items was recorded. The letter was used for the analysis (Pippo Says, range: 0 – 20).

Statue Task (Korkman et al., 1998). It involved withholding a motor response for an extended period of time. In this task, children were required to stay still, posing as a statue for 75 seconds; meanwhile, the examiner attempted to distract them by coughing, dropping her pencil, clearing her throat and knocking on the table. Every 5 seconds, presence of eye and body movement and vocalizations was scored: 2 points were given if the child was still; 1 point if he made one mistake (eye movement or body movement or vocalization); 0 points were given if he made at least two mistakes (Statue, range: 0 - 30).

Luria's Hand Game (Lerner & Lonigan, 2014). It was a go/no go task, involving withholding a motor response. This task was structured in two phases: in the first practice phase, children learned to imitate the examiner's gesture, either a fist or one finger pointing; in the target phase, children were required to imitate only the pointing gesture but to do nothing when the examiner showed a fist. Before each trial, children were required to place their dominant hand on a flat surface. Each phase included 25 trials, 12 of which were fist trials. Each fist trial was scored 3 in case of correct inhibition, 2 in case of self-correction, 1 in case of wrong gesture and 0 in case of absence of inhibition (Luria, range: 0 – 36). Cronbach's alpha calculated on a sample of 289 children (M = 55.74, SD = 7.56) was .76 (Lerner & Lonigan, 2014).

Circle Drawing Task (Bachorowski & Newman, 1985). This task required the involvement of the motor dimension of inhibition. Children were presented with the drawing of a 17 cm diameter circle. This task was structured in two phases: in the first one, children were required to trace the circle with their finger from the starting point to the ending point at natural speed. In the second one, they were required to trace again the circle with their finger but that time as slowly as they could. Time in seconds was recorded for each trail. Scores were computed as the slowdown relative to the total time using the formula: (T2 - T1) / (T2 + T1), where T1 and T2 respectively represented the times recorded for the first and second trials (Circle, range: negative to positive values – no limit). Test re-test reliability calculated on a sample of 43 children (M = 68.6; SD = 3.6) was .57 (Usai, Traverso, Gandolfi, & Viterbori, 2017).

Knock Tap (Korkman et al., 1998). It involved a conflict between two motor responses. This task was structured in two phases: in the first practice phase, children learned to imitate the examiner's gesture, either knocking on the table with the knuckles or tapping on the table with an open palm. in the target phase, children were required to perform the opposite of the examiner's gesture (i.e., knock when examiner tapped and vice versa). Each phase included 12 trials. Each target trial was scored 0 for imitating the researcher, 1 for self-correction and 2 for correct response (Knock Tap, range: 0 – 24). Cronbach's alpha calculated on a sample of 289 children (M = 55.74, SD = 7.56) was .90 (Lerner & Lonigan, 2014).*Fruit Stroop* (Monette et al., 2015). It involved a conflict between cognitive representations and required a verbal response. This task was composed by three conditions: in the first one, the experimenter showed children a page with red strawberries and yellow bananas and children were told to name the color of the fruits as quickly as possible in 1 min; if children completed the page within the time limit, they were instructed to continue at the top of the page. In the second condition, children were presented with a page with the same fruits, but some were not in the right color: they were instructed to name the color the fruit would normally be ''in real life.'' In the third condition, children were presented with a page with the same fruits, but all of them were not the right color: as before, they were instructed to name the color the fruit would normally be in real life. For the second and the third condition, time and number of errors were recorded. We calculated the sum of the errors recorded for phases 2 and 3 as measure of inhibition (Fruit, range: 0 – 40). Test re-test reliability calculated on a sample of 89 children (range of age: 7–12 years) was .82–.93 (Archibald & Kerns, 1999).

Flanker Fish Task (Viterbori et al., 2012). It involved a conflict between different stimuli and required a motor response. In this computerized task, children were required to press the key corresponding with the direction at which a centrally located target fish was oriented, despite the presence of interfering stimuli (other fishes). This test included 32 trials randomly presented, attributable to two conditions: 16 congruent trials (the target fish and the interfering stimuli were oriented towards the same direction) and 16 incongruent trials (the target fish and the interfering stimuli were oriented towards the opposite direction). Accuracy for each condition and response time were recorded. We chose to consider the accuracy in incongruent items (Flanker, range: 0 – 16). Test re-test reliability calculated on a sample of 43 children (M = 68.6; SD = 3.6) was .50 (Usai et al., 2017).*Day/Night Stroop Task* (Gerstadt et al., 1994). It involved a conflict between cognitive representations, requiring a verbal response. This task was composed by two phases: a control phase, in which children learnt to say "day" when a white card with a yellow sun drawing was shown, and “night” for a black card with a moon; a stroop phase, in which they were required to say “night” when the card with the sun was shown, and “day” when they saw the card with the moon. Each measurement instance involved the consecutive presentation of 16 such cards. Time and accuracy were recorded for each phase. We used the time variable in the stroop phase (Day/Night, range: 0 – no limit). Cronbach’s alpha calculated on a sample of 289 children (M = 55.74, SD = 7.56) was .81 (Lerner & Lonigan, 2014).

2.2.4 Updating Tasks

The following tasks were used to assess updating.

Magic House (Panesi & Morra, 2017). This task assesses updating. Each item shown to the child featured three, four or five toy animals placed sequentially in a cardboard house. Subsequently, the child was required to recall the last two animals in the house. This is an updating task that assesses the constant monitoring and addition or deletion of working memory contents. The measure comprised nine items, each of which was scored 0, 1, or 2 points, depending on whether the child recalled none, one, or two animals (Magic House, range: 0 – 18). Cronbach’s alpha calculated on a sample of 125 children (M = 53.02 months, SD = 9.55) was .72 (Panesi & Morra, 2020).*Self-Ordered Pointing Task* (Petrides & Milner, 1982). In this updating test, children were shown a set of black and white abstract pictures. They were required to touch a different picture on each trial, until all pictures had been touched once. The task was formed by 7 progressive levels, including from 2 to 8 pictures. In case of one error, a trial of the same level of the incorrect one was presented; if this was also wrong, the test was stopped. One point was given for each level completed (SOPT, range: 0 – 7).

Keep Track (Traverso, Viterbori & Usai, 2015, adapted from Van der Ven, Kroesbergen, Boom and Leseman, 2011). The child was shown some pictures, each of which belonged to one of the following five categories: animals, sky, fruit, vehicles and clothes. Before each trial, the child was asked to pay attention to one or two designated categories. During the presentation of each series, the child had to name each picture. At the end, the child had to recall the last item in each designated category. During picture presentation, small pictures symbolizing the to-be-remembered categories were shown to serve as a reminder. 1 point was given for each correct response. 0.5 points were given if the child gave the correct response after seeing all the pictures in the requested category again because he/she was not able to recall the item. Finally, 0 points were given in case of wrong response (Keep Track, range: 0 – 9). Test re-test reliability calculated on a sample of 126 children (M = 65.4; SD = 4.3) was .54 (Traverso, Viterbori & Usai, 2019).

2.2.5 Shifting Tasks

Dots Task (Traverso et al., 2015, adapted from Diamond et al., 2007). It is a computerized task which required children to remember two rules: when a heart appeared on the screen, they had to press the ipsilateral key, while when a flower appeared, they had to press the contralateral key. This test included 20 trials, of which 10 congruent (heart) and 10 incongruent (flower). Accuracy for each condition and time of response were recorded. We calculated the accuracy for all the correct response (Dots, range: 0 – 20). Test re-test reliability calculated on a sample of 43 children (M = 68.6; SD = 3.6) was .62 (Usai et al., 2017).

Dimensional Change Card Sort (Traverso & De Franchis, 2016, adapted from Zelazo, 2006). In this task, children were shown a deck of cards, each of which displays a figure with two variables - shape (rabbit, boat) and color (red, blue) – and features a secondary variable, namely the presence or absence of a black border. During the pre-switch phase, children were required to sort the cards according to shape, while in the post-switch phase, the cards had to be sorted according to color. In the third phase, children had to sort the cards with a black border according to shape, and those without border according to color. There were six trials in the pre-switch phase, six in the post-switch phase, and 12 in the border phase. One point was assigned for each correct item (DCCS, range: 0-24). Cronbach's alpha calculated on a sample of 175 children (M = 68.5 months, SD = 3.4) was .81 (Viterbori, Usai, Traverso & De Franchis, 2015).

2.2.6. Inhibition and Shifting Task

Shape School (Espy, 1997). Colored figures (circles and squares) were presented to children. This task included four conditions: in the first control condition, children were required to name the color of each figure. In the second condition, which required inhibitory processes, happy and sad faces were added to the stimulus figures; children were required to name the color only of the happy figures. In the third condition, which involved shifting, hats were added to some of the figures shown; when a figure wore a hat, children had to name the figure's shape (circle or square), if not they had to name the color. The last condition required both processes: some stimulus figures wore hat and at the same time all of the figures showed happy or sad expressions. Children were required to name figure's shape or the color depending on which was wearing the hat, but only of the figure showed a happy expression. For each condition, time and number of errors were recorded. We chose the time recorded in phase 2 as measure of inhibition (Shape 2, range: 0 – no limit). To measure shifting, we employed the time recorded in phase 3 (Shape 3, range: 0 – no limit) and residuals of errors in phase 4 in the regression on errors in phase 2 (Shape 4, range: negative to positive values – no limit). Cronbach's alpha calculated on a sample of 219 children (M = 68.5 months, SD = 3.4) was .71 in phase 2, .80 in phase 3 and .74 in phase 4 (Viterbori, Usai, Traverso & De Franchis, 2015).

Table 1 summarizes WM and EF tasks, joint to the label and the variables selected for the analysis.

Table 1. WM and EF task, labels and variables used for the analysis.

Task	**Label**	**Variable**	**Construct**
Mr. Cucumber	Mr. Cucumber	Accuracy	WM
Backward Ward Span	BWS	Accuracy	WM
Direction Following Task	DFT	Accuracy	WM
Pippo Says	Pippo	Accuracy in no-go items	Inhibition
Statue Task	Statue	Accuracy	Inhibition
Luria’s Hand Game	Luria	Accuracy	Inhibition
Cirlce Drawing Task	Circle	(T2 - T1) / (T2 + T1)	Inhibition
Knock Tap	Knock Tap	Accuracy	Inhibition
Fruit Stroop	Fruit	Total errors in phases 2 and 3	Inhibition
Flanker Fish Task	Flanker	Accuracy in incongruent trials	Inhibition
Day/Night Stroop Task	Day/Night	Time in stroop phase	Inhibition
Shape School - phase 2	Shape 2	Time	Inhibition
Magic House	Magic House	Accuracy	Updating
Self-Ordered Pointing Task	SOPT	Level	Updating
Keep Track	Keep Track	Accuracy	Updating
Dots Task	DOTS	Accuracy	Shifting
Dimensional Change Card Sort	DCCS	Accuracy	Shifting
Shape School – phase 3	Shape 3	Time in phase 3	Shifting
Shape School – phase 4	Shape 4	Residuals of errors in phase 4 in the regression on errors in phase 2	Shifting

2.2.1 Control tasks

The following tasks were used to assess Italian vocabulary and fluid intelligence, used as criteria for the inclusion in the sample.

Peabody Picture Vocabulary Test (Peabody, Stella, Pizzoli, & Tressoldi, 2000): it is a test aimed at assessing receptive vocabulary. Children were shown matrices composed of four pictures, representing different objects or actions, and they had to point at the picture corresponding to the instruction given by researcher. We followed the procedure established by the instruction manual to assign scores.

Coloured Progressive Matrices (CPM, Raven, 1947): it is a test aimed at assessing fluid intelligence. Children were showed 36 visual patterns, with one piece missing. For each visual pattern, they had to choose the correct piece that could complete the puzzle, between various alternative pieces. The visual patterns were grouped in three sets of 12 items each; one point was given for each correct response.

2.3. Procedure

Each child was individually tested by trained graduate or PhD students in a quiet room at the preschool. The whole assessment was divided into four sessions lasting about twenty or thirty minutes each, without breaks. Furthermore, the tasks were organized in the sessions according to four different orders to avoid that the sequence of the tests could condition children's performance. Children were randomly assigned to each order. The structure of each order is showed in Table 2. For each session of each order, we aimed to arrange the tasks so that tests measuring the same construct were not placed consecutively and to balance the duration of each session as much as possible. Additionally, we sought to alternate more demanding tasks with more enjoyable ones to prevent the child from becoming overly tired or bored, which could risk compromising their performance. At the end of each session, children received a small gift for their effort. The whole battery was administered in two weeks, as each child was test twice a week. Overall, the children were well-engaged and willingly participated in the various sessions.

Table 2. Tasks included in each order.

Order 1

Session 1	**Session 2**	**Session 3**	**Session 4**
CPM	Mr. Cucumber	Day/Night	Knock Tap
Circle	Statue	DOTS	Magic House
BWS	Fruit	Keep Track	DFT
DCCS	SOPT	Flanker	Shape School
	Luria	Pippo	

Order 2

Session 1	Session 2	Session 3	Session 4
CPM	Day/Night	BWS	Mr. Cucumber
Statue	Magic House	Luria	Flanker
DFT	Circle	Shape School	DCCS
Knock Tap	DOTS	SOPT	Keep Track
	Fruit	Pippo	

Order 3

Session 1	Session 2	Session 3	Session 4
CPM	DFT	DCCS	Circle
Luria	Pippo	Mr. Cucumber	SOPT
Magic House	Flanker	Knock Tap	Day/Night
Shape School	Keep Track	Fruit	BWS
	DOTS		Statue

Order 4

Session 1	Session 2	Session 3	Session 4
CPM	Shape School	Circle	DOTS
Day/Night	Knock Tap	DFT	Pippo
Mr. Cucumber	BWS	Flanker	SOPT
Statue	DCCS	Magic House	Fruit
Keep Track			Luria

2.3 Statistical analysis

First of all, we did descriptive analysis (mean, standard deviation, score range, skewness, and kurtosis) in order to investigate the distribution and possible presence of floor or ceiling effects in test scores. Moreover, we identified possible missing data and outliers. Multidimensional outliers, i.e. subjects which had an unusual combination of scores on the dependent variables, were identified with the use of Mahalonobis distance, which is the distance of a data point from the calculated centroid of the other cases, where the centroid is calculated as the intersection of the mean of the variables being assessed. Once they were identified, they were removed from the analysis. Then, we calculated zero-order (Pearson) correlations to investigate the association between subjects' performance on tasks. We took into account also the effect of age thanks to partial correlations. Descriptive statistics, Mahalanobis distance, and zero-order correlations, as well as partial correlations, were calculated using SPSS Statistics (IBM SPSS Statistics 23).

Finally, to achieve our research goal, a series of Confirmatory Factor Analysis (CFA) was conducted using Lisrel 8.80 (Jöreskog & Sörbom, 2006). Various fit indices were considered to evaluate the fit of each model to the observed data. In particular, we used the X^2 statistic, the root mean square error of approximation (RMSEA), the standardized root mean squared residual (SRMR), Bentler's comparative fit index (CFI), the non-normed fit index (NNFI), THE goodness of fit index (GFI) and the Akaike Information Criterion (AIC). X^2 statistic was used to evaluate the fit of the model to the observed data: if it was non-significant, the model resulted to have an acceptably good fit to the data. However, because the chi-square test is overly sensitive to deviations from perfect fit in large samples, other fit indices were employed as well. RMSEA measures how closely the covariances predicted by the model match the actual covariances; values ≤ .05 represent a good fit, values between .05 and .08 represent an adequate fit, values between .08 and .10 represent a mediocre fit and values greater than .10 are not acceptable (Browne & Cudeck, 1993). SRMR represents the differences between the observed and predicted covariances; if values are <.10 are acceptable, while values smaller than .05 represent a good fit. CFI compares the covariance matrix predicted by the model with the observed covariance matrix; values >.95 are acceptable, while values >.97 represent a good fit. NNFI is the proportion by which the tested model improves fit compared to the null model while controlling for the degrees of freedom; interpretation criteria are the same of CFI. GFI is the proportion of variance accounted for by the estimated population covariance; value of over .9 generally indicating acceptable model fit. Finally, AIC allows to compare competing models; the models with the lowest AICs are considered having a better fit. The various indices and their respective ranges, to understand them, are outlined in Table 3.

Table 3. Fit indices and their interpretation

Indices	**Interpretation**
X^2	Adequate fit: p < .05
RMSEA	Good fit: ≤ .05
	Adequate fit: between .05 and .08

	Mediocre fit: between .08 and .10
	Not acceptable: > .10
SRMR	Good fit: < .05
	Acceptable fit: <.10
CFI	Good fit: >.97
	Acceptable fit: >.95
NNFI	Good fit: >.97
	Acceptable fit: >.95
GFI	Acceptable fit: > .90
AIC	The models with the lowest AICs are considered the best

3. Results

3.1 Descriptive statistics and correlations

Table 4. Preliminary descriptive statistics and reliability for WM and EF tasks.

	N	Min	Max	Mean	S.D.	Skewness	Kurtosis	Cronbach's α
Statue	208	8.00	30.00	26.00	4.15	-1.85	4.20	.81
Luria	208	0.00	36.00	23.82	10.02	-1.02	-0.01	.89
Circle	208	-0.76	0.91	0.46	0.26	-1.43	3.79	-
Day/Night	208	20.00	69.25	35.69	9.37	0.97	0.77	.82
Pippo	208	0.00	20.00	7.90	6.79	0.26	-1.38	.82
Flanker	205	0.00	16.00	11.57	4.54	-0.83	-0.29	-
Fruit	208	0.00	39.00	7.47	10.69	1.15	-0.41	.97
Knock Tap	208	0.00	24.00	20.04	5.36	-2.33	5.67	.89
Shape 2	208	11.94	77.08	26.86	11.25	1.95	4.92	.81
BWS	208	1.00	4.00	2.35	0.72	-0.30	-0.65	.76
Mr. Cucumber	208	0.00	4.00	1.65	0.79	0.24	0.19	.80
DFT	208	0.00	4.00	2.16	1.15	0.10	-0.81	.86
Magic House	208	1.00	18.00	11.41	3.34	-0.39	0.00	.78
Keep Track	208	0.00	9.00	4.12	2.05	0.31	-0.40	.60
SOPT	208	1.00	8.00	4.01	1.42	0.31	-0.20	-
Shape 3	207	16.41	119.71	43.67	16.59	1.64	3.75	.86
DCCS	208	6.00	24.00	19.16	2.19	-0.28	5.77	.31
DOTS	207	1.00	20.00	13.71	4.47	-0.15	-0.83	-
Shape 4	208	-6.10	8.02	0.00	2.38	0.78	0.71	.82

Descriptive statistics for WM and EF were conducted. Table 4 shows preliminary results. As we can observe, significant interindividual variability was recorded for most tasks. Some floor or ceiling effects were found, especially in Fruit Stroop. Moreover, the skewness and kurtosis coefficients for some variables were not sufficiently low, so they were transformed. Specifically, the exponential of the accuracy rate proportion for Knock Tap and the arcsine of the accuracy rate proportion for DCCS were calculated in order to normalize the distribution.

The reliability of every measure was acceptable or high, ranging from .60 to .97. The only exception was DCCS, which unexpectedly showed a reliability of .31. Furthermore, we noticed the presence of some missing data in Flanker, in the third level of the Shape School and in DOTS. The missing data in the Flanker and Dots tasks were due to technical issues with the computer, which failed to record the performance of some participants. A similar issue occurred with measuring the time taken by a participant to complete the third task in the Shape School. We then removed from the sample the subjects responsible for the missing data, along with two multivariate outliers identified using Mahalanobis distance. Therefore, our final sample consisted of 203 subjects. The definitive descriptive statistics are shown in Table 5.

Table 5. Final descriptive statistics for WM and EF tasks

	N	**Min**	**Max**	**Mean**	**S.D.**	**Skewness**	**Kurtosis**
Statue	203	8.0	30.0	26.02	4.19	-1.86	4.17
Luria	203	.0	36.0	23.8	10.05	-1.02	-.01
Circle	203	-.76	.91	.46	.26	-1.45	3.93
Day/Night	203	20.00	69.25	35.64	9.38	.97	.79
Pippo	203	.0	20.0	7.99	6.77	.24	-1.38
Flanker	203	.00	16.00	11.62	4.52	-.85	-.25
Fruit	203	.00	39.00	7.26	10.58	1.21	-.26
Knock Tap	203	1.00	2.72	2.37	.40	-1.71	2.98
Shape School 2	203	11.94	77.08	26.67	10.87	1.84	4.53
BWS	203	1.00	4.00	2.36	.71	-.30	-.59
Mr Cucumber	203	.00	4.00	1.64	.80	.24	.20
DFT	203	.0	4.0	2.17	1.15	.10	-.82
Magic House	203	1.0	18.0	11.46	3.31	-.40	.09
Keep Track	203	.0	9.0	4.13	2.04	.30	-.38
SOPT	203	1.0	8.0	4.03	1.43	.31	-.22
Shape School 3	203	16.41	119.71	43.53	16.63	1.67	3.85
DCCS	203	.25	1.57	.96	.20	1.53	3.22
DOTS	203	1.00	20.00	13.68	4.49	-.15	-.83
Shape 4	203	-6.09	8.02	-.018	2.39	.82	.75

Zero-order (Pearson) and partial correlations controlled for age are reported in Table 6. As we can observe, zero-order correlations seemed to be significant between most of the tasks. However, when the age was partialled out, some of these correlations lost their significance. Specifically, Circle Drawing Task showed significant correlations with Statue, Day/Night Task, Shape School Level 2, Mr Cucumber, Magic House and DOTS. Partialling out for age, these correlations kept being significant, with exception of the ones with Mr Cucumber and DOTS, which lost their significance. Statue had significant correlations with Circle Drawing Task, Luria, Day/Night Task, Simon Say's, Fruit Stroop, Knock Tap, Shape School Level 2, DFT, Magic House, Keep Track, SOPT, DCCS and DOTS. However, partialling out for age only correlations with Day/Night Task, Fruit Stroop, DFT and DCCS remained significant. Luria's Hand Game showed significant correlations with Day/Night Task, Simon Say's, Flanker, Fruit Stroop, Knock Tap, Shape School Level 2, BWS, Mr. Cucumber, DFT, Magic House, Keep Track, SOPT, Shape School Level 3 and DCCS. Partialling out for age, correlations with Flanker, Keep Track, SOPT, DCCS and DOTS lost their significance. Day/Night Task significantly correlated with all the task except Flanker and DOTS. Partialling out for age, correlations with Simon Says, Flanker, Fruit Stroop, Mr. Cucumber, DFT, SOPT, DCCS and DOTS lost their significance. Similarly, also Simon Says significantly correlated with all the task except Cirlce Drawing Task. Correlations with Statue, Day/Night Task, SOPT, Shape School Level 3 and DOTS did not resist with age partialled out. Flanker Fish Task showed significant correlations with Statue, Simon Says, Fruit Stroop, Knock Tap, Shape School Level 2, Mr. Cucumber, DFT, Magic House, Keep Track, SOPT, Shape School Level 3 and DOTS. However, with age partialled out only Fruit Stroop, Knock Tap, Shape School Level 2, DFT, Magic House, Keep Track and SOPT significantly correlated. Zero-ordered correlations between Fruit Stroop and other tasks are almost all significant except Circle Drawing Task and SOPT. Partialling out, also correlations with Day/Night Task, BWS, Shape School and DCCS lost their significance. Knock Tap showed significant correlations with almost all the tasks except Circle Drawing Task and SOPT. However, partialling out for age, only Luria, Day/Night Task, Simon Says, Flanker Fish Task, Fruit Stroop and BWS kept their significance. Shape School Level 2 significantly correlated with all the tasks except DOTS. Partialling out for age, it lost significance in correlations with Statue, Flanker Fish Task, Magic House, DCCS and DOTS. BWS had significant correlations with Luria, Day/Nighy Task, Simon Says, Fruit Stroop, Knock Tap, Shape School Level 2, Mr. Cucumber, DFT, Magic House, Keep Track, SOPT, Shape School Level 3 and DCCS. These correlations remained significant even partialling out for age, except SOPT, Shape School Level 3 and DCCS. Mr. Cucumber showed significant correlations with almost all the tasks except Statue and Knock Tap. Partialling out for age, correlations with Circle Drawing Task, Day/Night Task, Flanker Fish Task, Knock Tap, BWS, SOPT and DOTS lost their significance. DFT significantly correlated with all the tasks except Circle Drawing Task and Knock Tap. Partialling out for age, these correlations maintained their significance except Day/Night Task. Magic House showed significant correlations with all the tasks. Partialling out for age, correlations with Statue, Knock Tap and Shape School Level 3 lost their significance. Keep Track showed significant correlations with all the tasks except Circle Drawing Task and Knock Tap; Day/ Night Task, Simon Says, Flanker Fish Task, BWS, Mr. Cucumber, DFT, Magic House, SOPT, DCCS and SOPT showed significant correlations with Keep Track partialled out for age. SOPT did not significantly correlate with Circle Drawing Task, Fruit Stroop, Shape School Level 3, DCCS, and DOTS. Partialling out for age, only Flanker Fish Task, Shape School Level 2, DFT, Magic House and Keep Track maintained their significant correlations. Shape School Level 3 did not show significant Pearson's correlations with Circle Drawing Task, Statue and Knock Tap. Partialling out for age, only correlations with Luria, Day/Night Task, Mr. Cucumber, DFT and DCCS remained significant. DCCS had significant correlations with almost all the tasks, except Flanker Fish Task, Knock Tap, Shape School Level 3 and DOTS. Partialling out for age, correlations with Circle Drawing Task, Luria, Day/Night Task, Shape School Level 2 and BWS lost their significance. DOTS showed significant correlations with Circle Drawing Task, Statue, Simon Says, Flanker Fish Task, Fruit Stroop, Mr. Cucumber, DFT, Magic House, Keep Track and Shape School Level 3. Partialling out for age, only Flanker Fish Task, Fruit Stroop, DFT, Magic House and Keep Track maintained significant correlations.

Among inhibition tasks, significant correlations are observed in a range from -0.44 and 0.39. ($p < .01$). Among WM tasks, the range of significant correlations is between 0.14 and 0.32 ($p < .01$). Significant correlations between updating tasks go from 0.14 and 0.31 ($p < .01$). Finally, among shifting tasks, significant correlations are observed in a range from -0.16 and 0.15 ($p < .05$).

Table 6. Zero-order (upper triangle) and partial correlations controlled for age (lower triangle)

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.
1. Circle	-	0.24**	0.12	-0.25**	0.13	0.10	-0.11	0.14	-0.24**	0.11	0.17*	0.01	0.18*	0.13	-0.04	-0.13	0.15*	0.16*	-0.09
2. Statue	0.21**	-	0.15*	-0.26**	0.19**	0.07	-0.21**	.15*	-0.21**	0.13	0.11	0.21**	0.18**	0.19**	0.16*	-0.13	0.24**	0.15*	-0.11
3. Luria	0.08	0.10	-	-0.21**	0.39**	0.14*	-0.36**	.28**	-0.33**	0.34**	0.26**	0.28**	0.19**	0.15*	0.15*	-0.23**	0.18**	0.11	-0.22**
4. Day/Night	-0.20**	-0.19**	-0.14*	-	-0.26**	-0.09	.15*	-0.26**	0.39**	-0.35**	-0.22**	-0.18*	-.27**	-0.30**	-0.14*	0.26**	-0.16*	-0.11	0.26**
5. Pippo	0.03	0.10	0.34**	-0.07	-	0.18**	-.44**	0.26**	-0.40**	0.35**	0.31**	0.35**	0.24**	0.35**	.19**	-0.27**	0.31**	0.17*	-0.21**
6. Flanker	0.07	0.04	0.11	-0.04	0.13	-	-.18**	0.21**	-0.19**	0.13	0.16*	0.22**	0.21**	0.19**	0.26**	-0.15*	0.14	0.32**	-0.06
7. Fruit	-0.05	-0.15*	-0.32**	0.03	-0.34**	-0.14*	-	-0.35**	0.21**	-0.29**	-0.30**	-0.33**	-0.26**	-0.21**	-0.08	0.17*	-0.21**	-0.25**	0.32**
8. Knock Tap	0.09	0.11	0.18**	-0.17*	0.15*	0.18*	-0.30**	-	-0.22**	0.26**	0.13	0.13	0.18*	0.06	0.17*	-0.09	0.06	0.11	-0.28**
9. Shape 2	-0.17*	-0.12	-0.26**	0.25**	-0.21**	-0.14*	0.07	-0.11	-	-0.34**	-0.40**	-0.28**	-0.26**	-0.25**	-0.29**	0.61**	-0.15*	-0.13	0.32**
10. BWS	0.04	0.05	0.29**	-0.23**	0.19**	0.08	-0.19**	0.18**	-0.19**	-	0.23**	0.32**	0.31**	0.29**	0.16*	-0.24**	0.20**	0.12	-0.28**
11.Mr. Cucumber	0.12	0.03	0.20**	-0.10	0.17*	0.11	-0.22**	0.05	-0.28**	0.11	-	0.14*	0.27**	0.26**	0.18*	-0.29**	0.26**	0.16*	-0.29**
12. DFT	-0.03	0.17*	0.25**	-0.10	0.29**	0.20**	-0.28**	0.08	-0.21**	0.26**	0.07	-	0.40**	0.30**	0.17*	-0.22**	0.27**	0.24**	-0.16*
13. Magic House	0.14*	0.14	0.14*	-0.20**	0.15*	0.19**	-0.20**	0.12	-0.17*	0.24**	0.20**	0.37**	-	0.31**	0.26**	-0.20**	0.23**	0.24**	-0.20**
14. Keep Track	0.07	0.12	0.08	-0.19**	0.22**	0.15*	-0.11	-0.02	-0.10	0.18*	0.16*	0.25**	0.25**	-	0.19**	-0.20**	0.31**	0.24**	-0.11
15. SOPT	-0.08	0.13	0.11	-0.08	0.11	0.24**	-0.02	0.13	-0.23**	0.10	0.13	0.14*	0.22**	0.14*	-	-0.11	0.10	0.04	-0.10
16. Shape 3	-0.08	-0.07	-0.17*	0.16*	-0.13	-0.11	0.08	-0.01	0.55**	-0.13	-0.20**	-0.17*	-0.13	-0.10	-0.06	-	-0.22**	-0.15*	0.15*
17. DCCS	0.10	0.19**	0.13	-0.05	0.21**	0.10	-0.14*	-0.01	-0.03	0.11	0.18**	0.23**	0.18**	0.24**	0.05	-0.14*	-	0.07	-0.16*
18. DOTS	0.13	0.11	0.08	-0.04	0.10	0.30**	-0.21**	0.07	-0.05	0.06	0.11	0.21**	0.20**	0.20**	0.01	-0.10	0.03	-	-0.16*
19. Shape 4	-0.04	-0.06	-0.18*	0.19**	-0.12	-0.03	0.27**	-0.23**	0.24**	-0.21**	-0.23**	-0.11	-0.15*	-0.03	-0.06	0.08	-0.11	-0.12	-

Notes: * $p < .05$ ** $p < .01$

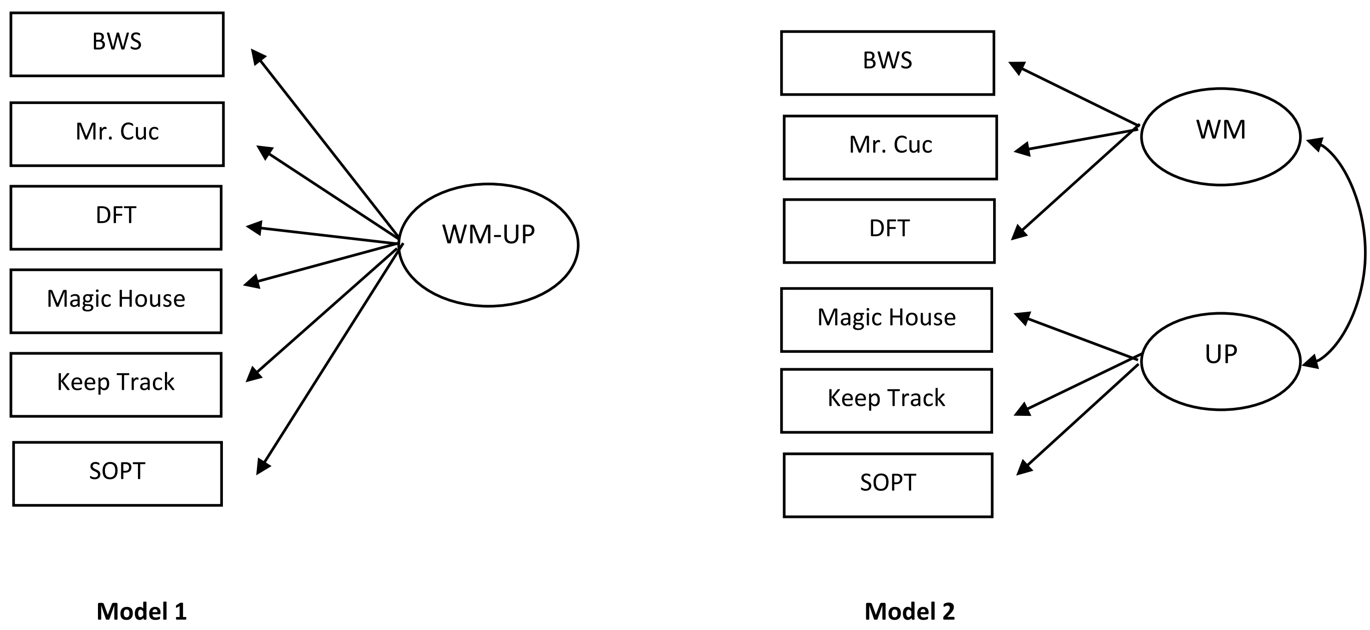
3.2 Confirmatory Factor Analysis

First, we decided to focus on the models that describes WM and updating and on the models that describe the inhibition construct. Starting from the results found, we then built and verified different models comprising all the variables examined.

3.2.1 WM and updating

One of our aims was to investigate the structure of WM and updating, in order to clarify if they are overlapping (Model 1) or separate (Model 2) constructs. For that purpose, we used confirmatory factor analysis testing two different models, reported in Figure 1.

Figure 1. Alternative models for WM and updating



As shown in Table 7, Model 1 fit the data sufficiently well. $\chi 2$ was not significant, SRMR was < .05, NNFI and CFI were >.97. Furthermore, all the factor loadings were significant ($p<.001$). Model 2 was not testable, because matrix phi was not positive definite, i.e., the correlation between factors was estimated as > 1. In Table 8, we only showed the parameters of the one-factor model, as it turned out to be the one that fits best with the data.

Table 7. Goodness of fit indices of Model 1., indicated in bold

Models	χ2(p)	df	SRMR	RMSEA	CFI	NNFI	AIC	GFI
Model 1	**6.52 (0.69)**	**9**	**0.029**	**0.0**	**1.00**	**1.02**	**30.52**	**0.99**

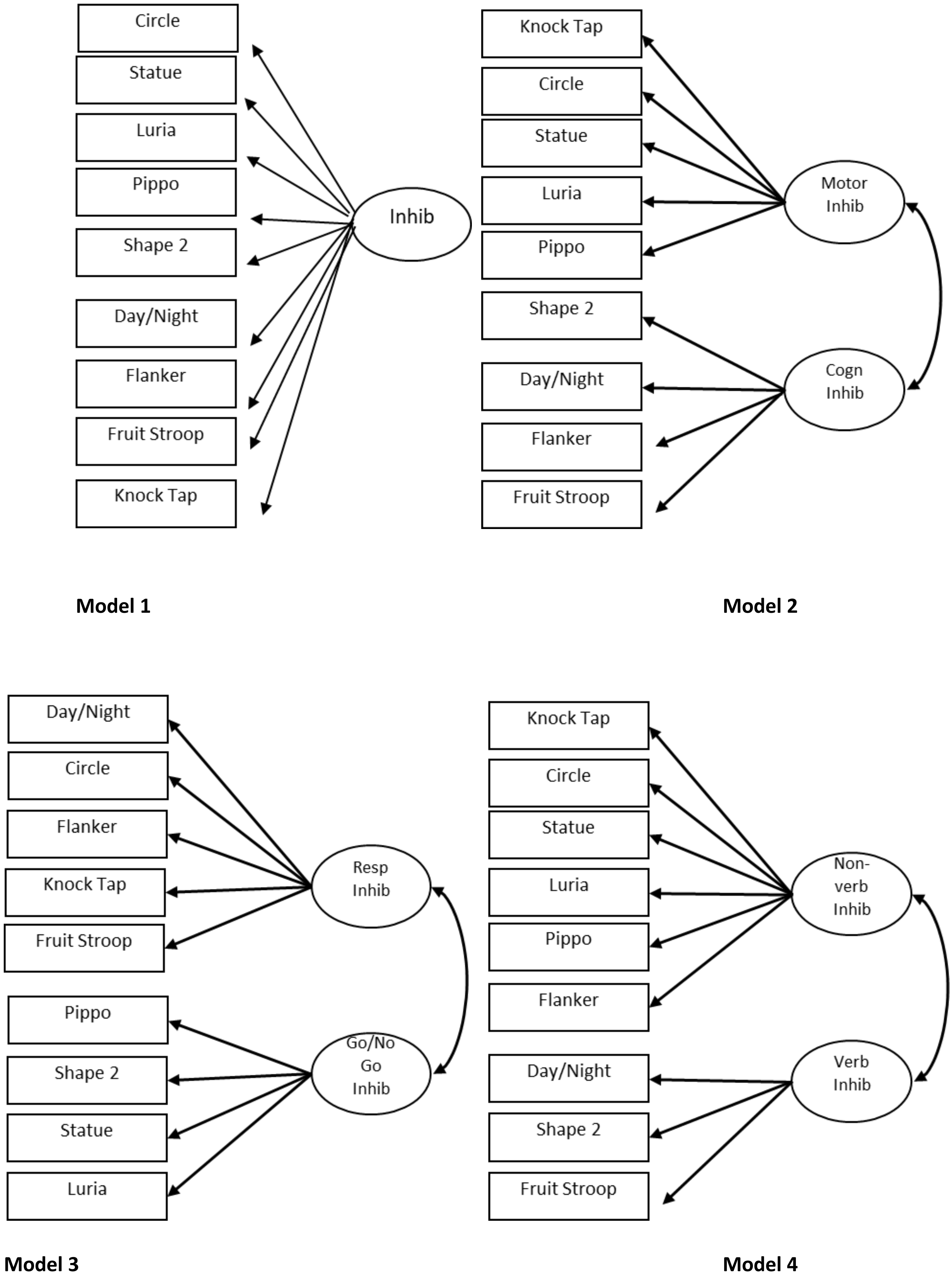
Table 8. Factor loadings of each task according to Model 1

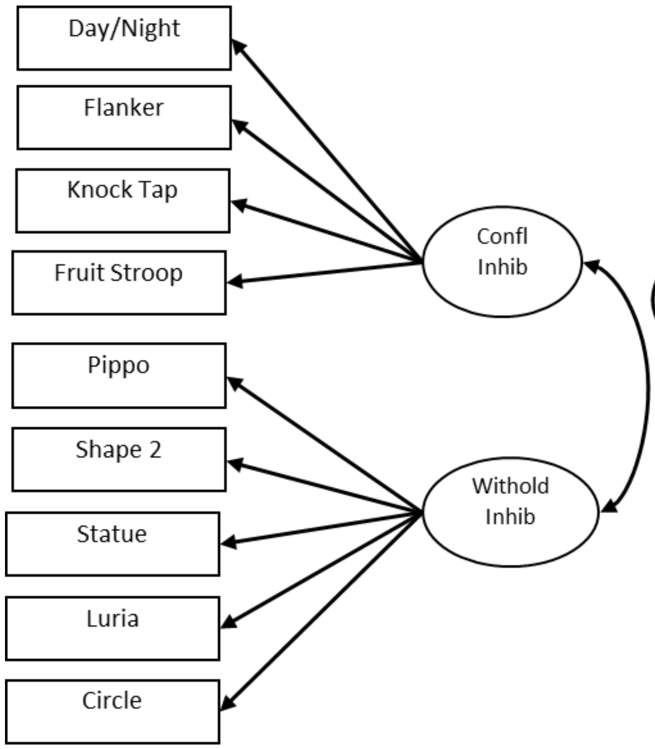
Task	Estimate	S.E.
BWS	0.52	0.08
Mr. Cucumber	0.40	0.08
DFT	0.57	0.08
SOPT	0.36	0.08
Magic House	0.65	0.08
Keep Track	0.53	0.08

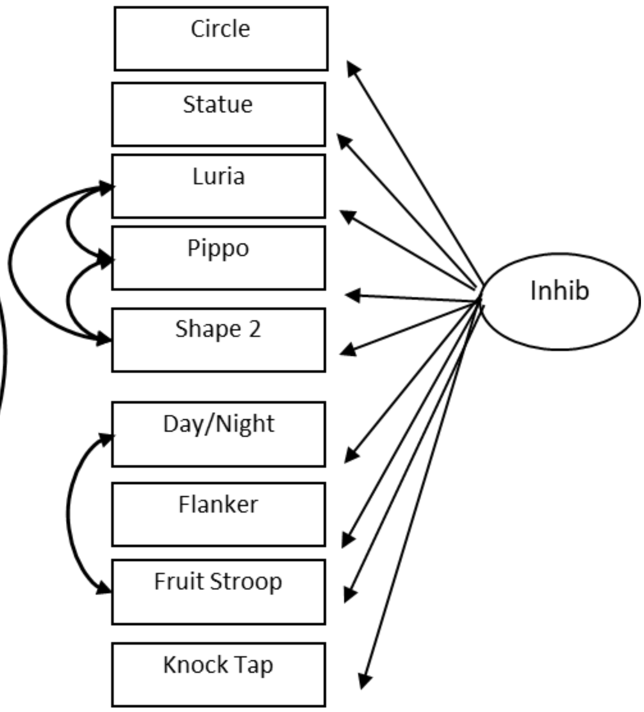
3.2.2 Inhibition

With the aim of identifying the components of inhibition, we used CFA testing six different models, reported in Figure 2. Model 1 was a one-factor model, comprising a single inhibition factor; Models 2, 3, 4 and 5 were two-factor models: Model 2 included cognitive and motor inhibition, Model 3 distinguished verbal and non-verbal inhibition, Model 4 was composed by a response latent factor versus a go-no go latent factor, while Model 5 included withholding response and conflict inhibition. Finally, Model 6 was a one-factor model which took into account also residual covariances between go-no-go and between Stroop tasks.

Figure 2. Alternative models for inhibition







Model 5 **Model 6**

As result of CFA, Model 1 fit the data sufficiently well. Model 2 and Model 3 were not testable, because matrix phi was not positive definite, i.e., the correlation between factors was estimated as > 1. Models 4 and 5 fit the data sufficiently well, but not significantly better than the unitary model: in both cases, AIC was higher than in Model 1. Finally, Model 6 showed the best fit to the data, as we can observe from the indices. Moreover, the difference with Model 1 was $\Delta\chi^2$ =20.85 (df =4, p<.001). Therefore, Model 6 resulted to have the best fit to the data. All nine tasks loaded significantly (p<.001on the single factor. Goodness of fit indices for the alternative models are summarized in Table 9. Table 10 shows the parameters of the best fitting model.

Table 9. Goodness of fit indices of alternative inhibition models. The endorsed model is indicated in bold

Models	**χ^2(p)**	**df**	**SRMR**	**RMSEA**	**CFI**	**NNFI**	**AIC**	**GFI**
Model 1	51.28 (.003)	27	0.062	0.066	0.92	0.90	87.28	0.95
Model 4	50.38 (.003)	26	0.062	0.068	0.92	0.89	88.38	0.95
Model 5	50.31 (.003)	26	0.062	0.068	0.92	0.89	88.31	0.95
Model 6	**30.43 (.14)**	**23**	**0.051**	**0.040**	**0.98**	**0.97**	**74.43**	**0.97**

Table 10. Factor loadings of each task according to Model 6

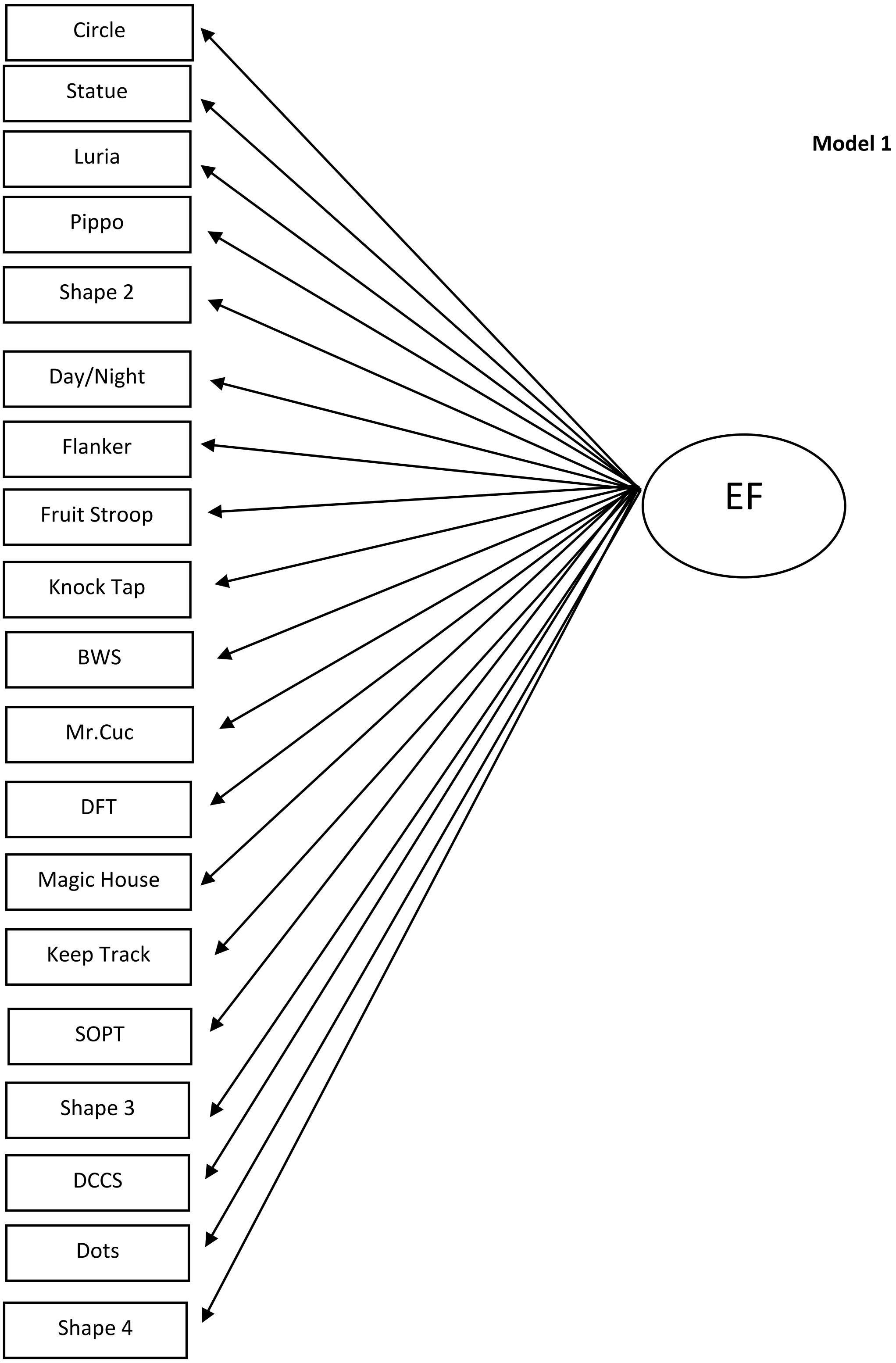
Task	Estimate	S.E.
Circle	0.26	0.08
Statue	0.39	0.08
Luria	0.46	0.08
Day/Night	-0.52	0.09
Pippo	0.56	0.08
Flanker	0.27	0.08
Fruit	-0.72	0.08
Knock Tap	0.49	0.08
Shape 2	-0.18	0.08

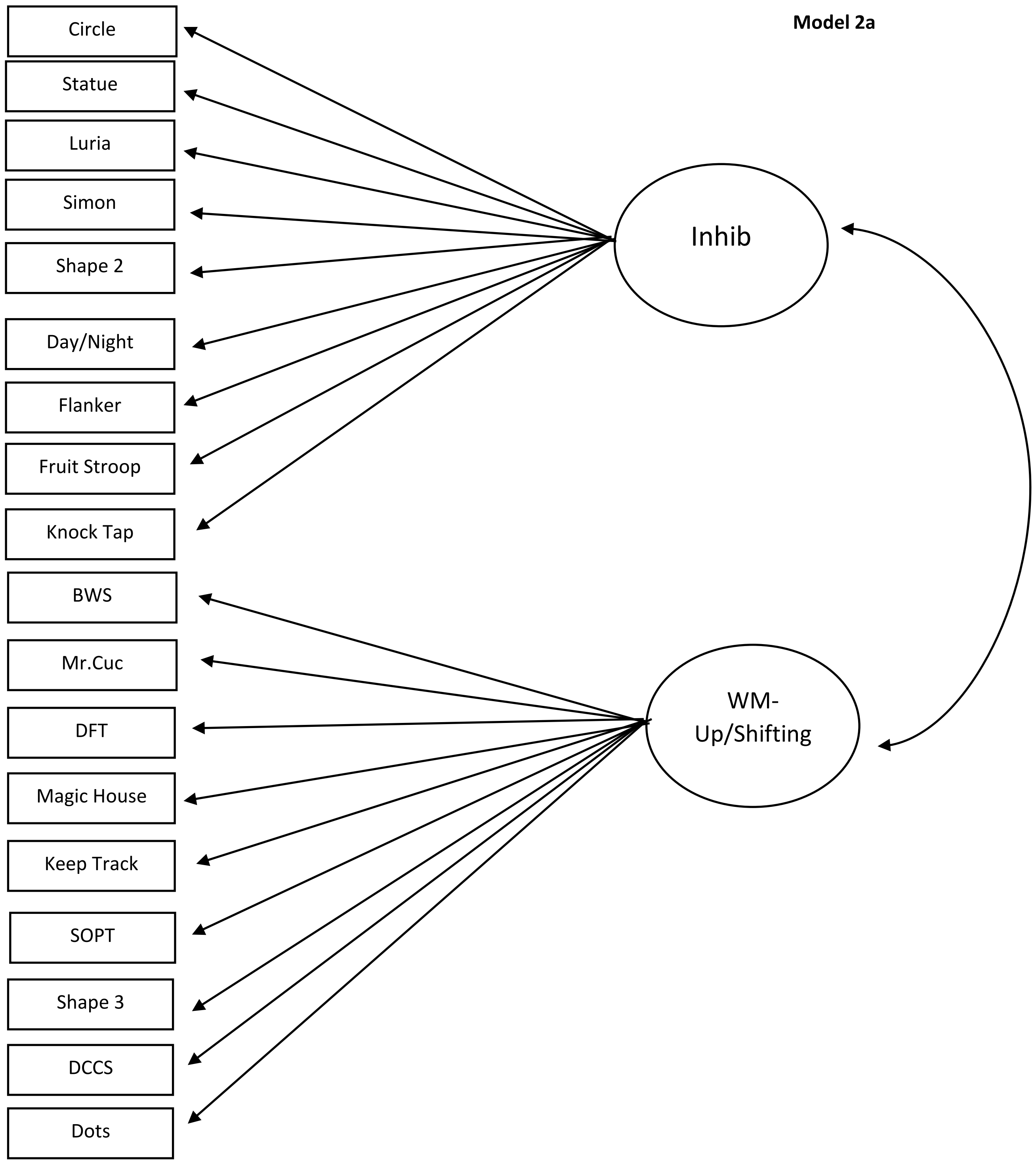
3.2.3 EF

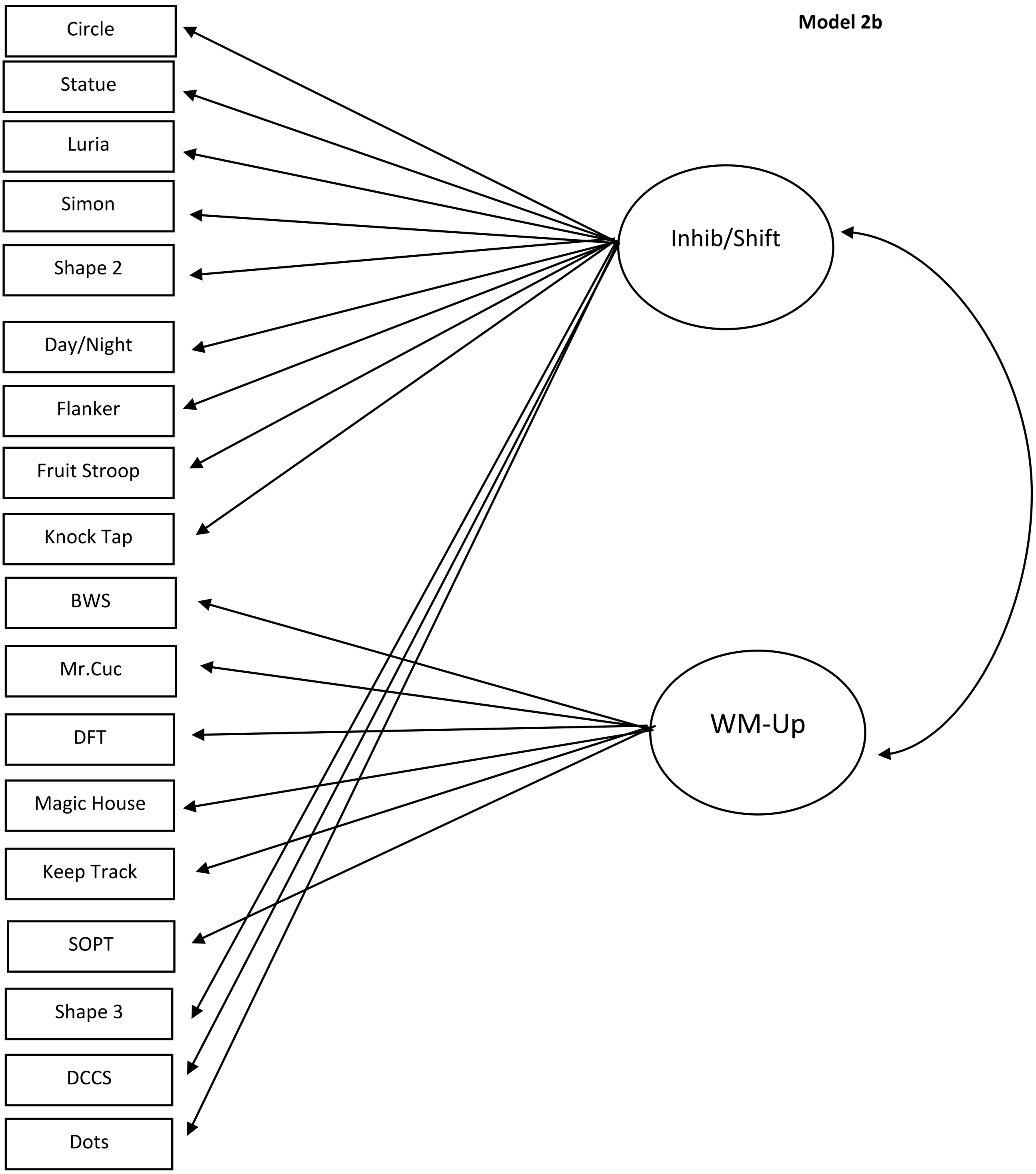
To determine the EF structure, first we tested five different models, representing different theoretical hypothesis. These models are shown in Figure 3. Specifically, Model 1, based on Wiebe's general executive control model (2008), was a one-factor model. Models 2a, 2b and 2c were two-factor models: in Model 2a inhibition was differentiated from other functions (WM-updating and shifting), similarly to the model found by Miller et al. (2012), Usai et al. (2014) and Monette et al. (2015). Model 2b included an inhibition-shifting factor, separated by WM-updating. In Model 2c one factor was formed by inhibition, WM, and updating, while the other one include shifting. Finally, Model 3 was a three-factor model, similar to Miyake et al.'s model (2000), where inhibition, WM-updating and shifting were distinguishable functions.

When incorporating all the indicators into the models, we eliminated the correlations between the errors in the Stroop-type and go-no-go inhibitory tasks, because we found that this improved the fit with the data. Therefore, it should be noted that when examining a single component in detail, additional information can be obtained compared to considering the EF model as a whole.

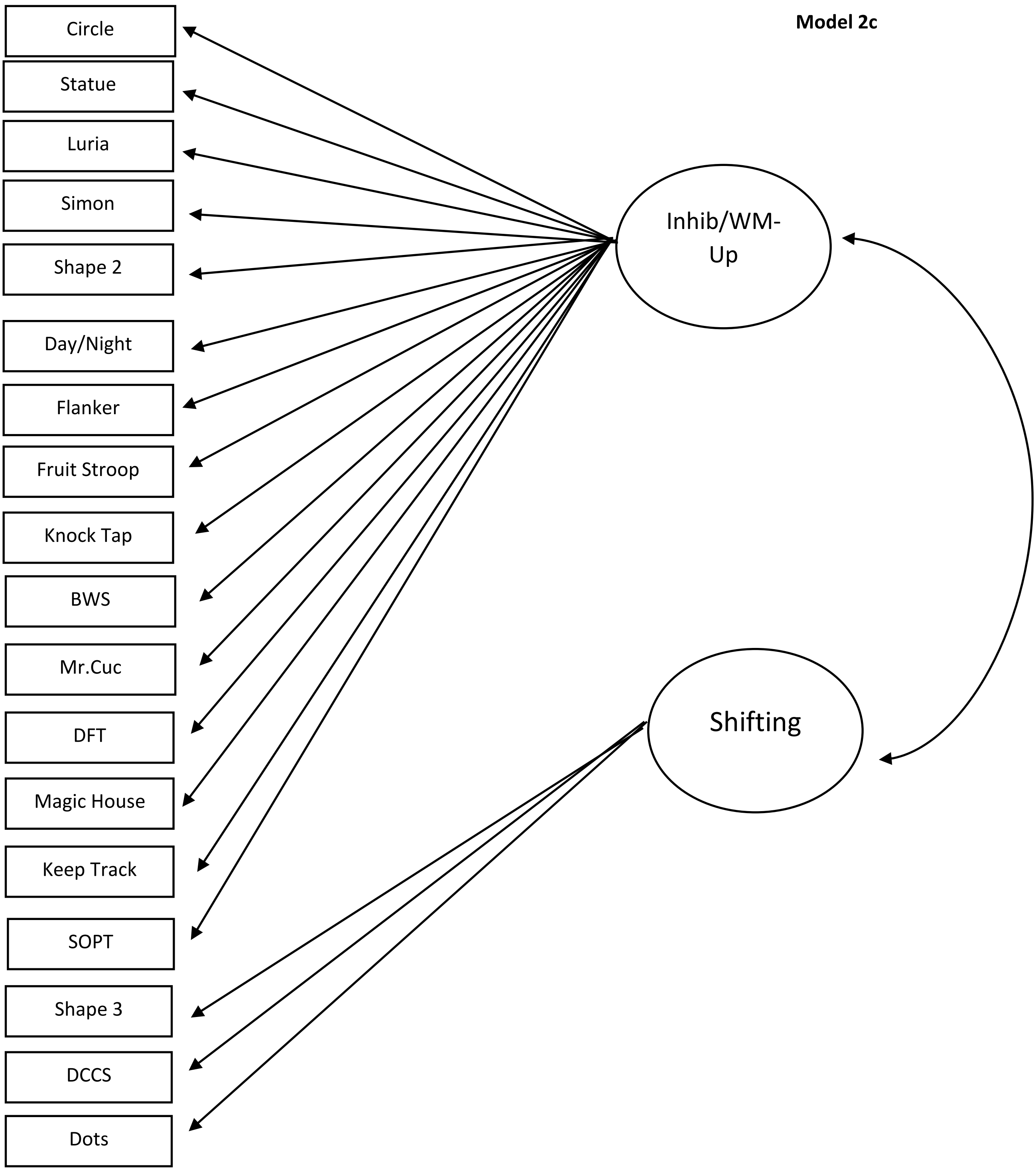
Figure 3. Alternative models for EF



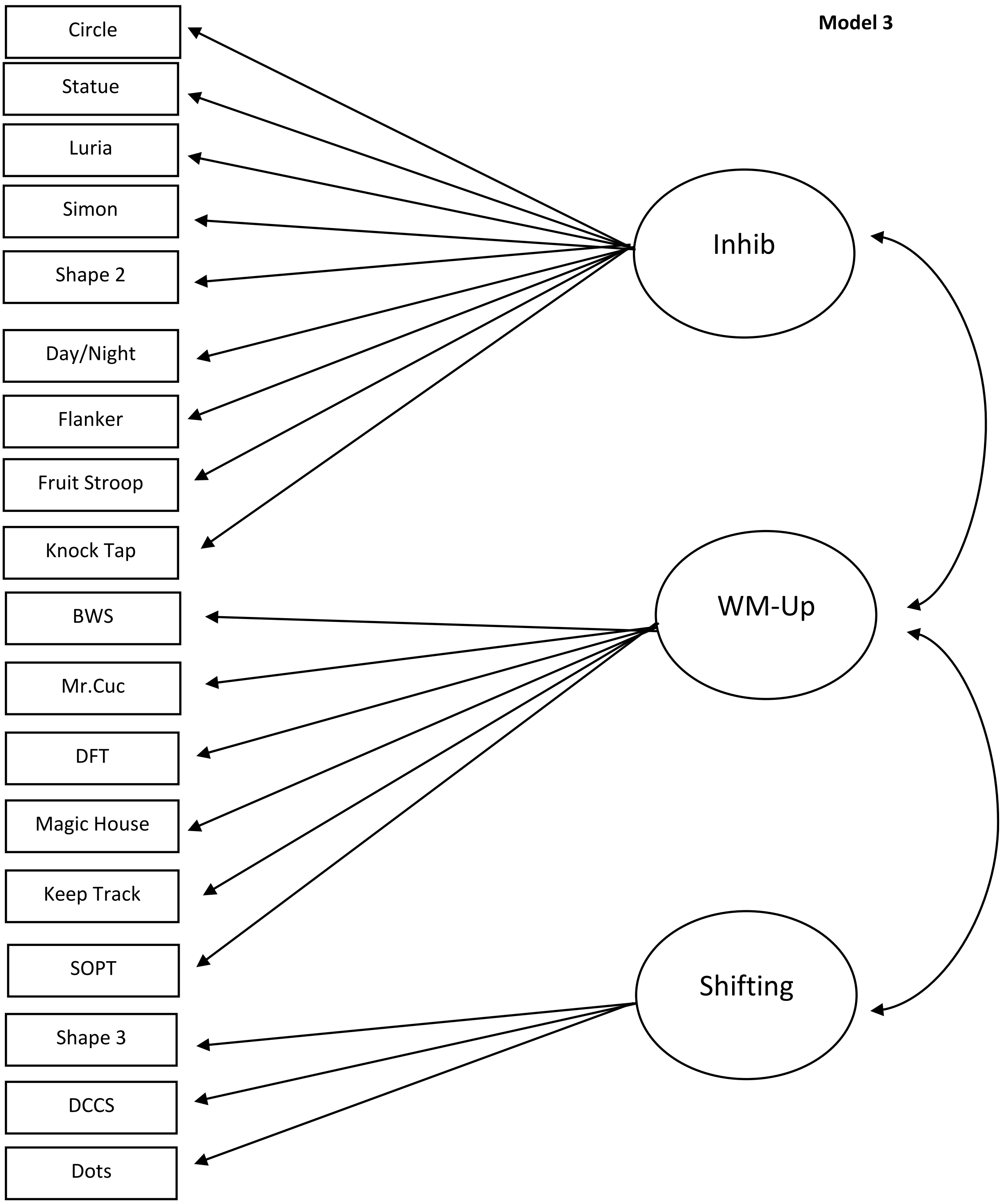

Model 2a
Circle
Statue
Luria
Simon
Shape 2
Day/Night
Flanker
Fruit Stroop
Knock Tap
BWS
Mr.Cuc
DFT
Magic House
Keep Track
SOPT
Shape 3
DCCS
Dots
Inhib
WM-
Up/Shifting


Model 2b
Circle
Statue
Luria
Simon
Shape 2
Day/Night
Flanker
Fruit Stroop
Knock Tap
BWS
Mr.Cuc
DFT
Magic House
Keep Track
SOPT
Shape 3
DCCS
Dots
Inhib/Shift
WM-Up

Model 2c


Circle
Statue
Luria
Simon
Shape 2
Day/Night
Flanker
Fruit Stroop
Knock Tap
BWS
Mr.Cuc
DFT
Magic House
Keep Track
SOPT
Shape 3
DCCS
Dots
Inhib/WM-Up
Shifting

Model 3



Circle
Statue
Luria
Simon
Shape 2
Day/Night
Flanker
Fruit Stroop
Knock Tap
BWS
Mr.Cuc
DFT
Magic House
Keep Track
SOPT
Shape 3
DCCS
Dots
Inhib
WM-Up
Shifting

Table 11 shows the goodness of fit indices for the alternative models. As we can see, Model 1 fit the data sufficiently well, even though $\chi2$ is significant ($p < .01$). The same situation happened for Model 2a and Model 2b. Model 2c was not testable, because matrix phi was not positive definite (correlation between factors > 1). The same is true for Model 3. Model 2a resulted to be the best fit model. Specifically, the difference between Model 1 and Model 2a was significant ($\Delta\chi2 = 4.69$; df = 1, $p < .05$), therefore this allowed us to adopt the more complex model. Model 2b was excluded because its difference with the more parsimonious Model 1 was not significant ($\Delta\chi2 = 3.17$; df = 1, $p > .05$), Moreover, Model 2a showed a lower value of AIC.

Table 11. Goodness of fit indices of alternative EF models. The endorse model is indicated in bold

Models	**χ2(p)**	**df**	**SRMR**	**RMSEA**	**CFI**	**NNFI**	**AIC**	**GFI**
Model 1	203.56 (.001)	150	0.056	0.042	0.97	0.96	283.56	0.90
Model 2a	**198.87 (.004)**	**149**	**0.056**	**0.041**	**0.97**	**0.96**	**280.87**	**0.91**
Model 2b	200.39 (.003)	149	0.056	0.041	0.97	0.96	282.39	0.91

Table 12. Factor loadings of each task according to Model 2a

Task	**Estimates**	**S.E.**
Circle	0.29	0.08
Statue	0.36	0.07
Luria	0.53	0.07
Day/Night	-0.49	0.07
Pippo	0.65	0.07
Flanker	0.32	0.08
Fruit Stroop	-0.56	0.07
Knock Tap	0.42	0.07
Shape 2	-0.60	0.07
BWS	0.57	0.07
Mr Cucumber	0.50	0.07

DFT	0.54	0.07
Magic House	0.54	0.07
SOPT	0.33	0.08
Keep Track	0.51	0.07
DCCS	0.43	0.07
DOTS	0.33	0.08
Shape 3	-0.42	0.07
Shape 4	-0.43	0.07

However, in model 2a the correlation between the factors is very high. For this reason, we decided to consider the developmental aspect, in order to investigate whether age changes have an effect on the variables of the model. In fact, the correlations between the two variables might be too high because part of them could be explained by the fact that both increase with age, while the other part could be attributable to the correlation between the residual components of the two endogenous latent variables. Therefore, we tried to set the model as causal, in which exogenous age variable was measured without error and the psi parameter was freed of its covariance. This model, showed in Figure 4, has quite good goodness of fit indices and all estimated parameters have statistically plausible values significant. All the indices are reported in Table 13, while the factor loadings are reported in Table 14.

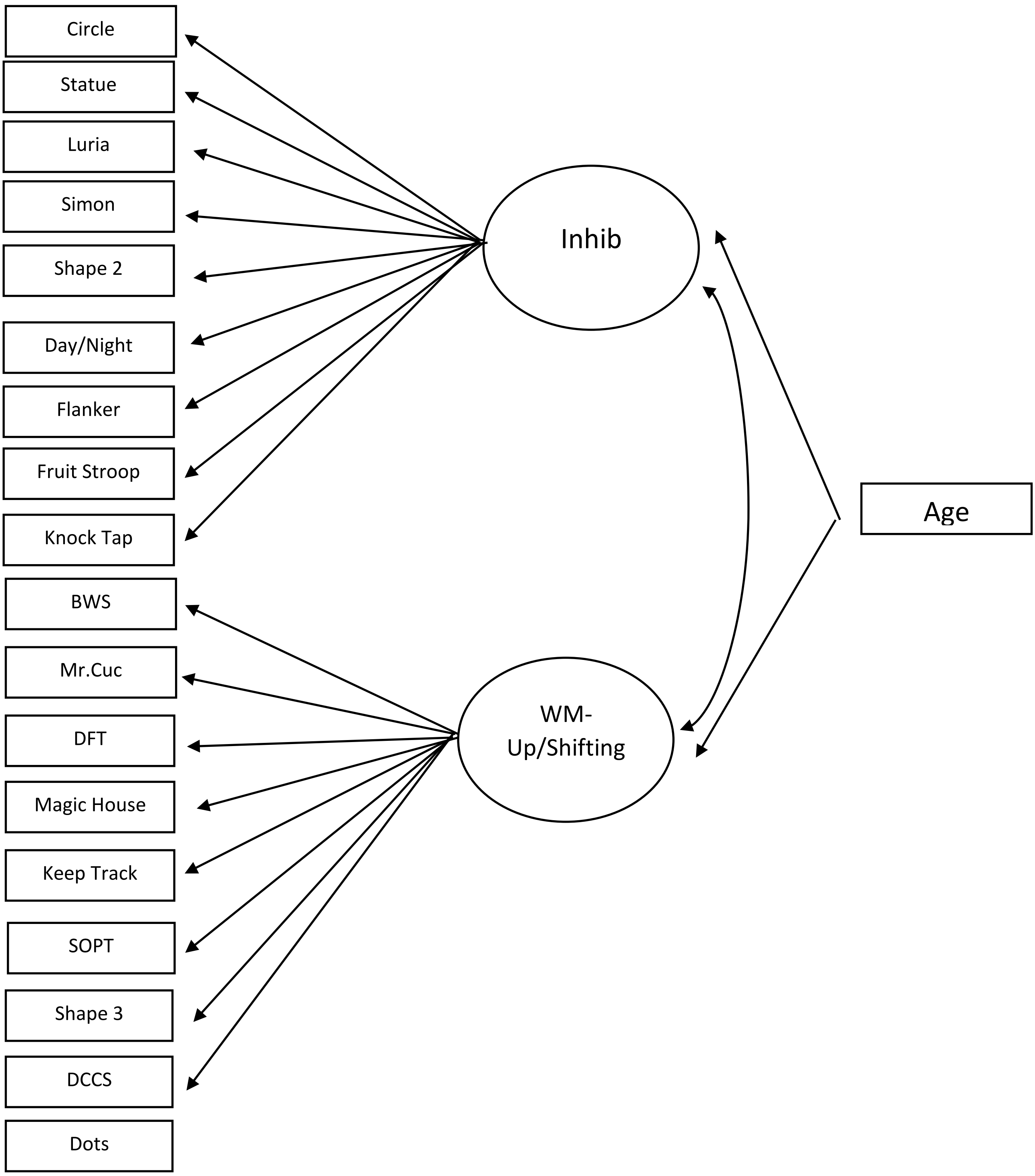
Table 13. Goodness of fit indices of the causal model

Models	**χ2(p)**	**df**	**SRMR**	**RMSEA**	**CFI**	**NNFI**	**AIC**	**GFI**
Causal Model	**228.42 (.004)**	**166**	**0.056**	**0.043**	**0.97**	**0.96**	**316.42**	**0.90**

Table 14. Factor loadings of each task according to the causal model

Task	Estimates	S.E.
Circle	0.29	0.08
Statue	0.36	0.08
Luria	0.49	0.08
Day/Night	-0.51	0.08
Pippo	0.67	-
Flanker	0.30	0.08
Fruit Stroop	-0.54	0.08
Knock Tap	0.41	0.08
Shape 2	-0.62	0.08
BWS	0.57	-
Mr Cucumber	0.51	0.09
DFT	0.52	0.09
Magic House	0.53	0.09
SOPT	0.33	0.08
Keep Track	0.52	0.09
DCCS	0.44	0.09
DOTS	0.32	0.08
Shape 3	-0.44	0.09
Shape 4	-0.42	0.09

Figure 4. Causal Model



4. Discussion

As previously explained, the issue of the structure of EF in children, specifically pre-schoolers, is one of the main open questions in developmental literature. In adulthood, studies have identified three distinct but related EF: inhibition, shifting, and updating (Miyake et al., 2000). While it is well established that these functions are distinct in adults, there is no agreement in developmental literature about the model which better describes the structure of these constructs. Some authors have identified two-factor models (e.g., Lerner & Lonigan, 2014; Panesi & Morra, 2020; Usai et al., 2014), while others have obtained supportive results of the existence of a unifactorial model (e.g. Hughes et al., 2010; Shing et al., 2010; Wiebe et al., 2008; Wiebe et al., 2011). Another debated issue is the consideration of WM and updating as two distinct functions (see Morra et al., 2018; Panesi et al., 2022) or as a single construct which can be considered as one of the EF (Garon et al., 2008; Diamond, 2013). Furthermore, there is no clarity on the nature of the inhibition construct, as several models can be found in literature, claiming that inhibition could be a multifactor function (e,g., Diamond, 2013; Dempster, 1993; Friedman and Miyake, 2004; Garon et al., 2008; Nigg, 2000).

The aims of the present study were to investigate the relationship between WM and updating, analyse the model that best describes the structure of inhibition and investigate the latent structure of EF, using CFA. To the best of our knowledge, this is the first study that employed such a rich battery of EF tasks, including several measures of inhibition, WM, updating, and shifting.

Starting from our first purpose, we tested the factorial structure of WM and updating. Specifically, we tested a one-factor model and a two-factor model. Our results suggested that WM and updating are overlapping functions in preschoolers, as the one-factor model resulted to best fit to our data. Our finding is in line with Garon et al. (2008) and Diamond (2013), that considered WM and updating as synonymous within the three-factor model of EF proposed by Miyake et al. (2000) for adults. As a consequence, there seems not to be a distinction between WM and updating tasks, which can be used indiscriminately. However, these results were a surprise for us: in fact, they are in contrast with Panesi et al. (2022), where we found that updating skills in preschoolers depends on WM but does not coincide with it. Possible explanations for this inconsistency can be found in the fact that we employed a larger set of updating tasks: in fact, in the present study we used three tasks (Magic House, Keep Track and SOPT), while Panesi et al. (2022) used only one (Magic House). At the time, this was actually reported as a limitation of the study, because a more numerous set of updating measures would provide more complete information about its relationship with WM. Additionally, our sample was broader and we used different analysis.

Our second aim was to investigate the structure of inhibition. To do that, we compared one-factor and two-factor models, which involved different dimensions of inhibition tasks: cognitive VS motor inhibition, verbal VS non-verbal inhibition, response VS go/no go and withholding response inhibition VS conflict inhibition. Also in this case, results suggested that the structure of inhibition is better described by a one-factor model.

Finally, we proceeded to investigate the latent structure of EF. We started from the analysis carried out previously: due to the previous results, we considered WM-updating as a single latent factor, as well as inhibition. For our purpose, we tested a one-factor model, three two-factor models and a three-factor model, based on theoretical hypothesis. From results, the model which seems to better describe the latent structure in preschool children is a two-factor model, in which inhibition tasks loaded on a separate factor from WM-updating and shifting, which represent the other latent factor. This result is consistent with previous literature, according to which a two-factor model is more likely to emerge in older preschoolers than a one factor model, while three-factor model is generally found in children from school age (Karr et al., 2018). Regarding the nature of the model, our findings are in line with Miller et al. (2012), Monette et al. (2015) and Usai et al. (2014).

The present study can be considered a sort of novelty in developmental literature dealing with this topic. Although studies investigating the structure of EF through CFA in preschoolers have proliferated in recent years, most have considered only on a limited number of constructs. As explained before, the majority of studies only focused on WM and inhibition, excluding other functions (e.g., Hume, 2015, Lerner & Lonigan, 2014; Miller et al., 2013). Some authors decided to include also the function of shifting (e.g., Miller et al., 2012; Monette et al., 2015; Usai et al., 2014), following Diamond's EF model (2013). However, almost no study has considered the updating function. Panesi and Morra (2020) were one of the few authors to include a specific updating task in their factor analysis. However, one of the limitations reported by the authors was that they employed only one measure of shifting (DCCS) and one of updating (Magic House). The contribution made by our study is an extension of the test battery, increasing the number of tasks for these functions. Furthermore, we focus our research on older preschoolers, as we previously seen that several changes happen between 3 and 6 years old, therefore it could be hard identifying the structure of EF in this age range.

Our study presents some limitations. One of them concerns the age range of our sample: although it was quite narrow, as we focused only on children between 4 and 6 years old, it might still be too broad for the purposes of our study. As explained before, indeed, in this age range, the development of EF undergoes a significant boost, with significant and rapid changes over time. Further narrowing the age range could provide more precise information about the timing of the development of these functions. Another limit concerns the sample selection: as mentioned above, 25% of the participants did not provide informed consent. It is a rather high percentage, which may have introduced a selection bias in the sample that could have impacted the results Moreover, the sample size could also be considered a limitation of our study. In this case as well, the number was quite large, but perhaps not sufficient given the numerous hypotheses to test at the same time. Future studies could replicate our study with a larger sample size. Moreover, a larger sample would allow to test a greater number of models. Finally, the present study did not focus on variables such as SES, gender, life experiences or the presence of cultural differences which could affect the development of EF. Therefore, future studies should take these variables into account.

5. References

Archibald, S. J., & Kerns, K. A. (1999). Identification and description of new tests of executive functioning in children. Child Neuropsychology, 5(2), 115–129. https://doi.org/10.1076/chin.5.2.115.3167

Bachorowski, J.A., & Newman, J.P. (1985). Impulsivity in adults: Motor inhibition and time-interval estimation. Personality and Individual Differences, 6, 133-136. https://doi.org/10.1016/0191-8869(85)90041-8

Blair C, & Razza RP. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development. 78(2):647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Case, R. (1985). Intellectual development: Birth to adulthood. Orlando, FL: Academic Press.

Dempster, F. N. (1993). Resistance to interference: Developmental changes in a basic processing mechanism. In Emerging themes in cognitive development: Volume I: Foundations (pp. 3-27). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4613-9220-0_1.

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.

Diamond, A., Barnett, W.S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. Science, 318:1387–88. https://doi.org/10.1126/science.1151148

Espy, K.A. (1997). The shape school: Assessing executive function in preschool children. Developmental Neuropsychology, 13(4):495–499. https://doi.org/10.1080/87565649709540690

Espy, K. A., Bull, R., Martin, J., & Stroup, W. (2006). Measuring the development of executive control with the shape school. Psychological assessment, 18(4), 373–381. https://doi.org/10.1037/1040-3590.18.4.373.Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. Journal of Experimental Psychology: General, 133 (1), 101–135. https://doi.org/10.1037/0096-3445.133.1.101.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Bulletin, 134(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gerstadt, C.L., Hong, Y.L., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3 1/2-7 years old on a Stroop-like day-night test. Cognition, 53, 129–153. https://doi.org/10.1016/0010-0277(94)90068-X.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In Interference and inhibition in cognition (pp. 175-204). Academic Press. https://doi.org/10.1016/B978-012208930-5/50007-6.

Hughes, C., and Ensor, R. (2007). Executive function and theory of mind: predictive relations from ages 2- to 4-years. Dev. Psychol. 43, 1447–145. https://doi.org/10.1037/0012-1649.43.6.1447

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: A latent variable approach. Developmental Neuropsychology, 35, 20–36. https://doi.org/10.1080/87565640903325691

Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. Child Development, 77, 1822–1841. https://doi.org/10.1111/j.1467-8624.2006.00976.x.

Im-Bolter, N., Johnson, J., Ling, D., & Pascual-Leone, J. (2015). Inhibition: Mental control process or mental resource? Journal of Cognition and Development, 16, 666–681. https://doi.org/10.1080/15248372.2014.930743.

Johnson J., Im-Bolter N., Pascual-Leone J. (2003). Development of mental attention in gifted and mainstream children: The role of mental capacity, inhibition, and speed of processing. Child Development. Vol. 74. No. 6. P. 1594 – 1614. https://doi.org/10.1046/j.1467-8624.2003.00626.x

Jöreskog, K.G. & Sörbom, D. (2006). LISREL 8.80 for Windows [Computer software]. Lincolnwood, IL: Scientific Software International, Inc.

Kane, M.J., Brown, L.H., McVay, J.C., Silvia, P.J., Myin-Germeys, I., & Kwapil, T.R. (2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. Psychological Science 18: 614–21. https://doi.org/10.1111/j.1467-9280.2007.01948.x

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The Unity and Diversity of Executive Functions: A Systematic Review and Re-Analysis of Latent Variable Studies. Psychological Bulletin. https://doi.org/10.1037/bul0000160.

Kline, R. B. (2015). Principles and Practice of Structural Equation Modeling, 4th edition. New York: Guilford Press

Korkman, M.; Kirk, U.; Kemp, S. NEPSY: A developmental neuropsychological assessment manual. The Psychological Corporation; San Antonio, TX: 1998. https://doi.org/10.1076/chin.4.3.199.3171

Lerner, M.D., & Lonigan, C.J. (2014). Executive Function Among Preschool Children: Unitary Versus Distinct Abilities. Journal of Psychopathology and Behavioral Assessment, 36:4, 626–639. https://doi.org/10.1007/s10862-014-9424-3.

Miyake, A., Friedman, N.P., Emerson, M.J.; Witzki, A.H., Howerter, A. & Wager, T.D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. Cognitive Psychology, 41:1, 49-100. https://doi.org/10.1006/cogp.1999.0734

Monette, S., Bigras, M. & Lafrenière, M.A (2015). Structure of executive functions in typically developing kindergarteners. Journal of Experimental Child Psychology, 140, 120-139. https://doi.org/10.1016/j.jecp.2015.07.005

Morra, S. (1994). Issues in working memory measurement: Testing for M capacity. The International Society for the Study of Behavioral Development, 17, 143–159. https://doi.org/10.1177/016502549401700109

Morra, S., Camba, R., Calvini, G., & Bracco, F. (2013). Italians do it better? M-capacity measurement and cross-linguistic differences in the direction following task (DFT). Journal of Applied Psycholinguistics, 13, 9–24.

Morra, S., Panesi, S., Traverso L., & Usai MC. (2018). Which tasks measure what? Reflections on executive function development and a commentary on Podjarny, Kamawar, and Andrews. Journal of Experimental Child Psychology, 167, 246-258. https://doi.org/10.1016/j.jecp.2017.11.004.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathol- ogy: Views from cognitive and personality psychology and a working inhibition taxonomy. Psychological Bulletin, 126 (2), 220–246. https://doi.org/10.1037/ 0033-2909.126.2.220.

Panesi, S. & Morra, S. (2017). La Casetta Magica Un nuovo strumento per indagare l'aggiornamento (updating) della memoria di lavoro in età prescolare. Psicologia clinica dello sviluppo, 21:3, 443-462.

Panesi, S., & Morra, S. (2020). Executive Functions and Mental Attentional Capacity in Preschoolers. Journal of Cognition and Development, 21(1), 72-91. https://doi.org/10.1080/15248372.2019.1685525

Panesi, S., Bandettini, A., Traverso, L., & Morra, S. (2022). On the Relation between the Development of Working Memory Updating and Working Memory Capacity in Preschoolers. Journal of Intelligence 10:5. https://doi.org/10.3390/jintelligence10010005.

Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's developmental stages. Acta Psychologica, 63, 301–345. https://doi.org/10.1016/0001-6918(70)90108-3

Pascual-Leone, J. (1987). Organismic Processes for neo-Piagetian theories: A dialectical causal account of cognitive development. International Journal of Psychology, 22, 531–570. https://doi.org/10.1080/00207598708246795.

Pascual-Leone, J., & Johnson, J. (2005). A dialectical constructivist view of developmental intelligence. In O. Wilhelm & R. Engle (Eds.), Handbook of understanding and masuring intelligence (pp. 177–201). Thousand Oaks, CA: Sage. https://doi.org/10.4135/9781452233529.n11

Pascual-Leone, J., & Johnson, J. (2011). A developmental theory of mental attention. Cognitive Development and Working Memory: A Dialogue between Neo-Piagetian Theories and Cognitive Approaches. Edited by Pierre Barrouillet and Vinciane Gaillard. Hove: Psychology Press, pp. 13–46.

Petrides, M., & Milner, B. (1982). Deficits on subject-ordered tasks after frontal- and temporal-lobe lesions in man. Neuropsychologia, 20:3, 249-262. https://doi.org/10.1016/0028-3932(82)90100-2

Raven, J. C. (1947). Progressive matrices. Set A, Ab, B, board and book form. London: H.K. Lewis.

Redick, Thomas S., and Dakota R. B. Lindsey. 2013. Complex span and n-back measures of working memory: A meta-analysis. Psychonomic Bulletin & Review 20: 1102–13. https://doi.org/10.3758/s13423-013-0453-9

Senn, T.E., Espy, K.A., & Kaufmann, P.M. (2004). Using path analysis to understand executive function organization in preschool children. Developmental Cognitive Neuroscience Laboratory - Faculty and Staff Publications. 8. https://doi.org/10.1207/s15326942dn2601_5

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S. C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. Developmental neuropsychology, 35(6), 679–697. https://doi.org/10.1080/87565641.2010.508546

Stella, G., Pizzoli, C., & Tressoldi, P.E. (2000). Peabody – Test di vocabolario recettivo. Torino: Omega.

Strommen, E. A. (1973). Verbal self-regulation in a children's game: Impulsive errors on "Simon says." Child Development, 44, 849–853. https://www.jstor.org/stable/1127737

Traverso, L., Viterbori, P., & Usai, M.C. (2015). Improving Executive Function in childhood: Evaluation of a training intervention for 5-year-old children. Frontiers in Psychology, 6, 525. https://doi.org/10.3389/fpsyg.2015.00525

Traverso, L., Viterbori, P., & Usai, M.C. (2019). Effectiveness of an Executive Function Training in Italian Preschool Educational Services and Far Transfer Effects to Pre-academic Skills. Frontiers in Psychology, 10, 2053. https://doi.org/10.3389/fpsyg.2019.02053

Usai, M.C., Traverso, L., Gandolfi, E., & Viterbori, P. (2017). Batteria per la valutazione delle funzioni esecutive in età prescolare (FE-PS 2-6). Erickson.

Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in five-and six-year-old children: A longitudinal study. European Journal of Developmental Psychology, 11, 447–462. https://doi.org/10.1080/17405629.2013.840578

van der Ven, S. H., Kroesbergen, E. H., Boom, J., & Leseman, P. P. (2013). The structure of executive functions in children: A closer examination of inhibition, shifting, and updating. British Journal of Developmental Psychology, 31, 70–87. https://doi.org/10.1111/j.2044-835X.2012.02079.x

Viterbori, P., Gandolfi, E., & Usai, M.C. (2012). Executive skills and early language development. Journal Applied Psycholinguist, 3, 17–32.

Viterbori, P., Usai, M. C., Traverso, L., & De Franchis, V. (2015). How preschool executive functioning predicts several aspects of math achievement in Grades 1 and 3: A longitudinal study. Journal of experimental child psychology, 140, 38–55. https://doi.org/10.1016/j.jecp.2015.06.014

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. Developmental Psychology, 44(2), 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Wiebe, S., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. (2011). The structure of executive function in 3-year-olds. Journal of Experimental Child Psychology, 108, 436–452. https://doi.org/10.1016/j.jecp.2010.08.008.

Zelazo, P.D. (2006). The dimensional change card sort (DCCS): A method of assessing executive function in children. Nature Protocols, 1, 297–301. https://doi.org/10.1038/nprot.2006.46

General discussion

EF and WM are increasingly recognized as crucial components in children's cognitive and social development. Indeed, the development of EF and WM during the preschool years is linked to enhanced socio-emotional skills, such as theory of mind, problem-solving abilities, and academic achievements, with effects that extend into later developmental stages. (Blair & Razza, 2007; Hughes & Ensor, 2007; Senn, Espy, & Kaufmann, 2004). However, many questions remain unresolved, including the structure of EF in preschoolers. A systematic review by Karr et al. (2018) found that studies on this age group often propose one- or two-factor models. This discrepancy may be due to different causes. Firstly, the studies investigating this topic exhibit methodological differences that could impact the results obtained. Additionally, there are some open questions regarding EF in developmental literature. First, there is an ongoing debate about whether WM and updating should be considered overlapping constructs (e.g., Diamond, 2013; Garon, Bryson, & Smith, 2008) or separate ones (e.g., Panesi, Bandettini, Traverso, & Morra, 2022). The tasks used to measure these functions often overlap, further complicating differentiation, especially given the scarcity of tasks specifically designed to measure updating in young children. Another prominent issue is the structure of inhibition, one of the most studied EF. There is a widespread view that inhibition is a multidimensional construct, as tasks measuring inhibition suggest the involvement of diverse processes.

In light of the aforementioned points, the objective of the present thesis to enhance the understanding of the EF construct in preschoolers. Specifically, our project aimed to address these inconsistencies by conducting two systematic reviews to analyse the literature on EF and its latent structure in preschool children, with a specific focus on the relationship between WM and updating. Additionally, we focused on the construct of inhibition in relation to existing models and tasks. Finally, we conducted an experimental study with preschoolers to investigate which models best describe the latent structures of (a) WM and updating, (b) inhibition, and (c) EF.

In the systematic review presented in the first chapter, we analysed the studies which investigated the latent structure of EF using CFA. Our findings revealed inconsistencies in EF conceptualization, in the methodologies used by the studies. Specifically, we identified discrepancies regarding the age range defined as preschool, the selection of tasks, and the construction of models. Additionally, we noted that studies focused on younger preschoolers generally identified a one-factor model, while those focused on older preschoolers typically found a two-factor model.

The second chapter regarded the relationship between WM and updating. Specifically, we conducted a systematic review showing that, despite inconsistencies, the prevalent view is that WM encompasses updating, aligning with models like Baddeley's (2000), rather than distinguishing them as separate constructs. Moreover, a general clarity in task application despite theoretical inconsistencies emerged.

Finally, we focused the third chapter on inhibition. We observed that inhibition tasks vary widely in their results and correlations, reflecting the complexity of the inhibition construct and the specific processes they measure. This variation underscores the importance of selecting tasks and methods tailored to specific research aims and populations. Moreover, the literature largely relies on theoretical models of inhibition, with few empirical studies using factor analysis to understand its latent structure, particularly in preschoolers. Therefore, we suggested that there is a need for more precise investigations into the dimensions of inhibition and the development of better methodological approaches to assess inhibitory control effectively.

Through the experimental study presented in the fourth chapter, we attempted to address these critical issues. Specifically, we analysed the structure of EF using CFA in a sample of preschool children. In doing this, we aimed to give importance to a series of methodological aspects that, as we have seen, can be critical. Firstly, in selecting our sample, we focused only on older preschoolers, starting from the age of 4. We made this choice because our systematic review showed that the structure of EFs changes significantly throughout the preschool years, therefore we decided to focus on a more specific age range. Secondly, in selecting the tests, we chose tasks that measure EF as conceptualized by the Miyake et al. (2000) model, without focusing solely on WM and inhibition as most studies examining EFs in this age group have done (e.g., Lerner and Lonigan, 2014; Wiebe et al., 2008). Thus, our battery included tasks for inhibition, shifting, updating, and WM. Particular effort was dedicated to identifying tasks that measure updating in preschool age, given the limited literature on this topic. Additionally, we selected a series of inhibitory tasks that evaluate the various sub-components of this construct (e.g., motor/cognitive, verbal/non-verbal, etc.).

In conducting the CFA, we first analysed the latent structure of the variables for WM and updating, as well as for inhibition. For WM and updating, the results aligned with the findings from our systematic literature review: the best-fitting model was the unifactorial one, where both WM and updating indicators corresponded to a single latent variable. As for inhibition, contrary to what is commonly found in the literature: among the diverse models we tested, our analyses yielded a best-fitting unidimensional model, in which all inhibitory tasks loaded onto a single latent factor. Finally, the last analyses, which included other functions as well, indicated that a two-factor model—where inhibitory tasks loaded onto one factor and WM-updating and shifting tasks loaded onto a separate, distinct factor—best fit the data. This result is consistent with the findings from our systematic review about the latent structure of EF, which showed that is more likely that a two-factor model will be detected in children over 4 years old.

The present project represents a notable innovation in developmental literature on EF in preschoolers. Moreover, a deeper understanding of the structure of EF and WM in a sensitive age like preschool years also allows for a clearer comprehension of how executive dimensions can interact with other socio-cognitive abilities, such as learning, emotional competence, and theory of mind. Furthermore, it provides significant implications for constructing effective interventions aimed at enhancing these skills.

References

Blair C, & Razza RP. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Development. 78(2):647–663. https://doi.org/10.1111/j.1467-8624.2007.01019.x

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. Psychological Bulletin, 134(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Hughes, C., and Ensor, R. (2007). Executive function and theory of mind: predictive relations from ages 2- to 4-years. Dev. Psychol. 43, 1447–145. https://doi.org/10.1037/0012-1649.43.6.1447

Karr, J. E., Areshenkoff, C. N., Rast, P., Hofer, S. M., Iverson, G. L., & Garcia-Barrera, M. A. (2018). The Unity and Diversity of Executive Functions: A Systematic Review and Re-Analysis of Latent Variable Studies. Psychological Bulletin. https://doi.org/10.1037/bul0000160.

Lerner, M.D., & Lonigan, C.J. (2014). Executive Function Among Preschool Children: Unitary Versus Distinct Abilities. Journal of Psychopathology and Behavioral Assessment, 36:4, 626–639. https://doi.org/10.1007/s10862-014-9424-3.

Miyake, A., Friedman, N.P., Emerson, M.J.; Witzki, A.H., Howerter, A. & Wager, T.D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. Cognitive Psychology, 41:1, 49-100. https://doi.org/10.1006/cogp.1999.0734

Panesi, S., Bandettini, A., Traverso, L., & Morra, S. (2022). On the Relation between the Development of Working Memory Updating and Working Memory Capacity in Preschoolers. Journal of Intelligence 10:5. https://doi.org/10.3390/jintelligence10010005.

Senn, T.E., Espy, K.A., & Kaufmann, P.M. (2004). Using path analysis to understand executive function organization in preschool children. Developmental Cognitive Neuroscience Laboratory - Faculty and Staff Publications. 8. https://doi.org/10.1207/s15326942dn2601_5

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. Developmental Psychology, 44(2), 575–587. https://doi.org/10.1037/0012-1649.44.2.575

Appendix

Ethical approval

UNIVERSITÀ DEGLI STUDI DI GENOVA
Comitato Etico per la Ricerca di Ateneo (CERA)

Parere N. 2022/03 del Comitato Etico per la Ricerca di Ateneo

Vista la richiesta di parere al Comitato etico per la ricerca di Ateneo pervenuta in data 03/11/2021 dallo sperimentatore principale/responsabile scientifico dott.ssa Alessia Bandettini per il progetto dal titolo: "Valutazione delle funzioni esecutive e della memoria di lavoro in età prescolare" e considerate le modifiche da apportare concordate con il responsabile scientifico.

Si comunica quanto segue:

il Presidente verificato che le richieste di modifica avanzate dal CERA sono state accolte e apportate, a seguito del mandato a procedere ricevuto dal Comitato nella seduta del 18/11/2021, esprime parere favorevole per l'attuazione dello studio.

Prof. G. Bonanno
(Presidente CERA)
(documento firmato digitalmente)