UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXXII CICLO DEL DOTTORATO DI RICERCA IN
NEUROSCIENZE E SCIENZE COGNITIVE

PRECURSORS OF MATHEMATICAL LEARNING: A COGNITIVE-ENVIRONMENTAL APPROACH TO UNDERSTANDING AND PROMOTING THE DEVELOPMENT OF EARLY NUMERICAL SKILLS

Settore scientifico-disciplinare: **M-PSI/04**

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Abstract

Referring to Bronfenbrenner’s (1979) and Rubinsten and colleagues’ (2018) theoretical models, the general purpose of this dissertation was to provide a cognitive-environmental approach to the study and promotion of early mathematical skills, underlining the multiplicity of factors that, already at a very early stage, come into play in the emergence and development of math learning from preschool to the beginning of primary school. In line with this main goal, the thesis is essentially divided into two parts: on the one hand, in Chapters 2 and 3, we have examined the role of some cognitive precursors, both domain-general and domain-specific, in predicting typically developing children’s early math knowledge; on the other hand, in Chapters 4 and 5, we have focused on the impact that environmental factors (i.e., the context to which an individual belongs with its peculiar socio-cultural, historical, economic, and political characteristics) may have on the development of early numerical skills.

The studies illustrated in the four Chapters strived to fill the following striking gaps in the literature, respectively:

a) To date, previous studies conducted on preschoolers have focused mainly on the factors underlying the level of acquisition of emergent math skills at a given time point, without investigating the factors predicting the growth in math competence at such an early age. Moreover, the predictive roles of subitizing ability and ANS acuity are still unclear;

b) There is still an absence of shared consensus on the relative contributions of WM domains and processes to math performance at different developmental stages of mathematical learning, especially before and after the onset of formal education;

c) Literature on EFs is lacking on children living in war-affected environments, and related refugee conditions, as well as no previous study has evaluated early mathematical abilities in children living in highly deprived contexts like these;

d) The few studies conducted on EFs development in war contexts have focused exclusively on emotional control and trauma and, to date, no EFs training has ever been specifically implemented in favour of children living in critical contexts such as refugee camps in Kurdistan.

In the light of these gaps in the literature, the studies presented in this dissertation addressed the following aims:

a) To investigate the domain-general and domain-specific cognitive predictors of growth in typically developing children’s early numerical competence as well as the developmental dynamics between different specific mathematical skills through the first two years of preschool (Chapter 2);

b) To examine the relative contributions of WM domains and processes to typically developing children’s math performance before and after the transition to primary school (Chapter 3);

c) To explore the signature of living in highly deprived environments (i.e., war context and refugee condition) on preschool children’s EFs and early mathematical skills (Chapter 4);

d) To further investigate hot and cool EFs in children living in a war context who survived genocide and implement a training program to improve these children’s EFs, also assessing its effectiveness (Chapter 5).

In summary, the studies presented in this dissertation have the aim to investigate and promote factors underlying school readiness, specifically mathematical learning, enhancing the organization of age-appropriate and effective trainings interventions that could base children’s learning and achievement abilities to become aware citizens, providing specific tools functional to the acquisition of a political and economic identity to contrast manipulation of minority groups. Taken together, the findings of this dissertation would be beneficial from both a theoretical, practical, and humanitarian point of view, moving in the direction of improving mathematical competence as well as the general quality of life of children from all over the world.

Chapter 1

General Introduction

1.0 Why is mathematical learning so important?

Numbers are everywhere, constantly attracting our attention and being an integral part of daily activities. Actually, mathematical abilities are involved in cooking, in shopping, in doing bank transactions, as well as in many other circumstances of life, such as reading the clock, verifying the correctness of the bill at the end of a dinner, calculating the time needed to reach a specific destination, choosing the most convenient telephone offer, deciding from which bank to apply for a loan based on the proposed interest rate, or generally budgeting money resources. All these examples show that mathematical competency is of prime importance in everyday life, being necessary for performing simple but essential tasks.

In scientific research, a growing literature has suggested that early numerical abilities predict educational, occupational, and financial individual success, reflecting into a variety of positive outcomes later in life, such as employment opportunities (Bynner, 1997; Rivera-Batiz, 1992), salary size (Dougherty, 2003), and socioeconomic status (SES) (Gerardi, Goette, & Meier, 2013; Gross, Hudson, & Price, 2009). In this regard, the Organization for Economic Co-operation and Development (OECD) Survey of Adult Skills has revealed that numeracy skills are widely used in many different work settings worldwide. More in detail, across participating OECD countries, 38% of workers aged 16 to 65 claimed to use fractions at work at least once a week, 29% formulas or simple algebra, and 4% advanced math knowledge (OECD, 2013a). Furthermore, demand for science, technology, engineering, and mathematics (STEM) professionals is on the rise worldwide, with many countries interested on enhancing STEM education (BBC, 2013; Lacey & Wright, 2009).

Mathematics competence is also related to longer-term physical and mental health outcomes, that is to general personal and social well-being (Gross et al., 2009; Furlong, McLoughlin, McGilloway, & Geary, 2016). Consistently, low numeracy, due to more frequent difficulties or errors in understanding and applying critical numerical information, was found to be associated to a distorted risk perception and evaluation as well as to biases in judjment and decision-making process, for example in the medical field (Ancker & Kaufman, 2007; Reyna & Brainerd, 2007; Reyna, Nelson, Han, & Dieckmann, 2009). The knowledge of some basic mathematical notions is also a prerequisite for an active and informed participation in both the political and economic life of a country, for example being involved in the understanding of concepts such as proportional electoral system or Gross Domestic Product (GDP).

Overall, mathematical proficiency is increasingly recognized as fundamental to economic success for nations, thus showing relevant implications not only at an individual but also at a collective/societal level (Foley et al., 2017; Peterson, Woessmann, Hanushek, & Lastra-Anadón, 2011). Given the relevant impact of numeracy on many aspects of human life, it is increasingly crucial to understand in detail which are the factors underlying the emergence of mathematical learning and its development already during the preschool years, in order both to promote the enhancement of early numerical skills and to prevent the onset of any Mathematical Learning Disabilities (MLD) or difficulties.

1.1 The state of mathematics in contemporary society: A focus on the Italian context.

Despite the pervasiveness of numeracy in different contexts and everyday situations in modern societies, children's underachievement in mathematics remains a consistent and significant problem (Dowker, 2004). Generally, around 20% of students show low numeracy skills and, depending on the classification criteria, 4% to 14% of children and adolescents have been identified with a substantive learning deficit in at least one mathematical area (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Butterworth, 2011; Shalev, 2007; Shalev, Manor, & Gross-Tsur, 2005). More in detail, international literature suggests that

Developmental Dyscalculia (DD), namely a specific disability in achieving normal levels of arithmetical skills, is characterized by a prevalence of about 5 to 7% in the school population (Butterworth, Varma, & Laurillard, 2011; Reigosa-Crespo et al., 2012).

Referring to the Italian context, approximately 5 children per class are identified as children with deficit in calculation, which means that 20% of the Italian student population would have significant difficulties in mathematical learning (Cornoldi, 2007; Cornoldi & Zaccaria, 2014). However, the percentages are significantly reduced if we refer to the most stringent standard diagnostic criteria of the DSM-5 (APA, 2013), according to which only in about 0.5-1% of cases we can actually speak of specific learning disorder with impairment in calculation, with a percentage between 2.5 and 3.5% for cases of comorbidity, namely cases of coexistence of specific numerical difficulties with other disorders (ISS, 2011; Lucangeli, Tressoldi, & De Candia, 2005; Passolunghi, De Vita, & Traficante, 2018).

Data from the *Program for International Student Assessment (PISA)*, a triennal survey promoted by the OECD which tested 15-year-olds' academic achievement worldwide, has shown that in Italy 43% of students reported that they feel helpless or very nervous when doing mathematics problems, wheres across OECD countries, on average, 31% of students claims to have these kinds of feelings (OECD, 2013b). Furthermore, Italy, after Austria and Lebanon, is the third country with the largest gender gap in mathematics performance. Indeed, in our country, boys outperform girls by 20 points (500 vs 480 points), while, at international level, the average difference is only 8 points in favour of boys (OECD, 2015). Therefore, albeit recent publications (e.g., Devine, Fawcett, Szűcs, & Dowker, 2012; Hill et al., 2016) suggested that the gender gap on mathematics is generally disappearing, in Italy it is still a current problem. Moreover, the results of the OECD (2013b) showed that in Italy only 14% of young women who entered university for the first time chose science-related fields of study.

In addition to the gender gap, the survey conducted by the OECD in 2015 also found that in the areas of southern Italy the percentage of top performers is lower than the national average. More in detail, the official INVALSI report (2019), which assessed students' mathematical skills in four different macro-areas - *Data and projections, Numbers, Space and figures, Relations and functions* – showed that a significant divergence between the scores of the North and the South (and islands) of our country emerges only from the middle school (24 points at Grade 8). The gap between the north and the rest of Italy is further widening in secondary education, reaching 33 points of difference between the north-east and south (and islands) at Grade 10, and remaining unchanged at Grade 13.

In the light of the critical situation that characterizes the Italian context, as our society becomes progressively more dependent on numbers, difficulties in maths may increasingly act as a filter, reducing the chances of success for an individual, in particular for girls (e.g., Halpern et al., 2007). All these data make it a good reason to deepen the understanding of the factors that, already at a very early stage, come into play in the complex process of mathematical learning, in order to promote the development of mathematical skills from preschool onwards, thus reducing the risk of onset of learning difficulties or disabilities and all the negative consequences on both an individual and a social level.

1.2 A framework for studying the development of mathematical learning: towards a multifactorial approach.

Mathematical learning is a very articulated process both for the breadth and complexity of the field of investigation represented by mathematics and for the variety of skills involved in mathematical tasks. In view of these features, a multifactorial approach, which takes into account at the same time the role of different factors, actors and levels, seems to be the most suitable for studying the development of mathematical learning already at pre-school age.

1.2.1 Bronfenbrenner’s ecological multi-systemic model: from the individual to the socio-political and cultural context.

In this regard, Bronfenbrenner’s ecological model (1979) represents a theoretical framework which, through the description of a multi-systemic context, lends itself to understanding of the dynamic interrelationships between various personal and environmental factors that, influencing each other, intervene in math learning (see Figure 1). This model distinguishes different environmental systems (Microsystem, Mesosystem, Exosystem and Macrosystem) with which an individual interacts, characterized by roles and rules that contribute to modeling psychological development. More in detail, the *Microsystem* refers to an organized pattern of interpersonal relationships, shared activities, roles and rules, of which the subject has experience in a given context and which have particular concrete physical characteristics. At this level, therefore, there is the individual characterized by specific endogenous (e.g., genetics, maturing processes), cognitive, and emotional factors.

The *Mesosystem* is a system of microsystems: it refers to the interrelationships between two or more environmental situations or contexts in which the subject directly participates in an active way. At this level we find, for example, the family within which a child is born and grows up, and the learning opportunities and stimulations offered by parents, or the schools (with teachers and classmates) an individual attends during his life. The *Exosystem* is the result of the interconnection between two or more social contexts, at least one of which is external to the direct action of the subject. This level refers, for example, to neighbours, friends of family, school board, or legal and welfare services that, to some extent, have an impact on the psychological development of a child. Finally, the *Macrosystem*, the most "external" system, includes political and economic institutions, cultural values, customs, laws and in general the culture in which individuals live. It refers to the global models of ideology and organization that characterize a given society or social group, such as various forms of social pressure or stereotypes (e.g., gender-related stereotypes), in other words an individual's socio-cultural, historical, economic, and political background. The effects of the principles defined by the macrosystem, which are constantly evolving, have a cascading influence on all other levels that dynamically interact with each other.

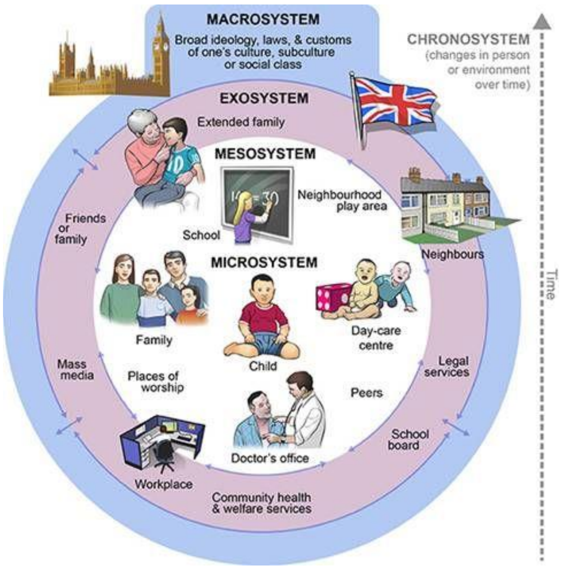

Figure 1.1 Bronfenbrenner's ecological multi-systemic model (1979).

1.2.2 The developmental bio-psycho-social model of Rubinsten and colleagues: the interplay between within-child and environmental factors.

Along the lines of Bronfenbrenner' model, more recently, Rubinsten and colleagues (2018) have proposed a developmental bio-psycho-social model that describes the complex pathways towards the development of Math Anxiety (MA) with a focus on dynamism. This model, which is specifically focused on MA, can be referred, in a broader sense, also to the development of mathematical learning. In detail, Rubinsten and colleagues consider the dynamic interplay between the following different aspects:

a) intrinsic factors → e.g., neuro-cognitive, biological, and genetics predispositions, including neural correlates, brain malfunctions, and heritage;

b) cognitive factors → general and specific abilities related to numerical cognition, such as Working Memory (WM) (Ashcraft & Kirk, 2001; Passolunghi, Caviola, De Agostini, Perin, & Mammarella, 2016), counting (Cordes, Gelman, Gallistel, & Whalen, 2001; Gallistel & Gelman, 1992), or symbolic and non-symbolic magnitude processing abilities (e.g., Dietrich, Huber, Moeller, & Klein, 2015; Douglas & LeFevre, 2018);

c) affective factors → e.g., tendency toward anxiety in general, with worries and intrusive thoughts, motivation, self-esteem, self-efficacy, self-confidence in math, self-concept, academic resilience, or MA (e.g., Chang & Beilock, 2016; Hoffmann, 2010; Mammarella, Donolato, Caviola, & Giofre, 2018);

d) environmental factors → e.g., parenting style, that is parents' actions or feelings (e.g., MA) regarding mathematics, their numerical skills, or their practices, such as pressure to mantain high achievements and involvement in math-learning processes (e.g., Daches Cohen & Rubinsten, 2017; Roberts & Vukovic, 2011); teachers' attitudes towards math, MA, instruction strategies and teaching methods; the feelings and thoughts of other formal agents of society about math; general social style, that is wider social effects, such as national pressure on mathematics or cultural norms.

All these factors can either interact or cancel each other during development. The first three categories of factors are related to the individual dimension, namely the microsystem in Bronfenbrenner's model, and are defined as *within-child* factors. On the contrary, the environmental factors act outside the dimension of the individual, coming into play, at different levels, in the Mesosystem, Exosystem, and Macrosystem of Bronferbrenner's model. Actually, children spend most of their life at home or school, and also their learning processes are strongly influenced by interactions with parents, other family members, teachers, and peers. Therefore, difficulties in mathematics may be the result, for example, of poor activity-sharing with parents in the home environment, social interactions with teachers with high MA or inappropriate math instruction strategies. More specifically, the environmental factors can act as both mediators or moderators (having both magnitude and direction towards the neurocognitive predisposition), or in some case as an indipendent and direct developmental factor affecting the development of mathematical learning. Therefore, environmental factors may help the child “overcome” the deficits, generating adaptive behavior (Rubinsten, Marciano, Levy, & Cohen, 2018).

It should be noted that the link between within-child and environmental factors is bidirectional, since they both contribute to the development of a child's mathematical learning. Overall, Rubinsten and colleagues’ model allows us to consider mathematical learning from a developmental, dynamic, and bio-psycho-social perspective, which takes into account multiple causal interacting influences. Namely, heterogeneous mathematics performances may emerge from multiple developmental pathways that reflect the dynamic interplay between the characteristics of children (intrinsic predispositions, cognitive, and affective aspects) and the environment in which they live (e.g., teachers, parents and wider social effects) over time.

1.3 The cognitive precursors of mathematical learning.

Mathematical learning is a complex and articulated process in which both domain-general and domain-specific cognitive abilities come into play. The cognitive factors that underlie and support the development of mathematical knowledge at a very early stage are called *markers* or *precursors* of mathematics learning. More in detail, they are defined as cognitive abilities that are causes or preconditions of mathematical learning and that allow prediction of future math achievement (e.g., Assel, Landry, Swank, Smith, & Steelman, 2003; Passolunghi & Lanfranchi, 2012; Passolunghi, Mammarella, & Altoè, 2008; Passolunghi, Vercelloni, & Schadee, 2007). In fact, a precursor is something that comes first, that precedes, announces, anticipates, intervenes in a preliminary phase with respect to the subsequent development of a given process or phenomenon. In view of their function as "forerunners", the precursors of mathematical learning are, therefore, ideal cognitive factors on which to act early to promote the emergence and development of future skills. In particular, the earlier the intervention is made, the greater the probability of preventing subsequent difficulties in mathematical learning (Coleman, Buysse, & Neitzel, 2006).

1.3.1 Domain-general precursors of mathematical achievement.

Domain-general cognitive precursors that underlie the development of mathematical learning include some general cognitive skills, transversal to the different disciplinary fields, which predict performance not only in mathematics but also in other school subjects (Passolunghi & Lanfranchi, 2012; Passolunghi, Lanfranchi, Altoè, & Sollazzo, 2015). In other words, they are general skills that serve as a cognitive substratum on which learning processes are grafted and that allow, for example, the acquisition of new content, the processing of information, the understanding and execution of more or less complex cognitive tasks. Domain-general cognitive precursors include, for example, intelligence level, processing speed, Working Memory (WM), and Executive Functions (EFs).

1.3.1.1 The *Working Memory*: the multicomponential and *continuum* models.

Working Memory (WM) refers to a limited-capacity mental working space involved in both temporaly storing and actively manipulating or processing information during the performance of a cognitive task (see Baddeley, 1986; Miyake & Shah, 1999). The most widely accepted model proposed by Baddeley and Hitch (1974) is the multicomponential model (see Figure 1.2), describing WM as a three-way system comprising two slave systems, the phonological loop and the visual-spatial sketch pad, and a central executive, that is a limited-capacity processing system lying at the heart of this model. Specifically, the phonological loop represents a temporary storage mechanism capable of storing limited amounts of language-based information in terms of its phonological form, while the visuo-spatial sketch pad is specialized for the retaining and maintenance of visuo-spatial information, that is represented in terms of its visuo-spatial features. Both the phonological loop and the visual-spatial sketch pad are in direct contact with the central executive, responsible for attentional control over actions and for processing and coordinating the two slave systems, also scheduling multiple cognitive activities (see Baddeley, 1986). A further subcomponent of WM identified by Baddeley (2000) is the episodic buffer, that is suggested to be responsible for integrating information from a variety of sources in the cognitive system, including both temporary and Long-Term Memory[1] (LTM) systems.

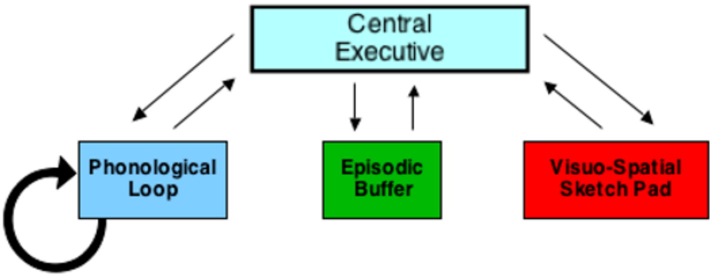

Figure 1.2 Baddeley's multicomponential WM model (1986, 2000).

Regarding different WM processes, Cornoldi and Vecchi (2000, 2003) proposed a distributed *continuum* model, suggesting that WM processes vary according to the nature of information as well as the degree of active information processing. The model includes a horizontal dimension reflecting differences between memory contents (i.e., verbal and visuo-spatial), and a vertical dimension representing differences between active and passive

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[1] Long-Term Memory is a vast store of knowledge and a record of prior events (see Cowan, 2008).

processing. One main feature of the vertical continuum is the reduction of content differences with increasing involvement of active processing (see Figure 1.3).

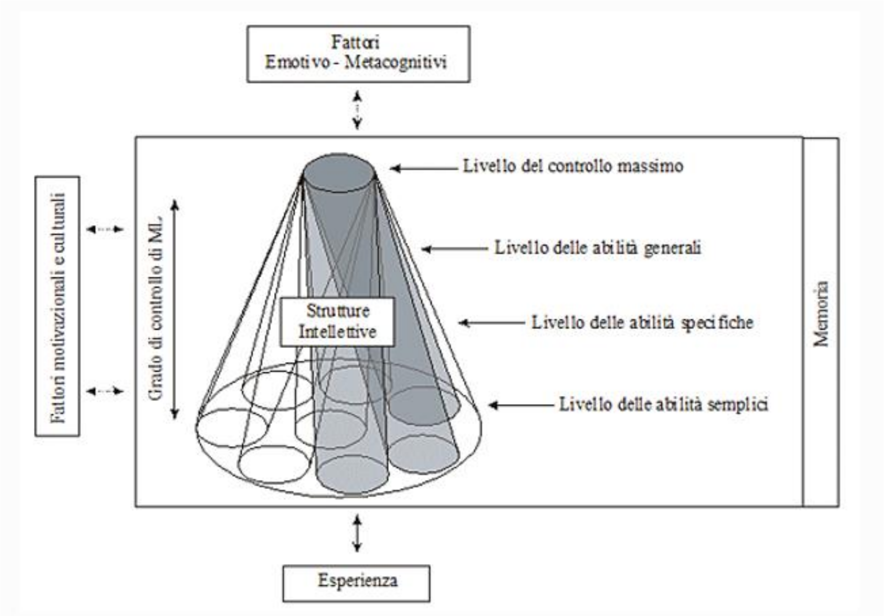

Figure 1.3 Cornoldi and Vecchi's *continuum* WM model (2000, 2003).

According to this model, *high-control* processes are *active* processes which tipically require concurrent storage, processing, and effortful mental activity (Kail & Hall, 2001; Miyake & Shah, 1999), and entail a main role of central executive component of WM (Cowan, 1995; Gathercole & Pickering, 2000; Passolunghi & Siegel, 2001, 2004). They are usually assessed using dual-tasks involving concurrent storage and manipulation of the temporarily held information, such as backward span tasks or reading/listening span tasks (Daneman & Carpenter, 1980). Conversely, *low-control* WM processes refer to a passive storage system and typically require to passively retain small amounts of information that is then recalled without any manipulation. They are usually assessed using digit or word span forward tasks, requiring participants to recall a sequence of verbal or visuo-spatial information in the same format of presentation without any cognitive processing, manipulation or trasformation (see also Cantor, Engle, & Hamilton, 1991; Cornoldi & Vecchi, 2000; Engle, 2002; Swanson, 1993).

In literature, some authors (see Bull, Espy, & Wiebe, 2008; Gathercole & Alloway, 2006; Passolunghi & Siegel, 2001; Swanson & Luxenberg, 2009), to better underline the distinction between high-control and low-control WM processes, used on the one hand the term *Working Memory* (WM) to indicate active processes involving the central executive, on the other hand the term *Short-Term Memory* (STM) to refer to passive processes involving the slave systems. As a whole, the passive and active memory tasks can be considered along a continuum (Cornoldi & Vecchi, 2000) where STM tasks are closer to the passive pole, whereas WM tasks are closer to the active pole. According to this view, several studies suggest the separability of the capacities of WM and STM also as precursors of early mathematics learning (Cowan, 1995; Shah & Miyake, 2005; Swanson, 2006). For example, Passolunghi and colleagues (2007) found that WM is a distinct and significant predictor of mathematics learning at the beginning of primary school, suggesting that, conversely, STM tasks did not show a causal relationship with mathematics achievement. Similarly, previuos evidence indicated that children or adults with learning disabilities may have WM problems independent of problems in STM (Passolunghi & Siegel, 2004). In the present dissertation, being our interest the differentiation between these two levels of information processing, we consider high-control or active WM processes and low-control or passive WM processes (or STM) as separated, even if interindependent, constructs.

1.3.1.2 The *Executive Functions*: from theoretical models to training interventions.

Executive Functions (EFs) refer to an umbrella term used to define the various cognitive skills needed to behave adaptively and flexibly in new situations or whenever new or complex tasks are to be accomplished (see Van der Ven, Kroesbergen, Boom, & Leseman, 2012). In other words, they consist of a set of neurocognitive top-down mental processes that allow an individual to control and regulate thoughts and actions to guide behavior toward a future goal (see Diamond, 2013; Miyake & Friedman, 2012). Baddeley (1996) already proposed several specific functions associated to the central executive of WM, deputy to both holding and manipulating information, that is, the coordination of simultaneous performance in multiple tasks, inhibition of irrelevant stimuli, selective attention, and switching of retrieval strategies. Anyway, afterwards, Miyake and colleagues (2000) enucleated three main basic EFs, i.e., *updating*, *inhibition*, and *shifting*, that have been found to be correlated with each other. More in detail, *updating* is defined as the ability to monitor information processing in the form of adding relevant and deleting irrelevant information, replacing the latter with new information functional to the performance of a given task. *Inhibition* refers to the ability to suppress or inhibit a previously learnt inappropriate dominant automatic response and replace it with a more adequate one. Finally, *shifting* is described as the ability to flexibly move and shift between different rules, mental sets, or tasks.

More recent research generally agrees on the use of a broader characterization of EFs in relation to the motivational significance, distinguishing the more *cool* cognitive aspects of EFs, usually operating in abstract, decontextualized, affectively neutral contexts lacking a significant motivational or affective component, and the relatively *hot* affective aspects of EFs, coming into play in emotionally and motivationally significant high-stakes situations (see Happaney, Zelazo, & Stuss, 2004; Zelazo & Müller, 2002). Regarding cool components, Diamond (2013) describes three core EFs: WM, inhibition or inhibitory control, including both self-control (behavioral inhibition) and interference control (cognitive inhibition and selective attention), and cognitive or mental flexibility, also called shifting or switching. Among hot EFs, delay of gratification is an aspect of self-regulation which define the ability to inhibit impulsive behavior as well as shift attention from temptation towards goal-directed behavior, thus postponing immediate gratification (Brock, Rimm-Kaufman, & Wanless, 2014; Mischel, Shoda, & Peake, 1988).

Several studies have shown associations between tasks tapping cool EFs and maths skills (e.g., Blair & Razza, 2007; Bull & Scerif, 2001; D'Amico & Guarnera, 2005; Espy et al., 2004; Gathercole & Pickering, 2000; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; van der Sluis, de Jong, & van der Leij, 2007). However, results are still inconsistent and inconclusive, specifically those related to inhibition and shifting (e.g., Censabella & Nöel, 2008; Rasmussen & Bisanz, 2005; van der Sluis, de Jong, & van der Leij, 2004). As regards delay of gratification, it may play a important role in the early years of school, intervening for example in the ability to follow directions or take turns (Rimm-Kaufman, Pianta, & Cox, 2000). However, despite the value of this skill in terms of behavioural, emotional and social functioning, there is a paucity of research linking delay of gratification with school achievement at an early age.

Although individual differences in EFs seem to be relatively stable across the lifespan, emerging growing evidence suggests that both hot and cool EFs are surprisingly malleable and can be improved by practice, with corresponding changes in neural function and relavant practical implications and opportunities for early prevention and intervention (see Zelazo & Carlson, 2012). The combination of stability and plasticity of EFs in the course of life highlights the potential value of encouraging and promoting the healthy development of these cognitive skills, thus indicating EFs as the ideal target for age-appropriate and tailored training programs. In this regard, Diamond (2013) in her review suggested that EFs are trainable and can be improved at any age across the life cycle, comprising in the elderly and in infants, suggesting, however, that preschool years seem a particularly valuable temporal developmental window for intervention (see Diamond & Lee, 2011; Klingberg, 2010). Indeed, preschool period appears to be characterized by remarkable plasticity, and an improvement in EFs just before the beginning of formal schooling may trigger a cascade of beneficial effects for children at a cognitive, behavioural, relational and social level. For instance, an higher level of EFs may facilitate more effective, reflective, and proactive learning processes, reduce behavioural problems, foster motivation to learn, as well as allow children to establish better relations with teachers and peers (see Diamond, 2013). In pursuing these goals, a key factor in the success of a training intervention seem the repeated practice, since EFs gains have been shown to depend on the amount of time spent doggedly working on those skills with the intention of improving them (Diamond, 2013; Klingberg et al., 2005). Consequently, it would be ideal if school curricula embedded the practices of a EFs training intervention in all activities throughout the day, not only in a module, ensuring also the benefit of varying the kind and content of the specific EFs practice (Diamond, Barnett, Thomas, & Munro, 2007; Lillard & Else-Quest 2006; Riggs, Greenberg, Kusché, & Pentz, 2006). Moreover, previous research showed that children most behind in EFs, such as children living in deprived or disadvantaged environments, are the ones that benefit most from any EFs program or intervention (e.g., Flook et al., 2010; Karbach & Kray, 2009; Lakes & Hoyt, 2004). Therefore, an early EFs training not only could foster the development of educational (e.g., math-related), social and emotional skills, but also may reduce broader social disparities in academic achievement, health, as well as general well-being, helping to ensure equal opportunities for all children (O'Shaughnessy et al., 2003).

1.3.2 Domain-specific precursors of mathematical achievement.

Domain-specific precursors include a whole range of skills within the strictly numerical domain that are specifically associated to mathematical learning. This macro-category basically includes the so-called 1) *Number Sense* (Dehaene, 2001), that refers to a variety of early non-symbolic numerical skills, and 2) *Early Numeracy* (Passolunghi & Costa, 2016), comprising a set of core symbolic numerical abilities, both foundational-specific skills crucial to the subsequent development of arithmetic skills and general math achievement.

1.3.2.1 The *Number Sense.*

The expression *Number Sense* defines a very nuanced, varied and criticized concept in the literature. It includes a variety of skills, such as *subitizing*, *Approximate Number System (ANS)* acuity, the ability to move flexibly between different numerical formats and patterns, to exclude implausible results of operations, as well as to make estimates and perform numerical transformations (Berch, 2005; Jordan, Kaplan, Locuniak, & Ramineni, 2007). It is an innate, non-verbal, and not symbolic capacity, shared also by non-human animal species (Brannon, Jordan, & Jones, 2010), such as rats, fish, monkeys, and birds, which allows individuals to perceive, represent, and manipulate numerical information in different contexts from birth onwards (Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004; Lipton & Spelke, 2003; Xu, Spelke, & Goddard, 2005). In a society full of numbers like today's, the sense of number is a fundamental tool to guide the choices of individuals who have to process quantitative information in the different circumstances of everyday life.

Referring to Number Sense, *subitizing* is defined as a rapid pattern-matching process that allows to accurately and quickly recognize the exact number of items in a set of fewer than 5 items, without counting (Desoete, Ceulemans, Roeyers, & Huylebroeck, 2009; Starkey & Cooper Jr, 1995). This mechanism seems to be supported by the *Object Tracking System* (OTS), a non-symbolic numerical system for representing and keeping track of individual objects (Agrillo, Piffer, & Adriano, 2013; Trick & Pylyshyn, 1994). Several studies (e.g., Desoete et al., 2009; Landerl, Bevan, & Butterworth, 2004; Landerl & Kolle, 2009) argued that deficits in subitizing ability may cause severe learning disabilities in mathematics. However, to date, a paucity of research has examined its predictive role for later mathematical development in preschoolers (e.g., Gray & Reeve, 2014; Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Hannula, Räsänen, & Lehtinen, 2007; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; LeFevre et al., 2010).

Another central component of the Number Sense is the *Approximate Number System* (ANS), a non-verbal primitive cognitive system that allows the approximate, imprecise and intuitive representation of large quantities of objects, without recourse to counting or symbolic numbers (Gilmore et al., 2013; Hubbard et al., 2008). It is innate (Izard, Sann, Spelke, & Streri, 2009), amodal, being involved in the manipulation of quantities through different sensory modalities (e.g., visual and audutory) (Gimbert, Gentaz, Camos, & Mazens, 2016), undergoes important developmental change over the lifespan (Halberda & Feigenson, 2008) and seems to support basic numerical computations such as adding, subtracting and comparing quantities without using counting or numerical symbols (Feigenson, Libertus, & Halberda, 2013). ANS acuity is defined as the degree of precision of the internal quantity representation and there are considerable individual differences in ANS precision (Park & Starns, 2015). Compared to those on subitizing, studies on the relationship between ANS acuity and prescholers' mathematical knowledge are more abundant. However, they provided mixed results since such association emerged in some studies (e.g., Bonny & Lourenco, 2013; Libertus, Feigenson, & Halberda, 2011; Libertus, Odic, & Halberda, 2012; Mazzocco, Feigenson, & Halberda, 2011; vanMarle et al., 2016) but not in others (e.g., Negen & Sarnecka, 2015; Sasanguie, De Smedt, Defever, & Reynvoet, 2012; Sasanguie, Van den Bussche, & Reynvoet, 2012). As a result, it remains controversial the role of ANS acuity in early mathematical knowledge. Furthermore, it is surprising that only one study (vanMarle et al., 2016) to date has explored the relative contributions to preschoolers' early mathematical skills of subitizing and ANS acuity in combination.

1.3.2.2 The *Early Numeracy.*

The general term *Early Numeracy* refers to a series of skills associated with the ability to understand and manipulate numerical information through symbolic representations, such as counting ability (e.g., the acquisition of cardinality principle), digit recognition, and symbol-quantity mapping (Gersten, Jordan, & Flojo, 2005; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Van De Rijt & Van Luit, 1999). Among these skills, counting ability, in particular verbal counting, that implies the understanding of the one-to-one relation between objects in a set and their numerical representations, was found to be one of the most efficient and discriminating precursors of children's mathematical learning (Mazzocco & Thompson, 2005; Passolunghi et al., 2007), serving as capstone of early mathematical knowledge (Clements & Sarama, 2007; Nguyen et al., 2016). In line with this statement, some studies have revealed that subjects with different scores in arithmetic tasks also showed different levels in counting (see Geary, Hoard, & Hamson, 1999). In particular, the acquisition of cardinality principle, that is understanding that the last number word in a counting sequence represents the quantity of that set (Le Corre & Carey, 2007; Sarnecka & Carey, 2008), seems to provide a natural scaffold, for example, for calculation or learning arithmetic (Batchelor, Keeble, & Gilmore, 2015; Purpura, Baroody, & Lonigan, 2013). In this regard, recent research suggested that preschoolers' conceptual insight that number words represent specific quantities (i.e., conceptual understanding of cardinality) is strongly associated to their later number-system knowledge at the beginning of first grade (Geary et al., 2018) and the age at which they achieve this insight predicts their readiness for mathematics learning in school (see Geary, vanMarle, Chu, Hoard, & Nugent, 2019). Moreover, previous research suggested that children with a higher digit recognition skill are also more proficient in both cardinality and ordinality comprehension of digits (see Knudsen, Fischer, Henning, & Aschersleben, 2015).

Always referring to Early Numeracy, knowledge of the verbal counting sequence, that is number names and their order, is considered a precursor skill for symbol-quantity mapping that would be acquired later in math learning development (Krajewski & Schneider, 2009; Lira, Carver, Douglas, & LeFevre, 2017). Indeed, in order to perform symbol-quantity mapping tasks, children need to employ an efficient counting strategy as well as the skill in linking together symbolic and non-symbolic numerical processes (Holloway & Ansari, 2009; Rousselle & Noël, 2007). Symbol-quantity mapping would emerge in turn as a crucial skill that children must master before they can deal with more complex mathematical tasks (Knudsen et al., 2015; Purpura et al., 2013). Despite the many specific and different skills that are part of Early Numeracy, much previous research has used global measures of mathematics achievement including a wide range of numerical skills and math domains to assess preschoolers' math knowledge (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Kroesbergen et al., 2009; Passolunghi et al., 2015; Xenidou-Dervou, Molenaar, Ansari, van der Schoot, & van Lieshout, 2017), without the possibility to determine how the different early-emerging math skills are intertwined with each other. Moreover, to the best of our knowledge, no previous research examined the developmental dynamics between different specific early math skills, and the sequential order in which they develop over time during preschool years.

1.4 The role of environmental factors in the development of early mathematics: a look from the microsystem to the macrosystem with a focus on socio-cultural, historical, economic, and political background.

In a global panorama such as the present one, characterized by increasingly widespread inequalities, a growing unemployment, and conditions of deprivation and educational poverty, the approach to the analysis of a phenomenon cannot ignore the consideration of the social, political, economic, and cultural aspects identifying a specific context. Even with respect to the complex process of acquiring and developing mathematical competence, factors such as income and SES (OECD, 2013), even more so than gender or ethnicity, are particularly significant in predicting individual differences in subsequent mathematical performance. In this regard, the PISA survey, launched by the OEDC in 2012, found that the school performance of a more socio-economically advantaged student is equivalent to that of a student who has almost one more year of schooling (OECD, 2013). With specific regard to mathematical performance, a negative correlation between mathematical competence and income inequality among the richest and poorest citizens of a given country has emerged and this correlation has been significantly more pronounced for students aged 16-24 (OECD, 2013). In other words, the gap in the level of mathematical skills between more and less socio-culturally advantaged individuals not only exists but would tend to consolidate and maintain itself during the schooling period, with long-term effects, once compulsory schooling has been completed (Stotesbury & Dorling, 2015).

According to some authors, in societies characterized by a high level of inequality, a poorer mathematical performance could be due to causes such as anxiety, widespread perception of insecurity, increasing social conflicts, violence, etc. (Dowling, 1998; Wilkinson & Pickett, 2010), or even the presence of stigmas, prejudices, and social expectations that impact on the academic aspirations of individuals, reducing and bringing them back to the limits of the context they belong to (OECD, 2013). Therefore, although some students from disadvantaged socio-cultural backgrounds are able to succeed against the odds (Bempechat, 1998), riding the wave of social mobility, most of them end up being blocked by their system they belong to, without any opportunity for social and intellectual redemption. Consequently, as highlighted by Gates and Vistro-Yu in the text "Is mathematics for all?" (2003), mathematics is configured as a discipline "only for some", those who have the necessary resources to undertake an adequate training course. In particular, recent analyses suggest that the cultural markers of many social problems and differences, for example in academic achievement, are substantially attributable to inequality in the allocation and distribution of material, economic, and educational resources (OECD, 2014; Pickett & Wilkinson, 2015; Stotesbury & Dorling, 2015; Wilkinson, 2005).

Askew and colleagues (2010), in a study on mathematical education in countries characterized by a high performance in this subject, have highlighted how the success in mathematics of an individual is much more strongly associated with the historical-political and socio-cultural context in which he lives than with the way in which the discipline is taught. Thus, one can find realities characterized by egalitarian education and high standards, as in Finland, as well as countries characterized by selective education and equally high standards, such as Singapore (Askew, Hodgen, Hossain, & Bretcher, 2010). The resulting message is of considerable human and moral depth: it is not necessary to sacrifice high levels of performance to achieve greater equality in educational opportunities; on the contrary, greater equity is a prerequisite for achieving an improvement in performance that can truly consolidate and maintain itself over time. In this respect, Mexico, Turkey, and Germany are three examples of countries that have simultaneously invested in enhancing mathematical performance and equality levels in the distribution of resources (OECD, 2013). This state of the art suggests on the one hand to approach the theme of mathematical education by considering not only its purely educational aspects but also its social and political dimension, on the other hand the importance of supporting and encouraging, through targeted and effective strategies, a process of democratization of mathematics so that this discipline can become a tool potentially usable by all, in every part of the world.

1.4.1 Early numerical development in low-resource communities: influence of SES background.

As mentioned above, and in line with Vygotsky's socio-cultural approach (1978), children's mathematical learning can be considered as an *activity in sociocultural context* (Cole, 1995) and its nature, quality, and extent cannot be adequately understood without taking into account their broader context of education and the specificities of their socio-economic background. In this regard, previous studies have reported consistent relations between children's SES and their early numerical achievement (e.g., Clements & Sarama, 2011; Jordan, Kaplan, Nabors Oláh, & Locuniak, 2006; Starkey, Klein, & Wakeley, 2004), suggesting that children belonging to low-SES groups enter formal schooling with specific gaps in their numerical skills and are therefore at risk for extended low achievement in primary school (Jordan et al., 2009). More specifically, some research found that, even before kindergarten starts and during preschool, children from low-SES background performed poorly on certain numerical tasks, such as subitizing, counting, number comparison, verbal and nonverbal calculation, as compared to middle-SES background peers (Clements & Sarama, 2011; Jordan et al., 2006; Starkey et al., 2004).

These SES-related differences in early numerical development might be due to initial differences in the quantity and quality of early mathematics experiences and activities carried out at home with parents (e.g., Clements & Sarama, 2007; Starkey et al., 2004) as well as of mathematics teaching and its instructional strategies (e.g., Clements, Sarama, Wolfe, & Spitler, 2013). With respect to the latter point, Clements and colleagues (2013) found that children from low-resource communities who received high-quality, research-based mathematics teaching by implementing the TRIAD (Technology-enhanced, Research-based, Instruction, Assessment, and professional Development) scale up model from preschool to first grade, more efficiently acquired early numerical skills than their peers who did not benefit from such instruction. In the light of the above results, it is possible to state that, although it is important to provide high-quality early mathematics teaching and instruction to all children in order to enhance their numerical development, this is particularly crucial for children with a low-SES background, as it might help to reduce the SES-related gap in mathematical achievement (Clements & Sarama, 2011). Indeed, not providing people with sufficient math competencies could be a powerful political tool to manipulate minority groups, by not enabling them to have adequate developmental, educational and economical opportunities.

1.4.2 Precursors of mathematical learning in stressful environments: a focus on the development of EFs in deprived life conditions.

Early exposure to deprived environments, deviating considerably from the care that is typical for children, may represent a risk factor for negative longer-term outcomes and lasting alterations at both cognitive, social-emotional, and behavioral level (Merz, Harlé, Noble, & McCall, 2016). Experience-expectant models of development suggest that, for typical neural development to proceed, expected environmental input, such as the presence of a sensitive and responsive attachment figure, adequate physical resources (e.g., nutrition) as well as social and linguistic stimulation matched to child's developmental stages and needs, must be provided at certain sensitive periods (Marshall & Kenney, 2009).

EFs result particularly susceptible to environmental influences, such as low SES, stressful and traumatic experiences, at an early age (e.g., DePrince, Weinzierl, & Combs, 2009; Rogosch, Dackis, & Cicchetti, 2011; Welsh, Nix, Blair, Bierman, & Nelson, 2010), since these cognitive abilities develop postnatally over a protracted period, especially in the first five years of life, with rapid development during early childhood (Garon, Bryson, & Smith, 2008; Grossmann, 2013). Among EFs, WM and inhibition skills, developing earlier compared to other EFs components, seem to be particularly vulnerable to early deprivation (Garon et al., 2008; Jurado & Rosselli, 2007). Moreover, EFs, as domain-general functions underlying cognitive development in a broad sense, represent a crucial foundation that, by means of a cascade effect, will set the stage for the acquisition and mastering of more complex skills, such as early mathematical abilities (e.g., Bull & Scerif, 2001; Cragg, Keeble, Richardson, Roome, & Gilmore, 2017; Espy et al., 2004). Furthermore, EFs resulted to be robustly related to overal school achievement (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Bull et al., 2008; Bull & Lee, 2014; Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010), as well as to later academic outcomes (e.g., McClelland et al., 2014).

It is common knowledge that stressful experiences, experienced early in life, have deleterious effects on the development and functioning of the prefrontal cortex (PFC), namely the brain system that mediates EFs (McEwen, 2008; McEwen & Morrison, 2013), involved in purposeful and self-regulatory behaviors and characterized by considerable plasticity over the course life with consequent effects on children's cognitive functioning (McEwen & Gianaros, 2011; McEwen & Morrison, 2013). In this regard, Shonkoff and colleagues (2009), referring to the taxonomy proposed by the National Scientific Council on the Developing Child (2005) described three levels of stress experience - *positive*, *tolerable*, and *toxic* - that may affect the development of young children. The first level (i.e., positive stress) concerns normative life challenges experienced in the context of stable and supportive relationships that help to adopt adaptive responses and then to properly manage the stress condition. The second level (i.e., tolerable stress) occurs within a time-limited period (e.g., the death or illness of a loved one or a natural disaster) during which protective factors, such as supportive relationships, facilitate adaptive coping strategies, recovering from potentially damaging effects. The third level (i.e., toxic stress) refers to conditions characterized by severe, frequent and/or prolonged, namely chronic, stress in the total absence of protective factors that disrupt brain architecture and establish relatively lower thresholds for responsiveness that persist throughout life, thus enhancing the risk for stress-related disorders and cognitive impairment until adulthood. Possible examples of toxic stress conditions are family violence, parental substance abuse or depression, frequent emotional and/or physical abuse, neglect, trauma (DePrince et al., 2009), institutionalization (Merz et al., 2016), maltreatment (Rogosch et al., 2011), or growing up in a war context with extreme forms of poverty and deprivation. However, on the one hand, research on EFs in children living in traumatic contexts (e.g., war countries) is scant and primarily focused on the link between trauma and emotional control (Betancourt et al., 2012; Pat-Horenczyk et al., 2013); on the other hand, to date, no previous study has yet investigated mathematical abilities in children coming from war contexts or with a refugee background.

1.5 Outline of this dissertation.

The theoretical background described above raises several questions and emphasizes some striking gaps in the literature, which highlight the necessity for further research efforts in the field of precursors of numerical development and mathematical learning. From these premises, the four studies presented in this thesis attempted to contribute to the growing body of knowledge regarding this topic extending previous research in several ways.

Referring to Bronfenbrenner's (1979) and Rubinsten and colleagues' (2018) theoretical models, the general purpose of this dissertation was to provide a cognitive-environmental approach to the study and promotion of early mathematical skills, underlining the multiplicity of factors that, already at a very early stage, come into play in the emergence and development of math learning from preschool to the beginning of primary school. In line with this main goal, the thesis is essentially divided into two parts: on the one hand, in Chapters 2 and 3, we have examined the role of some cognitive precursors, both domain-general and domain-specific, in predicting typically developing children's early math knowledge, focusing on growth-promoting cognitive factors of math competence and developmental dynamics between different specific early math skills through the first two years of preschool (Chapter 2) and comparing children at different developmental stages before and after the onset of formal education, using a multigroup approach (Chapter 3); on the other hand, in Chapters 4 and 5, we have focused on the impact that environmental factors (i.e., the context to which an individual belongs with its peculiar socio-cultural, historical, economic, and political characteristics) may have on the development of early numerical skills.

As regards the first part of the dissertation, including Chapters 2 and 3 and examining early math learning from a cognitive point of view, we addressed two specific aims. The first aim was to investigate which are the cognitive predictors of growth in typically developing children's early numerical competence, considering at the same time the role of both domain-general (i.e., verbal intelligence, visuo-spatial WM, processing speed) and domain-specific (i.e., subitizing and ANS acuity) precursors and also exploring the developmental dynamics between different specific early math skills, through the first two years of preschool. To date, in fact, previous studies conducted on preschoolers (e.g., Geary et al., 2018; Geary et al., 2019; vanMarle et al., 2016) have focused mainly on the factors underlying the level of acquisition of emergent math skills at a given time point, without investigating the factors predicting the rate of change or growth in math competence at such an early age. Moreover, evidence on the predictive value of subitizing ability and ANS acuity is still limited and in part contradictory, with only few studies focusing on subitizing, and inconsistent findings regarding the relationship between ANS acuity and mathematical knowledge in preschoolers. In addition to that, only vanMarle and colleagues' work (2016) included both subitizing and ANS acuity in the same model to predict preschoolers' early mathematical knowledge. Considering these gaps in the literature, Chapter 2 focused on uncovering which are the general and specific precursors predicting not only the initial level but also the achievement growth in different early mathematical abilities, also clarifying the dynamic interrelations between simpler and more complex math skills, thus providing a unitary explanatory model and shedding light on the developmental trajectories in math competence at an age still little explored to date, that is between the age of 3 and 4.

The second aim of this dissertation concerned the role played by different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) in predicting typically developing children’s early mathematical knowledge specifically before and after the onset of formal education. Indeed, to date, there is still an absence of shared consensus on how the relative contributions of WM domains and processes to math performance change dynamically during child development, especially before and after the transition to primary school (see De Smedt et al., 2009, Meyer, Salimpoor, Wu, Geary, & Menon, 2010, and Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014 for an in-depth look at WM domains; see Fung & Swanson, 2017, Imbo & Vandierendonck, 2007, and Passolunghi & Lanfranchi, 2012 for an in-depth look at WM processes). In the face of previous inconsistent and unconclusive findings, Chapter 3 aimed at unraveling the role of different WM domains and processes in early math knowledge comparing, in a cross-sectional perspective and using a multigroup approach, a group of children attending the last preschool year and a sample of first graders. In a nutshell, Chapter 2 emphasized which are the growth-promoting cognitive factors of math competence and the developmental dynamics between different specific early math skills through the first two years of preschool, while Chapter 3, using a multigroup approach, focused on the relationship between WM and early math knowledge at different developmental stages, specifically before and after the onset of formal education. Both Chapters 2 and 3, suggesting which general and specific abilities are significant predictors of mathematical knowledge in different age groups, provide useful suggestions for the development of age-appropriate and effective cognitive training interventions aimed at promoting the enhancement of early mathematical skills already from preschool onwards.

Concerning the second part of the dissertation, including Chapters 4 and 5 and centred on the potential impact of the environment on preschool children’s early mathematical learning, we decided to focus specifically on the relationship between EFs' development and deprived and socio-culturally disadvantaged contexts, in the light of the well-known direct and indirect influences of EFs on early mathematics achievement (e.g., Blair & Razza, 2007; Bull et al., 2008; Clark et al., 2010) as well as the enormous relevance and topicality of issues such as war and refugee conditions in contemporary society (see Save the Children International, 2018). More in detail, the third aim of this dissertation was to explore the signature of living in highly deprived environments (i.e., war context and refugee condition) on EFs and early mathematical abilities, by comparing three groups of preschool children coming from different socio-cultural and economic backgrounds (i.e., Yazidis[2], Syrian refugees, and Italians). More specifically, Chapter 4 is guided by a twofold hypothesis: (a) on the one hand, we expected to confirm the association, already found in literature (e.g. Merz et al., 2016; Pellizzoni, Apuzzo, De Vita, Agostini, & Passolunghi, 2019; Welsh et al., 2010), between living in deprived environments, specifically war context and refugee condition, and showing poor EFs; (b) on the other hand, we expected to observe lower early mathematical skills in children exposed to specific deprived environments (i.e., war context and refugee condition) at an early age. In fact, although a growing number of studies has investigated the effects of socio-economic disadvantaged, deprived, or violent living conditions on EFs' development in children (e.g., Blair et al., 2011; Evans & Fuller-Rowell, 2013; Merz et al., 2016; Welsh et al., 2010), literature on EFs is surprisingly lacking on children living in war-affected contexts, and related refugee conditions, as well as no previous study has evaluated early mathematical abilities in children living in highly deprived contexts like these. In the face of these gaps in the literature, Chapter 4 is the first attempt to explore the relationship between EFs and math achievement in children coming from war context and refugee

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[2] Yazidis are a Kurdish religious minority living primarily in northern Iraq, southeastern Turkey, and northern Syria, who, from August 2014 onwards, have suffered numerous atrocities perpetrated by ISIS described as genocide (United Nations Human Rights Council, 2016, June 15, 32nd session) (see Chapters 4 and 5).

condition, representing a theoretical foundation for implementing intervention strategies to promote early numerical skills.

To complete and in continuity with the third aim, the fourth aim of this dissertation was twofold. Considering the crucial role of EFs in early mathematical development, on the one hand, we aimed to assess hot and cool EFs (with specific reference to WM and inhibition) in Yazidi children living in a war context who survived genocide; on the other hand, we aimed to develop and implement a training program to improve these children's EFs, also assessing its effectiveness. In fact, as already explained in relation to the Chapter 4, despite the fact that it is widely known that EFs development is critically affected by stress and trauma as well as the socio-economic context in which children grow up (see Welsh et al., 2010), research in this field is extremely lacking in relation to war contexts and the few studies conducted to date have focused exclusively on emotional control and trauma (Betancourt et al., 2012; Pat-Horenczyk et al., 2013). This gap is even more surprising when we consider that approximately one in six children today lives in a war context (Save the Children International, 2018). Furthermore, a careful literature review revealed that no EFs training has ever been specifically implemented in favour of children living in critical contexts such as refugee camps in Kurdistan. In the light of this state of art, Chapter 5 represents the first attempt at both (a) evaluating hot and cool EFs in five-year-old children living in a critically adverse context (Yazidi minority group) compared to children living in a typical environmental context (Italian children), and (b) assessing the effectiveness of a cognitive training method on hot and cool EFs in children that survived genocide. As a whole, Chapter 5 provides useful suggestions not only from a theoretical point of view, in relation to cognitive consequences of war trauma, but also from a practical standpoint, representing the first example of training intervention specifically designed for such a children's population. Taken together, Chapters 4 and 5 may be considered a starting point for providing an entire cohort of children (i.e., Yazidis who survived genocide and refugees) concrete tools to base learning and achievement abilities and preventing them from becoming a "lost generation”.

In summary, the studies presented in this dissertation addressed the following aims:

a) To investigate the domain-general and domain-specific cognitive predictors of growth in typically developing children’s early numerical competence and the developmental dynamics between different specific mathematical skills through the first two years of preschool (Chapter 2);

b) To examine the relative contributions of WM domains and processes to typically developing children’s math performance at different developmental stages, specifically before and after the transition to primary school (Chapter 3);

c) To explore the signature of living in highly deprived environments (i.e., war context and refugee condition) on EFs and early mathematical abilities, by comparing three groups of preschool children coming from different socio-cultural and economic backgrounds (i.e., Yazidis, Syrian refugees, and Italians) (Chapter 4);

d) To further investigate hot and cool EFs in Yazidi children living in a war context who survived genocide and implement a training program to improve these children’s EFs, also assessing its effectiveness (Chapter 5).

In summary, the studies presented in this dissertation have the aim to investigate and promote factors underlying school readiness, enhancing the analysis and organization of trainings interventions that could base children’s ability to become aware citizens. Taken together, the findings of the present work would be beneficial from both a theoretical, practical, and humanitarian point of view, moving in the direction of improving mathematical learning as well as the general quality of life of children from all over the world.

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Chapter 2

Predictors of growth in early mathematical skills

De Vita, C., Tomasetto, C., & Passolunghi, M. C. (Manuscript in preparation). Predicting growth in early mathematical skills: developmental trajectories from age 3 to age 4.

Abstract

This study investigated the role of domain-general and domain-specific cognitive precursors in predicting both the initial level and the growth of early mathematical skills over the first two years of preschool. Participants were 354 children tested at two time points from 3.8 to 4.4 years of age. Latent Change Score (LCS) model revealed that both domain-general and domain-specific predictors contributed to the initial level of math skills, whereas only subitizing directly predicted skills' growth over time. Importantly, dynamic relations emerged between simpler skills (i.e., counting) and the development of more complex acquisitions (i.e., symbol-quantity mapping and cardinality). Implications of these findings for the early detection of at-risk children and the promotion of children's numerical development are discussed.

2.0 Introduction

Mastering mathematical knowledge is a prerequisite to adequately functioning in society. Numbers are everywhere, and mathematical skills play a prominent role in individuals' academic, occupational, and financial success in life, as well as in sustaining their health and wellbeing (Butterworth, Varma, & Laurillard, 2011; Reyna & Brainerd, 2007). Early numerical abilities develop well before children start formal education and are pivotal to later mathematical achievement (see Jordan, Kaplan, Ramineni, & Locuniak, 2009). Accordingly, it is crucial to define which cognitive predictors support the developmental trajectories of early mathematical skills. Such an early investigation would be beneficial from both a theoretical point of view, to deepen our understanding of the mechanisms underlying early mathematical development, and an educational standpoint, to guide early screening programs in order to identify children at risk of struggling with math, inform preschool education programs, and implement effective training interventions. In this way, the education system would prevent at-risk children from falling behind in mathematical learning development (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Nguyen et al., 2016).

Extensive research over the past decade highlighted the role of both domain-general (e.g., verbal intelligence, working memory [WM], processing speed) and domain-specific (e.g. subitizing, Approximate Number System acuity [ANS]) cognitive precursors in predicting preschoolers' mathematical knowledge (e.g., Geary et al., 2018; Geary, vanMarle, Chu, Hoard, & Nugent, 2019; Gray & Reeve, 2014, 2016; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; LeFevre et al., 2010; Passolunghi, Lanfranchi, Altoè, & Sollazzo, 2015; vanMarle et al., 2016; Xenidou-Dervou, Molenaar, Ansari, van der Schoot, & van Lieshout, 2017). However, one notices some striking gaps in the literature. First, the few studies examining the predictors of early mathematical development at the beginning of preschool education (e.g., Geary et al., 2018, 2019;

vanMarle et al., 2016) have focused on the factors underlying the level of acquisition of emergent math skills at a given time point, whereas no study thus far has sought to determine which factors predict the *rate* of change or growth (i.e., the development) of early mathematical skills from age 3 to age 4. Focusing on change, and highlighting which are the growth-promoting cognitive factors of math competence, is vital, because the rate of growth in early math skills prior to school entry has emerged as the best predictor of high-school math achievement – above and beyond the level of mastery of such skills at a given time point (see Watts, Duncan, Siegler, & Davies-Kean, 2014). Second, to the best of our knowledge, no previous research examined the developmental dynamics between different specific early math skills, and the sequential order in which they develop over time at an early age. As global measures of mathematics achievement including a wide range of numerical skills and math domains are commonly used in research with preschoolers (e.g., Aunola et al., 2004; Kroesbergen et al., 2009; Passolunghi et al., 2015; Xenidou-Dervou et al., 2017), it is difficult to determine how the different early-emerging math skills are intertwined with each other. Finally, empirical evidence on the predictive value of number-specific precursors of math (i.e., subitizing and ANS acuity) is still limited and in part contradictory, with only few studies focusing on subitizing, and inconclusive findings regarding the relationship between ANS acuity and mathematical knowledge in preschoolers. To our knowledge, no previous study to date, except for vanMarle and colleagues' work (2016), included both subitizing and ANS acuity in the same model to predict early mathematical knowledge.

In the light of these premises, the present longitudinal study strived to fill these gaps, extending previous research in several ways. First, we sought to provide a unitary model taking into account both domain-general (i.e., verbal intelligence, visuo-spatial WM, and processing speed) and domain-specific (i.e., subitizing, and ANS acuity) cognitive precursors of early mathematical knowledge at the beginning of preschool education. Second, we examined whether each predictor differentially contributes to both initial level and achievement growth in different early mathematical skills (i.e., counting ability, symbol-quantity mapping, and cardinality proficiency) from age 3 to age 4, through the first two years of preschool. Third, we aimed at clarifying the dynamic interrelations between the acquisition of simples, foundational skills (such as counting), and the development of more complex skills (i.e., symbol-quantity mapping and cardinality). The following sections briefly explain the rationale underlying the cognitive predictors and the mathematical skills considered in the study and our specific aims and research hypotheses.

2.0.1 Domain-general cognitive markers of early mathematical knowledge

It is well established that domain-general cognitive abilities are necessary as a scaffold for the early construction of mathematical knowledge (e.g., Clark et al., 2014; Cragg & Gilmore, 2014; Kroesbergen et al., 2009; Passolunghi et al., 2015). More specifically, verbal intelligence, measured as vocabulary ability, is claimed to support preschool children's math knowledge both directly and indirectly, by facilitating children's ability to access symbolic number information, which in turn may foster later mathematical learning (e.g., Geary & Reeve, 2016; LeFevre et al., 2010; Passolunghi et al., 2015).

Abundant research also highlighted an association between WM, that allows the temporary storage and manipulation of information during a cognitive task performance (Baddeley, 1986), and preschoolers' mathematical knowledge (see Raghubar, Barnes, & Hecht, 2010). Specifically, strong relations were found between early mathematical abilities and visuo-spatial WM in preschool years, when children, who are still in the process of acquiring the foundations of math competence, rely more on visuo-spatial representation of quantity and number than on verbal information while performing math tasks (e.g., De Smedt et al., 2009). Processing speed, defined as the rapidity and efficiency with which a simple cognitive task is executed (see Kail & Salthouse, 1994), has been found to be associated with preschoolers' early mathematical knowledge too (e.g., Clark et al., 2014; Passolunghi et al., 2015). Given that processing speed is conceptualized as a crucial mental skill that drives changes in higher-order cognition (see also Hale, 1990), it is plausible that a large proportion of the variability in preschool children's early mathematical skills may be explained by individual differences in processing speed. However, to date no study investigated in the same model the role played by both domain-general verbal intelligence, visuo-spatial WM, and processing speed abilities in predicting both initial level (i.e., starting point) in the first preschool year, and achievement growth (i.e., rate of development or change) from age 3 to age 4, in early mathematical skills.

2.0.2 Number-specific predictors of early mathematical knowledge: subitizing and ANS

Much research has highlighted the importance of numerical magnitude processing as a scaffold for higher-level mathematical knowledge (e.g., Butterworth et al., 2011; Jordan et al., 2009). Although both Butterworth and Dehaene's models refer to a "core quantity system", each model especially focuses on one of two different neuro-cognitive systems for representing numerosity. On the one hand, Butterworth (2005) emphasizes the role of the *Object Tracking System* (OTS) that, through the rapid pattern-matching process of *subitizing*, allows to accurately and quickly recognize the exact number of items in a set of 4 items or fewer (Gray & Reeve, 2014; Starkey & Cooper Jr, 1995). On the other hand, Dehaene's model highlights the role played by the *Approximate Number System* (ANS) acuity, which allows to approximately and imprecisely represent and compare relative large numerosities (Halberda & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2011).

To date, there is a shortage of studies examining the predictive role of preschoolers' subitizing ability for later mathematical development (e.g., Gray & Reeve, 2014; Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Hannula, Räsänen, & Lehtinen, 2007; Kroesbergen et al., 2009; LeFevre et al., 2010). Overall, there is evidence that subitizing contributes - both directly and indirectly - to the development of early math skills (e.g., counting and arithmetic abilities), over and above the influence of general cognitive functions, such as intelligence (see Hannula et al., 2015; Kroesbergen et al., 2009), thus suggesting that subitizing is a significant marker of math performance in preschool years. Studies are more abundant as regards the relations between ANS acuity and prescholers' mathematical knowledge, even though such association emerged in some studies (e.g., Libertus et al., 2011; vanMarle et al., 2016) but not in others (e.g., Negen & Sarnecka, 2015; Sasanguie, Defever, Maertens, & Reynvoet, 2014). It is surprising, however, that only one study to date has examined the relative contributions to early mathematical skills of subitizing and ANS acuity in combination (vanMarle et al., 2016). It remains thus unclear whether subitizing and ANS acuity are unique or overlapping precursors of early mathematical development. As a case in point, vanMarle et al.'s (2016) study showed that ANS acuity - but not subitizing - contributed to children's acquisition of cardinality in preschool years. Considering this gap in the literature, the present study included both subitizing and ANS acuity in the same model as two distinct cognitive precursors of preschoolers' math skills.

2.0.3 Developmental dynamics of math knowledge at an early age

Mathematical competence relies on the integration of a wide range of abilities and processes, and it has been suggested that mathematical development progresses in a hierarchical manner: Learning basic skills and concepts provides the basis for the subsequent acquisition and mastering of more complex skills and procedures. Thus, the development of mathematical knowledge may proceed over time following a cumulative pattern, whereby children who start with higher mathematical skills improve their performance over time more than those who start with lower skills (see Aunola et al., 2004; Gelman & Gallistel, 1978). Such a pattern should be characterized by the amplifying nature of the developmental processes, since the initial level of mastery would predict subsequent growth in performance, and, accordingly, increasing interindividual differences and heterogeneity in developmental trajectories in math performance over time (see also Aunola, Leskinen, Onatsu, Arvilommi, & Nurmi, 2002). To the best of our knowledge, however, no study so far investigated the developmental dynamics among early-emerging math competencies during the first two years of preschool. The current study sought to add to previous literature by examining the development of three specific early mathematical skills (i.e., counting ability, symbol-quantity mapping, and cardinality proficiency) from age 3 to age 4, that is, in the first phase of the preschool education.

Several studies have shown that, during early childhood, children start to construct a core suite of competencies that provide the basis for the development of formal mathematical knowledge (e.g., Jordan et al., 2009). Since counting, symbol-quantity mapping, and cardinality competencies serve as capstones of early mathematical knowledge, and represent the “anchors” for subsequent math learning (Geary & vanMarle, 2018; Geary et al., 2019; Nguyen et al., 2016; Purpura, Baroody, & Lonigan, 2013), in the current work we decided to focus on this specific set of competencies. However, to date, neither the sequential order in which counting ability, symbol-quantity mapping, and cardinality understanding develop over time, nor the cognitive precursors predicting each of these early mathematical skills, are clear.

Knowledge of the verbal counting sequence (“one, two, three…”) is a prerequisite for symbol-quantity mapping that would be acquired later in math development (Krajewski & Schneider, 2009; Lira, Carver, Douglas, & LeFevre, 2017). Indeed, in order to perform symbol-quantity mapping tasks, children need to employ an efficient counting strategy as well as the ability to link together symbolic and non-symbolic numerical information and processes (see Holloway & Ansari, 2009). Symbol-quantity mapping emerges in turn as a crucial skill that children must master before they can deal with more complex mathematical tasks (Knudsen, Fischer, & Aschersleben, 2015; Purpura et al., 2013).

Knowledge of the standard counting sequence is also a precursor of children's acquisition of cardinality, that is, understanding that the last number word in a counting sequence represents the quantity of that set (Gelman & Gallistel, 1978; Le Corre & Carey, 2007). Indeed, children must learn the number words before they can match them with the specific quantities they represent. This skill unfolds slowly during the preschool years (see Geary et al., 2019). Cardinality understanding, in turn, plays a critical role in promoting the development of more advanced mathematical skills, providing a natural scaffold, for example, for calculation or learning arithmetic (Geary et al., 2018; Purpura et al., 2013).

Some studies suggest that understanding cardinality is a necessary predecessor of mapping symbols (i.e., digits) to quantities, which would emerge later (e.g., Knudsen et al., 2015; Sella, Berteletti, Lucangeli, & Zorzi, 2017). However, only a few studies have explored the development of symbol-quantity correspondence directly (e.g., Knudsen et al., 2015), so that, so far, the specific order in which counting ability, symbol-quantity mapping, and cardinality understanding are acquired is not yet clear. Moreover, the literature suggests that the road to the conceptual understanding that each number word represents a unique quantity and that each successive number in the count list is one more than the number before it (i.e., cardinality understanding) is long and difficult (see Sarnecka & Carey, 2008; Wynn, 1990) thus showing that children's initial steps into symbolic mathematics (e.g., counting or symbol-quantity mapping) can occur even without the acquisition of this conceptual knowledge (see Geary et al., 2018). Considering this evidence and according to the theoretical perspective for which more basic skills act as a foundation for more complex ones (see Aunola et al., 2004), our expectation was that children first develop counting ability, secondly learn the symbol-quantity connection, and lastly acquire cardinality proficiency.

2.1 The current study

This study aimed to outline a longitudinal model investigating whether, how, and to what extent, general and specific cognitive precursors predict both the initial level (i.e., starting point) of different early mathematical skills in the first preschool year, and the rate of development (i.e., change over time) in each math skill from age 3 to age 4. Moreover, our work aimed to explore the dynamic relations between more basic and more complex math skills, in order to focus on the developmental changes occurring in math learning at such an early age.

In more detail, we first aimed at unraveling the contribution of both domain-general (i.e., verbal intelligence, visuo-spatial WM, and processing speed) and domain-specific (i.e., subitizing and ANS acuity) cognitive precursors of mathematical learning to the emergence of early math skills. Besides determining how each of the investigated precursors of math learning uniquely contributes to children’s level of acquisition of counting ability, symbol-quantity mapping, and cardinality proficiency, we sought to investigate how each of these precursors predicts the rate of development (i.e., change over time) in each early-emerging mathematical skill from age 3 to age 4. As regards domain-general precursors, we expected processing speed to exert a pivotal role in predicting early math skills, since previous studies found significant relationships between early numeracy and processing speed over and above the influence of intelligence and WM (e.g., Bull & Johnston, 1997; Clark et al., 2014; Fuchs et al., 2006; Passolunghi et al., 2015). As it concerns domain-specific precursors, we hypothesized that subitizing ability, in the light of its role of marker of numerical development suggested by previous studies, and due to its function in representing and processing exact numerosities, may emerge as a more critical predictor of early symbolic math skills than ANS acuity (see Butterworth, 2005; Noël & Rousselle, 2011).

Our second aim was to investigate the dynamic relations between the initial level of mastery and the subsequent development of each of the three investigated mathematical skills (i.e., counting ability, symbol-quantity mapping, and cardinality proficiency). Because simpler skills act as a foundation for more complex ones (see Aunola et al., 2002, 2004), our expectation was that the initial level of knowledge of more basic math abilities would predict subsequent increments not only in the same ability, but also in more complex abilities. Thus, we hypothesized that children with higher basic math skills at age 3 would improve their mastery of more complex skills from age 3 to age 4 at a higher extent than children with lower basic math skills at the beginning. In detail, initial level of counting ability was hypothesized to predict subsequent change in both symbol-quantity mapping and cardinality proficiency, whereas symbol-quantity mapping at age 3 was hypothesized to predict the improvement in the acquisition of the cardinality from age 3 to age 4. This expectation is consistent with the so-called "Matthew effect" (see Shin, Davison, Long, Chan, & Heistad, 2013), whereby high achievement gets higher and low achievement gets lower over time.

Finally, we reasoned that if domain-general and domain-specific cognitive precursors of math learning influence children's acquisition of basic mathematical skills, and basic skills – through a Matthew effect – favor the subsequent acquisition of more complex abilities, then part of the effect exerted by math precursors on change in more complex mathematical knowledge over time may emerge as an indirect effect. In other terms, we hypothesized that domain-general and domain-specific precursors prospectively influence the rate of development of more complex mathematical skills not only directly, but also indirectly, through the mediation of simpler math skills.

2.2 Method

2.2.1 Participants

A total of 354 children (168 females and 186 males) took part in the study. They were recruited from twenty-one preschools located in different urban areas of north-eastern Italy serving middle socioeconomic background families. All children were Caucasian and spoke Italian fluently. They all had normal or corrected-to-normal vision, and none had reported learning difficulties. All 354 participants were tested at two different moments. At time 1, they were attending their first year of preschool (M_{age} = 45.67 months, *SD* = 3.14, age range: 39-51 months); at time 2 the same children were in the second year of preschool (M_{age} = - 52.68 months, *SD* = 3.14, age range: 46-58 months).

2.2.2 Procedure

Formal consent was obtained from the school headmaster and from children' teachers and parents. Children also gave verbal assent before being assessed. Testing was conducted at two different time points, seven months apart. Children's assessment was carried out over a two-month period during the first year of preschool (spring, time 1), and then during the second year of preschool (fall, time 2). The first phase involved assessing the following abilities: (a) verbal intelligence; (b) visuo-spatial WM; (c) processing speed; (d) subitizing; (e) ANS acuity; (f) counting; (g) symbol-quantity mapping; and (h) cardinality proficiency. In the second phase, only early mathematical skills (i.e., counting, symbol-quantity mapping, and cardinality proficiency) were retested. In the first phase, data collection was conducted in two separate sessions lasting approximately 20 min each, while in the second phase the mathematical tasks were administered in a single session lasting about 15 min. In both phases a breaf break was provided to participants if requested. At both measurement occasions, children were tested individually in a quiet room in kindergarten without distracting stimuli. The order of tasks presentation was counterbalanced across participants.

2.2.3 Measures

2.2.3.1 Domain-general precursors.

Verbal intelligence**.** To assess verbal intelligence, we administered the *Receptive Vocabulary* subtest from the Wechsler Preschool and Primary Scale of Intelligence – Third Edition (WPPSI-III; Wechsler, 2008). In this task, for each trial, children were presented with four pictures and were asked to indicate the picture most closely matched with the meaning of the word pronounced by the researcher. One point was given for each correct answer (expected range 0-38). The subtest was administered using a self-terminating procedure, whereby it was interrupted when participants were not able to correctly perform five consecutive trials.

Visuo-spatial working memory**.** Visuo-spatial WM was tested using a visuo-spatial dual task, adapted from Lanfranchi, Cornoldi, and Vianello (2004). In this task, participants needed to remember a frog's starting position along a path taken on a 3 x 3 matrix, where one of the nine cells was colored red. Children also had to tap on the table when the frog jumped onto the red square. The task included four different levels of difficulty, depending on the number of times the frog jumped (i.e., two, three, four or five). Each level comprised two paths, for a total of eight trials. Participants were given a score of one when they both correctly remembered the frog's starting position and performed the secondary task (i.e., tapping) (expected range 0-8). The task was administered using a self-terminating procedure, whereby it was interrupted when participants were not able to correctly perform the two trials of the same difficulty level.

Processing speed. To assess processing speed, we administered the *Symbol Search* subtest from the WPPSI-III (Wechsler, 2008). This is a timed task (120 seconds) on which children visually scan geometric symbols to determine if they correspond to the stimulus symbols. The raw score is the number of items correctly completed within the time limit minus the number of wrong answers, reflecting both accuracy and speed of performance (expected range 0-50).

2.2.3.2 Domain-specific precursors. .

Subitizing and ANS acuity. To measure both subitizing and ANS acuity, we administered a version of *Panamath*, a computerized non-symbolic numerical comparison task (see Halberda & Feigenson, 2008; Libertus et al., 2011) (for a free download of the software visit www.panamath.org). Children sat facing a 15-inch laptop screen and were presented with two arrays of spatially separated yellow and blue dots with a variable numerosity in each set. The dots appeared simultaneously within background frames associated to two characters, Big Bird (yellow) on the left and Grover (blue) on the right and remained visible for a fixed interval (2500 ms) too brief to allow children verbal counting. Children were invited to indicate whether more of the dots were yellow or blue, by pressing the corresponding key on the keyboard (i.e., “A” for “yellow” and “L” for “blue”). On half of the trials the yellow dots were more numerous; on the other half the blue dots were more numerous.

In the subitizing task, the number of dots in each set ranged from 1 to 4 and the 24 test trials were randomly drawn from one of two numerical ratio bins (i.e., 1:2 and 2:3). In the ANS task, the number of dots in each set ranged from 5 to 16 and the 60 test trials were randomly drawn from one of four numerical ratio bins (i.e., 1:2, 2:3, 3:4, 6:7), with the absolute number of dots on each trial varying (such that a trial with 5 yellow versus 10 blue dots would go into 1:2 ratio bin). In both subitizing and ANS acuity tasks the score was total percentage correct (expected range 0-100).

2.2.3.3 Early mathematical skills.

Counting**.** To assess verbal counting, we used a measure of forward number sequence knowledge, adapted from the forward sequence subtest of the Numerical Intelligence Battery (BIN; Molin, Poli, & Lucangeli, 2007). Participants were asked to count forward from one to 20. If the child stopped before 20 or made a mistake, the counting could be repeated a second time. In this case the longest number sequence counted between the two was considered and score was the highest number correctly counted forward in that sequence (expected range 0-20).

Symbol-quantity mapping**.** Symbol-quantity mapping was tested using the digit-dots correspondence subtest from the BIN (Molin et al., 2007). In this task, children had to match a presented Arabic digit (ranging from 1 to 9) with the corresponding set of dots (i.e., quantities) among three different visually presented sets. The subtest included nine trials and children received one point for each correct answer (expected range 0-9).

Cardinality**.** To test cardinality proficiency, we used a task adapted from Le Corre and Carey (2007). Children were shown 16 cardsboards (presented in a random order) depicting from one to 16 colored objects and asked to count the items represented on each cardboard. Once they had counted the objects, children were asked how many items there were. One point was given if the children both correctly counted the items represented on each cardboard and correctly answered the second question without starting to count the objects again (expected range 0-16).

2.3 Data analyses

The software package SPSS 25 was used to perform descriptive and univariate analyses, and to compute zero-order bivariate correlations among the study variables.

To test our hypotheses, we used a Latent Change Score (LCS) modeling approach (McArdle, 2009), in which the rate of change in the value of a x variable between two subsequent time points t_1 and t_2 is modeled as a latent variable Δx, i.e., as a "true" value with an explicitly estimated measurement error. The LCS model was performed by using the software M-plus version 7.1 (Muthén & Muthén, 1998-2010), and Maximum-Likelihood Robust (MLR) estimator was used to provide reliable parameters estimates even in presence of non-normally distributions in observed indicators. Specifically, we performed a multiple LCS model in which one latent change variable was estimated for each of the three investigated mathematical skills, i.e., counting ability, symbol-quantity mapping, and cardinality proficiency. Known cognitive precursors of emerging math abilities in preschool years were included in the model as covariates to predict both initial levels of children's mathematical skills, as measured at age 3 (t_1), and subsequent change (Δx) in each skill from age 3 to age 4.

To investigate the dynamic interplays between the different math abilities, we also included in our model a set of causal paths linking initial levels of mastery of simpler mathematical skills to the rate of change in more complex abilities. In detail, causal paths were estimated between the initial level of counting ability and subsequent changes in both symbol-quantity mapping and cardinality proficiency, as well as between symbol-quantity mapping at age 3 and the improvement in cardinality understanding from age 3 to age 4.

Finally, we estimated the indirect effects linking each of the cognitive precursors of math learning to change in symbol-quantity mapping through the initial level of counting ability, and from each precursor to change in cardinality proficiency through counting and symbol-quantity mapping abilities. All the estimates were adjusted for children's age (in months) at time 1. Missing data were handled by using Full-Information Maximum Likelihood (FIML) estimation.

Several fit criteria were adopted to evaluate the goodness of fit of the hypothesized model: scaled Chi2 test, Comparative Fit Index (CFI), Non-Normed Fit index (NNFI), Root Mean Square Error of Approximation (RMSEA) with 90% Confidence Intervals (CI), and standardized root mean residual (SRMR). Models with a CFI and a NNFI equal or higher than 0.95, a RMSEA lower than 0.06, and a SRMR lower than 0.09 were considered as having a good fit to the data (Schermelleh-Engel, Moosbrugger, & Müller, 2003).

2.4 Results

2.4.1 Descriptive analyses

Descriptive statistics and bivariate correlations between all measured variables are reported in Table 2.1. It should be noticed that all the investigated variables were significantly associated with each other in both times, except for verbal intelligence with symbol-quantity mapping (t_1), and visuo-spatial WM and ANS acuity with counting (t_2). As regards the initial level of early mathematical skills (t_1), it should noted that a large number of children was able to correctly perform at least half of the tasks administered in the study already in the first year of preschool. More specifically, 151 participants could count beyond 10 (65 of which reached up to 20, getting the maximum score), 75 of them managed to match at least five of the nine symbols (i.e., digits) with their corresponding quantities, and 104 children obtained a score of at least eight in the cardinality proficiency task.

Table 2.1 Descriptive Statistics and Inter-Correlations Between All Variables.

	Descriptive statistics							*Zero-order correlations*										
	M	*SD*	Min	Max	Skewness	Kurtosis	Reliability	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Age (in months)	45.67	3.14	39.00	51.00	-0.18	-0.89	-	.43***	.17***	.20***	.24***	.24***	.32***	.19***	.35***	.17***	.19***	.25***
2. Verbal intelligence	11.76	3.42	4.00	19.00	0.17	-0.47	.94	-	.23***	.24***	.20***	.14**	.30***	.13*	.32***	.23***	.07	.18***
3. Visuo-spatial WM	1.23	1.79	0.00	8.00	1.50	1.29	.81	-	-	.34***	.27***	.21***	.19***	.22***	.32***	.06	.14**	.20***
4. Processing speed	5.35	5.70	0.00	24.00	1.01	0.19	.91	-	-	-	.31***	.26***	.27***	.31***	.42***	.18***	.25***	.32***
5. Subitizing	69.75	20.06	8.33	100.00	-0.12	-0.87	.82	-	-	-	-	.55***	.29***	.32***	.38***	.23***	.22***	.37***
6. ANS acuity	62.13	12.87	31.25	98.33	0.35	-0.33	.74	-	-	-	-	-	.12*	.21***	.21***	.09	.19***	.24***
7. Counting (t_1)	10.02	6.42	0.00	20.00	0.09	-1.03	.83	-	-	-	-	-	-	.31***	.53***	.46***	.26***	.50***
8. Symbol-quantity mapping (t_1)	2.49	2.56	0.00	9.00	0.71	-0.59	.74	-	-	-	-	-	-	-	.44***	.21***	.50***	.51***
9. Cardinality proficiency (t_1)	4.56	4.33	0.00	16.00	0.57	-0.87	.84	-	-	-	-	-	-	-	-	.35***	.36***	.57***
10. Counting (t_2)	13.20	5.56	0.00	20.00	-0.31	-0.89	.85	-	-	-	-	-	-	-	-	-	.28***	.45***
11. Symbol-quantity mapping (t_2)	4.36	2.50	0.00	9.00	0.17	-1.05	.81	-	-	-	-	-	-	-	-	-	-	.50***
12. Cardinality proficiency (t_2)	8.78	4.73	0.00	16.00	-0.37	-0.97	.90	-	-	-	-	-	-	-	-	-	-	-

2.4.2 Latent change model

A multiple LCS model was performed to test our hypotheses. Fit indices are satisfactory and indicate that the model provides an adequate representation of the observed data ($Chi^2_{(6)}$ = 10.200, *p* = .116, CFI = 0.995, NNFI = 0.955, RMSEA (90%CI) = 0.044 (0.000, 0.090), SRMR = 0.016). Standardized loadings are reported in Figure 2.1.

Figure 2.1 Latent Change Score model.

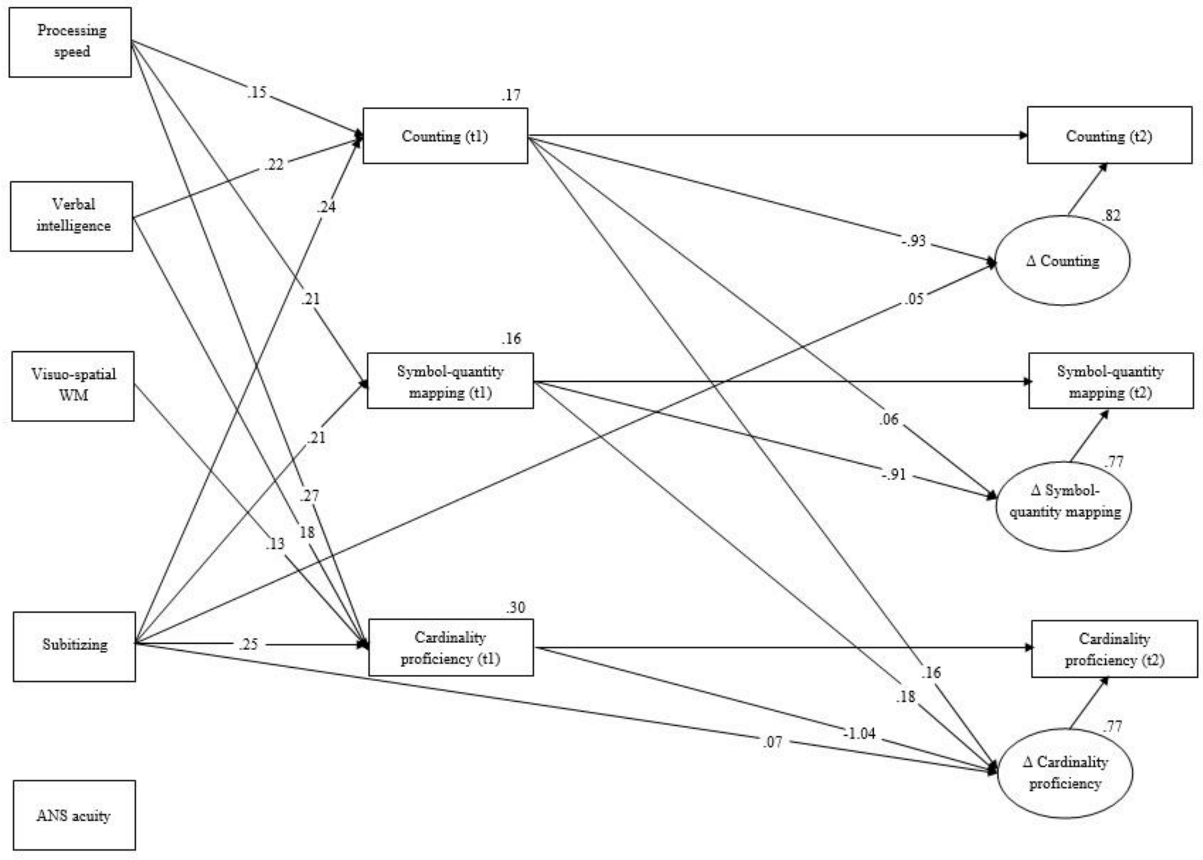

Figure 2.1 Standardized solution for the final LCS model adjusted for children’s age at time 1. All structural parameters are significant above the *p* < .05 level.

Notes. The squares represent the observed variables, while the circles represent latent variables. For clarity, only the significant paths are depicted. Latent intercepts and covariances are not shown. Unlabeled paths are fixed equal to 1.0 (see McArdle, 2009).

Estimated means and variances for initial levels and change in mathematical skills are reported in Table 2.2. Means of the latent variables describing change in counting ability, symbol-quantity mapping, and cardinality proficiency were all positive and significantly different from zero, thus indicating that children improved their level of mastery of each of the mathematical skills from age 3 to age 4. Change ranged on average from half a standard deviation for counting ability ($\Delta M = 0.509$) to approximately one standard deviation for cardinality proficiency ($\Delta M = 0.968$). More importantly, both initial levels and latent change variables had significant variances, meaning that there were non-negligible interindividual differences both in the initial levels of mathematical skills and in the subsequent developmental trajectories (see Aunola et al., 2002). We therefore moved to explore whether, and to what extent, such interindividual differences would be associated with known cognitive precursors of math learning (H1).

Table 2.2 Unstandardized intercept and variance estimates for mathematical skills variables from the LCS model.

	Estimate	*SE*	95%CI [lower / upper]	*p*
Intercepts				
Counting ability (change)	3.194	0.259	2.685 / 3.702	<.001
Symbol-quantity mapping (change)	1.873	0.113	1.651 / 2.096	<.001
Cardinality proficiency (change)	4.200	0.186	3.835 / 4.566	<.001
Variances				
Counting ability (level)	34.192	2.063	30.148 / 38.236	<.001
Symbol-quantity mapping (level)	5.515	0.385	4.761 / 6.269	<.001
Cardinality proficiency (level)	13.200	0.950	11.339 / 15.062	<.001
Counting ability (change)	23.819	1.610	20.664 / 26.975	<.001
Symbol-quantity mapping (change)	4.554	0.294	3.977 / 5.130	<.001
Cardinality proficiency (change)	12.313	0.798	10.748 / 13.878	<.001

Note. Intercepts for initial levels of mathematical skills are not reported as all variables were mean-centered at the observed values at age 3 ($M = 0$, $s^2 = 1$).

As it can be observed from Table 2.3 that reports estimates of direct effects, initial levels of each mathematical skill were predicted by different sets of domain-general and domain-specific cognitive precursors. Counting at age 3 was predicted by verbal intelligence (ß = .405 [95%CI: .212,.597], $p < .001$), processing speed (ß = .173 [95%CI: .044,.302], $p = .009$), and subitizing (ß = .077 [95%CI: .039,.115], $p < .001$) abilities. Processing speed (ß =

.095 [95%CI: .040,.151], *p* = .001) and subitizing (ß = .027 [95%CI: .011,.043], *p* = .001) – but not verbal intelligence – also predicted the initial level of symbol-quantity mapping. All the measured cognitive math precursors – except for ANS acuity – emerged as predictors of the acquisition of cardinality at age 3 (verbal intelligence: ß = .227 [95%CI: .104,.350], *p* < .001; visuo-spatial WM: ß = .327 [95%CI: .064,.590], *p* = .015; processing speed: ß = .204 [95%CI: .125,.282], *p* < .001; subitizing: ß = .054 [95%CI: .030,.078], *p* < .001).

When the contribution of cognitive math precursors to the initial levels of early mathematical skills was taken into account, two paths directly linking cognitive precursors to change in math abilities also remained significant. Specifically, subitizing at age 3 prospectively predicted change both in counting ability (ß = .030 [95%CI: .000,.060], *p* = .049) and in the acquisition of cardinality (ß = .025 [95%CI: .003,.047], *p* = .028), whereas the contribution of verbal intelligence to change in counting fell short of significance (ß = .144 [95%CI: -.014,.302], *p* = .074). In other terms, subitizing emerged as a unique precursor of improvement in counting and cardinality skills, above and beyond its contribution to the initial level of mastery of both abilities. Neither domain-general nor domain-specific cognitive precursors of math directly accounted for increments in symbol-quantity mapping.

Table 2.3 Unstandardized estimates of direct effects of cognitive math precursors on level and change in counting, symbol-quantity mapping, and cardinality proficiency from the LCS model.

	Counting				Symbol-quantity mapping				Cardinality proficiency			
	Estimate	*SE*	95%CI [lower / upper]	*p*	Estimate	*SE*	95%CI [lower / upper]	*p*	Estimate	*SE*	95%CI [lower / upper]	*p*
Predictors of level (t1)												
Verbal intelligence	0.405	0.098	0.212 / 0.597	<.001	0.011	0.040	-0.068 / 0.090	.784	0.227	0.063	0.104 / 0.350	<.001
Visuo-spatial WM	0.140	0.206	-0.264 / 0.544	.496	0.114	0.089	-0.061 / 0.288	.203	0.327	0.134	0.064 / 0.590	.015
Processing speed	0.173	0.066	0.044 / 0.302	.009	0.095	0.028	0.040 / 0.151	.001	0.204	0.040	0.125 / 0.282	<.001
Subitizing	0.077	0.019	0.039 / 0.115	<.001	0.027	0.008	0.011 / 0.043	.001	0.054	0.012	0.030 / 0.078	<.001
ANS acuity	-0.046	0.032	-0.109 / 0.016	.142	0.005	0.013	-0.019 / 0.030	.678	-0.015	0.021	-0.055 / 0.025	.470
R^2	0.171			<.001	0.160			<.001	0.300			<.001

	ΔCounting				ΔSymbol-quantity mapping				ΔCardinality proficiency			
	Estimate	*SE*	95%CI [lower / upper]	*p*	Estimate	*SE*	95%CI [lower / upper]	*p*	Estimate	*SE*	95%CI [lower / upper]	*p*
Predictors of change (Δ)												
Verbal intelligence	0.144	0.081	-0.014 / 0.302	.074	-0.032	0.039	-0.108 / 0.044	.408	-0.050	0.058	-0.163 / 0.063	.386
Visuo-spatial WM	-0.237	0.178	-0.585 / 0.111	.182	-0.005	0.076	-0.155 / 0.144	.946	-0.048	0.108	-0.259 / 0.163	.655
Processing speed	0.043	0.055	-0.064 / 0.150	.431	0.034	0.022	-0.009 / 0.076	.121	0.023	0.035	-0.045 / 0.092	.500
Subitizing	0.030	0.015	0.000 / 0.060	.049	<.001	0.007	-0.014 / 0.014	.988	0.025	0.011	0.003 / 0.047	.028
ANS acuity	-0.012	0.024	-0.060 / 0.036	.636	0.013	0.010	-0.007 / 0.033	.205	0.016	0.016	-0.014 / 0.047	.295
Counting (level)	-1.647	0.045	-1.736 / -1.558	<.001	0.044	0.021	0.002 / 0.086	.041	0.183	0.035	0.114 / 0.252	<.001
Symbol-quantity mapping (level)			---		-1.576	0.048	-1.671 / -1.481	<.001	0.508	0.076	0.358 / 0.657	<.001
Cardinality proficiency (level)			---				---		-1.741	0.057	-1.853 / -1.630	<.001
R^2	0.817			<.001	0.769			<.001	0.769			<.001

As predicted, substantial dynamic interrelations between initial levels of more basic mathematical skills and subsequent improvements in more complex abilities were also found. In detail, counting ability at age 3 predicted improvement in symbol-quantity mapping between age 3 and 4 (ß = .044 [95%CI: .002,.086], *p* = .041), whereas initial levels of both counting ability (ß = .183 [95%CI: .114,.252], *p* < .001) and symbol-quantity mapping (ß = .508 [95%CI: .358,.657], *p* < .001) accounted for change in cardinality proficiency.

2.4.2.1 Indirect effects. Finally, we examined the indirect paths linking cognitive math precursors to the latent variables describing change in mathematical skills between age 3 and 4, through the mediation of initial levels of such math skills at age 3. Estimates of indirect effects are reported in Table 2.4. The indirect contribution of verbal intelligence and subitizing abilities to change in symbol-quantity mapping fell above the conventional significance threshold (*p* = .057 and *p* = .071, respectively). Conversely, verbal intelligence (through counting, *p* = .001), processing speed (through initial levels of both counting and symbol-quantity mapping, *p* = .019 and *p* = .002, respectively), and subitizing (through counting and symbol-quantity mapping, *p* = .002 and *p* = .003, respectively) indirectly predicted change in cardinality proficiency from age 3 to age 4. Overall, these findings suggest that albeit only subitizing emerged as a significant direct predictor of developments in early mathematical skills, domain-general math precursors also exert an indirect influence on the development of preschoolers' math knowledge over time, by providing them with foundational skills which in turn allow to acquire and improve, over time, more advanced abilities.

Table 2.4 Unstandardized estimates of indirect effects of cognitive math precursors on change in symbol-quantity mapping and cardinality proficiency from the LCS model.

	Estimate	*SE*	95%CI [lower/upper]	*p*
Symbol-quantity mapping (through counting)				
Verbal intelligence	0.014	0.007	0.000 / 0.028	.057
Visuo-spatial WM	0.002	0.004	-0.005 / 0.010	.511
Processing speed	0.010	0.006	-0.002 / 0.022	.104
Subitizing	0.015	0.008	-0.001 / 0.032	.071
ANS acuity	-0.006	0.005	-0.015 / 0.004	.223
Cardinality (through counting)				
Verbal intelligence	0.035	0.010	0.014 / 0.055	.001
Visuo-spatial WM	0.006	0.009	-0.012 / 0.024	.496
Processing speed	0.025	0.011	0.004 / 0.045	.019
Subitizing	0.039	0.012	0.015 / 0.063	.002
ANS acuity	-0.015	0.010	-0.035 / 0.005	.151
Cardinality (through symbol-quantity mapping)				
Verbal intelligence	0.003	0.010	-0.016 / 0.021	.784
Visuo-spatial WM	0.014	0.011	-0.008 / 0.036	.216
Processing speed	0.038	0.012	0.013 / 0.062	.002
Subitizing	0.038	0.013	0.013 / 0.063	.003
ANS acuity	0.005	0.011	-0.017 / 0.027	.678

2.5 Discussion

The present work investigated the contribution of domain-general and domain-specific cognitive precursors of math learning to the emergence of different early mathematical skills in the first year of preschool, and to the improvement in each of these skills between age 3 and age 4. We also focused on dynamic interplays between basic and more complex mathematical abilities, highlighting the developmental trajectories and cascade effects in both acquisition and growth of math skills so early in children's development.

Taken together, our findings highlight that both domain-general and domain-specific cognitive precursors support the acquisition and the development of early mathematical skills through the preschool years. Within this framework, it is worth noticing that the precursors of initial levels (i.e., starting points) of each math skill were not the same as those predicting subsequent ability gains (i.e., development).

2.5.1 Precursors of initial levels of early mathematical skills at age 3

As we expected, processing speed emerged as a significant predictor of initial levels of counting, symbol-quantity mapping, and cardinality, in line with global theories of cognitive development conceptualizing processing speed as a central mental skill that drives changes in higher-order cognition (Case, Kurland, & Goldberg, 1982; Hale, 1990; Kail & Salthouse, 1994). Indeed, high processing speed may facilitate performance in a number of tasks across cognitive domains, by increasing the rapidity and efficiency with which stimuli can be processed, enhancing the capacity to represent information (e.g., digits, words, or shapes) from different standpoints, and allowing to carry out several operations simultaneously (Clark et al., 2014; Kail & Salthouse, 1994). It is generally acknowledged (see Passolunghi et al., 2015) that processing speed affects how quickly and successfully numbers are recited, sets of items are counted, associations are detected, and problems are matched with their solutions in WM before information decay. Moreover, in line with cascade models, growth in processing speed frees cognitive resources that can be devoted to higher-order functions (see Case et al., 1982). In the light of this, our results suggest that individual differences in processing speed may be involved to a large extent in predicting preschool children’s early mathematical skills, as well as higher-level later math performance.

As regards verbal intelligence, we found a direct influence of vocabulary knowledge in predicting both counting and cardinality abilities, but not symbol-quantity mapping. It is plausible that both counting and cardinality, contrary to symbol-quantity mapping, widely rely on verbal abilities in both understanding the instructions and carrying out the tasks. Our results are also consistent with previous findings on the role of vocabulary in supporting knowledge of the symbolic number system, such as naming numbers in counting (see LeFevre et al., 2010), which, in turn, serves as a basis for later more complex math knowledge. However, it is worth pointing out that, although knowledge of the symbolic number system is also implicated in symbol-quantity mapping, our results show no significant path between the latter and verbal intelligence.

The role of visuo-spatial WM was apparently more limited, as it only emerged as a predictor of the initial level of cardinality proficiency, with no effect on either counting or symbol-quantity mapping abilities. The limited contribution of visuo-spatial WM may depend on the very young age of children involved in the study. Indeed, as suggested by Clark and colleagues (2014), the distinction between WM and processing speed is not as clear-cut at age 3, and children’s domain-general processing speed might drive the relation between visuo-spatial WM performance and early mathematical skills. Thus, given that processing speed is so ubiquitously involved in performing cognitive tasks, it is plausible that a large proportion of the variance in children’s visuo-spatial WM at such an early age may be explained by individual differences in processing speed ability. Therefore, so early in the preschool period, WM tasks may not be sensitive indicators of a well-defined and independent WM construct, because WM is highly overlapped and intertwined with children's fluency of information processing (see Clark et al., 2014). As children grow older, WM abilities may independently relate to children's developing mathematical skills, over and above individual differences in general processing speed and verbal intelligence abilities.

Among domain-specific precursors, subitizing emerged as a significant predictor of counting, symbol-quantity mapping, and cardinality at age 3, whereas ANS acuity did not. This pattern of findings is consistent with our prediction that subitizing, given its function of representing and processing small exact numerosity, would have been a more critical cognitive precursor of early math knowledge as compared to ANS acuity. As ANS is primarily devoted to the imprecise representation of large approximate quantities, whereas subitizing is implied in exact pattern-matching process, it is plausible that subitizing - more than ANS - may act as a "hardcore" in the development of early mathematical skills, and represent a reasonable index of children's quantitative knowledge over time (see Desoete & Grégoire, 2006). The crucial role of subitizing in math learning is also understandable given that subitizing and counting (a capstone of symbolic math) abilities share the exactitude of the numerical labelling and are overlapping in their brain networks (see Piazza, Mechelli, Butterworth, & Price, 2002). They result complementary in the development of children's early math knowledge, since subitizing, that is a quick look at amount of items without using counting, is replaced by actual sequential counting when the quantity of items becomes four or more (Kroesbergen et al., 2009). Consistent with our results, highlighting subitizing ability as a natural foundational basis of children's later symbolic mathematical skills, recently, Lyons and colleagues (2018), although they have not specifically measured subitizing, emphasized the importance of acquiring a very basic grasp of exact number in fostering growth in the subsequent mathematical learning. In line with this standpoint, and with reference to atypical development, Butterworth (1999, 2005) suggested that impaired processing of exact numericities would be the specific source of mathematical difficulties for children with dyscalculia (see Butterworth, 1999, 2005), by preventing them to develop an exact representation of natural numbers (Noël & Rousselle, 2011).

2.5.2 Precursors of growth in early mathematical skills between age 3 and age 4

Results regarding the growth in early mathematical skills over time further emphasize the pivotal role of subitizing as a critical precursor of early math development. In fact, subitizing emerged as a unique predictor of improvement in both counting and cardinality, whereas neither ANS acuity nor domain-general cognitive abilities predicted any change in early math skills from age 3 to age 4. For the first time, this result highlights that subitizing not only underlies punctual levels of math knowledge at very young ages, but also influences the pace at which children improve their emerging abilities through the preschool years. Moreover, to the best of our knowledge, along with vanMarle and colleagues' work (2016), the present research is the first study to compare the potential role of subitizing and ANS acuity as domain-specific, non-symbolic predictors of early mathematical knowledge in the preschool years.

2.5.3 Interplays between early mathematical skills and indirect effects of precursors on their growth

As regards the associations between children's initial math skills at age 3, and their subsequent developments between age 3 and 4, we found substantial dynamic interrelations between the initial levels of simpler mathematical skills and later improvements in more complex abilities. This finding is in line with the "Matthew effect" phenomenon, according to which children with higher levels of basic skills at the beginning (i.e., at age 3), not only show higher levels of more complex skills concurrently, but also improve their mastery of those skills over time (i.e., between the age of 3 and 4) at higher rates than children with lower levels of basic skills at the beginning.

In line with the dynamic interrelations between simpler and more complex mathematical skills, we also found that domain-general (i.e., verbal intelligence and processing speed abilities) and domain-specific precursors (i.e., subitizing ability) prospectively influence the rate of improvement in children's acquisition of cardinality not only directly, but also indirectly, through their influence on children's initial mastery of counting and symbol-quantity mapping abilities. Therefore, even though only subitizing emerged as a significant direct predictor of improvement in preschoolers' early mathematical skills, processing speed and verbal intelligence also foster the development of math knowledge over time indirectly, through their positive influence on the emergence of foundational skills.

2.5.4 Limitations and implications

This work has some limitations. First, it focused only on the first two years of preschool. It would be indeed informative to monitor the development of early mathematical skills through a longer span, ideally covering the transition into primary school, i.e., when math learning becomes the object of formal education and evaluation. Second, we assessed only visuo-spatial WM and not the verbal one, since previous studies suggest that preschool children rely and depend heavily on visuo-spatial WM more than do older children (e.g., Hitch, Halliday, Schaafstal, & Schraagen, 1988; Rasmussen & Bisanz, 2005; for a review, see Raghubar et al., 2010). However, even though much previous research highlighted a stronger role of visuo-spatial than verbal WM in preschoolers' math knowledge (e.g., De Smedt et al., 2009), further studies should also examine the independent contribution of verbal WM in predicting the emergence and development of early mathematical skills, as well as expand the investigation to other potential domain-general cognitive precursors, such as executive functions (e.g., inhibition), attention, or phonological abilities (Cragg & Gilmore, 2014; Kroesbergen et al., 2009; Passolunghi et al., 2015). Thirdly, as regards subitizing and ANS acuity measures, it is possible that a certain percentage of children, by not performing significantly above chance, thus responding correctly on about 50% of trials, may not have correctly understood the task.

Overall, our findings may have important implications for both educational assessment and practice. Efficient subitizing, processing speed, and verbal intelligence at the onset of preschool may provide preschoolers with an advantage in the mathematical learning process, since such abilities appear to be crucial in fostering the emergence and the improvement of early math skills through the first two years of preschool. By consequent, children with low-level of subitizing, processing speed, or verbal intelligence abilities may be less likely to acquire basic numerical knowledge from as early as 3 years of age, and, more importantly, may be particularly at risk of developing a cumulative disadvantage in later mathematical learning. Our results demonstrate that early acquisition of simpler math skills (e.g., counting and symbol-quantity mapping abilities) plays a crucial role in setting children’s developmental learning trajectories related to more advanced mathematical knowledge (e.g., cardinality). Because cardinality has consistently emerged as the most critical prerequisite for subsequent numerical development (see Geary et al., 2018), children who start preschool with seemingly circumscribed weaknesses in basic prerequisites of cardinality, such as counting, may be more likely to fall behind in mathematical development as they grow up (see Karmiloff-Smith, 1998).

In conclusion, our results suggest that an early assessment of both domain-specific (i.e., subitizing) and domain-general (i.e., processing speed, verbal intelligence, and visuo-spatial WM) cognitive abilities could potentially be used as a screening tool for both identifying children at risk for math difficulties and preventing the development of Mathematical Learning Disabilities (MLD). At the same time, these general and specific abilities may represent the target of timely interventions programs aimed at an early enhancement of so crucial cognitive precursors of later mathematical achievement. In a synergistic perspective, engaging children in daily educational activities and games at home as well as efforts to teach basic competencies through effective preschool practices could also promote the improvement of subitizing, processing speed, and verbal intelligence, that, in turn, at such an early age, may foster both the emergence and development of increasingly complex math skills during preschool years.

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Chapter 3

Working Memory domains and processes in early mathematical knowledge

De Vita, C., Costa, H. M., Tomasetto, C., & Passolunghi, M. C. (submitted[3]). The contributions of working memory domains and processes to early mathematical knowledge between preschool and first grade.

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Abstract

Working Memory (WM) plays a crucial role in supporting children's mathematical learning. However, there is still an absence of shared consensus about the relative contributions of different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) to math performance, specifically before and after the onset of formal education. This cross-sectional study examined the relations between WM domains and processes and early mathematical knowledge, comparing a group of children in the final year of preschool (N = 66) to a group of first graders (N = 110). Results of multigroup path analysis showed that whereas visuo-spatial low-control WM significantly predicted early math knowledge only among preschoolers, verbal low-control WM was a significant predictor only among first graders. Instead, the contribution of visuo-spatial high-control WM emerged as significant for both age groups, as well as that of numerical-verbal WM, although the latter to a greater extent among the first ones. These findings provide new insights into the relations between WM domains and processes and early mathematical knowledge at different developmental stages, with implications for the implementation of interventions aimed at promoting the development of math competence from preschool age onwards.

3.0 Introduction

Mathematics represents one of crowning achievements human societies, and the question of what underlies its development has attracted a lot of research attention. The reason for this interest is simple: mathematical skills underlie attainment in the activities of everyday life as well as play a critical role in predicting educational and financial success, with relevant implications at both the individual and societal level (e.g., Ancker & Kaufman, 2007; Cragg & Gilmore, 2014; Geary, Hoard, Nugent, & Bailey, 2013; Reyna & Brainerd, 2007).

Among the cognitive underpinnings of mathematical competence, previous studies have pointed to Working Memory (WM) as a crucial determinant of children's mathematical learning, influencing both the early foundational stages of number knowledge acquisition and the subsequent emergence and development of problem solving skills (Alloway & Alloway, 2010; De Smedt et al., 2009; DeStefano & LeFevre, 2004; Menon, 2016). However, there is still an absence of shared consensus on the relative contributions of different WM domains and processes to math performance at different developmental stages of mathematical learning.

More in detail, to the best of our knowledge, no study to date has investigated the relations between different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and WM processes (i.e., low-control and high-control), on the one hand, and early mathematical knowledge, on the other, before and after the onset of formal education. The present study addressed this issue by comparing preschoolers with first-grade children, in order to shed light on the contribution of specific WM domains and processes to math knowledge before and after the transition to primary school. The results of this investigation could be useful not only to provide new theoretical insights on the relationship between WM and mathematics, but also from an educational point of view, by suggesting directions to develop age-appropriate training interventions aimed at strengthening the cognitive bases of mathematical learning at different ages.

3.0.1 Working memory and children's mathematical learning

The relationship between WM and children's mathematical learning has been widely investigated in the light of Baddeley and Hitch's multicomponent model (Baddeley, 1986; Baddeley & Hitch, 1974), which refers to WM as a system that allows both temporary storage and manipulation of information (see also Miyake & Shah, 1999). More in detail, this model includes two passive subordinate modality-dependent systems, the phonological loop and the visuo-spatial sketchpad, responsible for short-term storage of verbal and visuo-spatial information, respectively, alongside with a central executive component involved in coordinating the on-going storage and processing of information in the passive systems, as well as in high-level control, task switching, and monitoring allocation of attentional resources (Baddeley, 1986; Cowan, 2008). Therefore, within the Baddeley and Hitch's WM model it is possible to distinguish between low-control processes used for passively maintaining either verbal or visuo-spatial information, and high-control processes supported by the central executive (see also Cornoldi & Vecchi, 2003; Cowan, 2008).

Several cross-sectional and longitudinal studies showed a strong relationship between WM skills and mathematical development (e.g., Bull, Johnston, & Roy, 1999; De Smedt et al., 2009; Geary, 1993; Mazzocco & Kover, 2007; Passolunghi, Cornoldi, & De Liberto, 1999; Passolunghi & Siegel, 2001, 2004; Swanson, 1993). Indeed, even the simplest mathematical calculations require WM abilities, involving both passive (e.g., temporary storage of problem information, retrieval of relevant procedures) and active (e.g., manipulation of quantity representations and task-relevant information, and processing operations to convert them into numerical output) processes (Bisanz, Sherman, Rasmussen, & Ho, 2005; Geary, 2013; Hitch, 1978; LeFevre, DeStefano, Coleman, & Shanahan, 2005).

However, the nature of the relationship between WM and mathematical learning is likely to vary depending on factors such as task complexity and children’ age and mathematical proficiency (for a review see Raghubar, Barnes, & Hecht, 2010), thus dynamically changing over development (De Smedt et al., 2009; Holmes & Adams, 2006; Klesczewski et al., 2017; McKenzie, Bull, & Gray, 2003; Menon, 2016; Raghubar et al., 2010; Rasmussen & Bisanz, 2005).

3.0.1.1 Working memory domains and mathematical learning

Although previous research has extensively explored the role of verbal and visuo-spatial WM domains in the development of mathematical learning (for a review see Peng, Namkung, Barnes, & Sun, 2016), findings are still inconsistent and unconclusive. More specifically, visuo-spatial WM skills have been found to be strongly related to mathematics not only in preschool years, when children are in the process of acquiring basic number knowledge (e.g., De Smedt et al., 2009; Holmes & Adams, 2006; Kyttälä, Aunio, Letho, Van Luit, & Hautamäki, 2003; McKenzie et al., 2003; Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015), but also during primary school years, by being involved, for example, in the implementation of written calculation procedures and mental arithmetic (e.g., Ashkenazi, Rosenberg-Lee, Metcalfe, Swigart, & Menon, 2013; Bull, Espy, & Wiebe, 2008; Caviola, Mammarella, Lucangeli, & Cornoldi, 2014; Kyttälä & Lehto, 2008; Lee & Kang, 2002; Mammarella, Caviola, Giofrè, & Szűcs, 2017; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014; Trbovich & LeFevre, 2003).

Regarding the contribution of verbal WM domain to the development of mathematical knowledge, findings are especially controversial. Indeed, on the one hand, some studies suggest an increasing involvement of verbal WM skills in mathematical cognition as children grow older (De Smedt et al., 2009; Rasmussen & Bisanz, 2005; Roussel, Fayol, & Barrouillet, 2002), with specific implications in basic fact retrieval (Holmes & Adams, 2006) and mathematical multiple steps tasks such as calculation (Purpura, Schmitt, & Ganley, 2017). On the other hand, however, other research has showed that the contribution of verbal WM is typically more evident during very early stages of mathematical skills acquisition (i.e., ages 4-5), when phonological representations for numbers are still not consolidated and word-based problem-solving competence relies more on reading comprehension. Visuo-spatial WM skills would play an increasingly critical role during later stages of math learning in building quantity representation and efficiently manipulating it during problem solving, generally enhancing math proficiency (Menon, 2016; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Soltanlou, Pixner, & Nuerk, 2015). As a case in point, Szűcs and colleagues (2014) highlighted strong links between visuo-spatial WM skills, but not verbal WM measures, and math abilities in a large sample of 9 year-old children.

With reference to the verbal WM domain, the ability to memorize and process numerical information seems to play a specific role. Actually, studies conducted on children with Mathematical Learning Disability (MLD) showed that performance on verbal WM tasks involving the processing of numerical information (e.g., digit span tasks) is more frequently related to mathematical difficulties than performance on non-numerical verbal WM tasks (e.g., word span tasks) (e.g., Andersson & Lyxell, 2007; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Hitch & McAuley, 1991; Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2001, 2004; Peng, Congying, Beilei, & Sha, 2012; Peng & Fuchs, 2014; Peng et al., 2016). In line with these results, findings from neuropsychological and behavioural studies provide evidence for a neurobiological disassociation between numerical and verbal processing, thus suggesting that numerical and verbal WM domains might be distinct (Cappelletti, Butterworth, & Kopelman, 2001). Specifically, the horizontal segment of the intraparietal sulcus would be mainly activated during tasks involving only numerical information processing (Dehaene, Piazza, Pinel, & Cohen, 2003). Taken together, these findings suggest that numerical-verbal WM processing skills could be critical in predicting children's mathematical development (Peng & Fuchs, 2014). However, to our knowledge, research investigating the different role played by numerical and non-numerical verbal WM domains with respect to the development of math skills focused only on children with MLD, but not reporting on typically developing children.

3.0.1.2 Working memory processes and mathematical learning

In addition to focusing on WM domains, literature has also made a distinction between different WM processes (Cornoldi & Vecchi, 2000, 2003; Cowan, 1988, 1995, 2008; Gathercole & Alloway, 2006; Kail & Hall, 2001; Kintsch, Healy, Hegarty, Pennington, & Salthouse, 1999), suggesting that high-control WM processes requiring concurrent storage, processing, and effortful mental activity, are "active" and entail a main role of the central executive component (Gathercole & Pickering, 2000; Passolunghi & Siegel, 2004; Shah & Miyake, 2005). Conversely, low-control WM processes refer to a "passive" storage system involved in retaining small amounts of information subsequently retrieved without any manipulation (Cornoldi & Vecchi, 2003; Engle, 2002). Whereas dual-tasks involving concurrent storage and manipulation of the temporarily held information are traditionally used to assess high-control processes (Cowan, 1995, 2008; Gathercole & Pickering, 2000), span forward tasks requiring to recall a sequence of verbal or visuo-spatial information in the same order of presentation are typically used to measure low-control WM processes (Colbert & Bo, 2017; Cornoldi & Vecchi, 2003; Engle, 2002).

Previous literature highlights the contribution of high-control WM processes to mathematics both in the early and in the later phases of math learning. In preschool years, high-control WM processes provide scaffolding for building new semantic representations and contribute to emergent foundational math skills (Espy et al., 2004; Passolunghi &

Lanfranchi, 2012). At subsequent stages, in primary school, such processes support performance on single-digit addition arithmetic tasks and rule-based arithmetic word problems, through the active maintenance of intermediate results, and foster transitions from more basic (e.g., counting) to more complex (e.g., decomposition) arithmetic procedures and solution strategies (De Smedt et al., 2009; DeStefano & LeFevre, 2004; Geary, Hoard, & Nugent, 2012; Imbo & Vandierendonck, 2007; Menon, 2016; Passolunghi, 2012; Passolunghi & Pazzaglia, 2004; Passolunghi, Vercelloni, & Schadee, 2007; Swanson, 2006; Swanson & Kim, 2007).

Regarding the link between low-control WM processes and math knowledge, results are more inconsistent. On one side, some studies did not find a significant relation between low-control WM skills and mathematical achievement neither in preschoolers (e.g., Passolunghi & Lanfranchi, 2012) nor in primary school (e.g., Imbo & Vandierendonck, 2007). On the other side, an involvement of low-control WM skills emerged in counting (Logie & Baddeley, 1987) and calculation procedures requiring the temporary storage of information, but not carrying or borrowing operations (Fürst & Hitch, 2000) as well as in predicting primary school children's problem-solving accuracy (Fung & Swanson, 2017).

Taken together, these patterns of relations suggest that the relative contributions of different WM domains and processes may change dynamically over time depending on children's age, developmental stage, and expertise. However, it remains unclear which are the relative contributions of different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and WM processes (i.e., high-control and low-control) to mathematical knowledge, specifically before and after the onset of formal education.

3.1 The present study

This study had a two-fold aim. Firstly, we sought to explore the contribution of different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) to early mathematical knowledge at the transition between preschool and primary school. In line with previous studies (e.g., De Smedt et al., 2009; Holmes & Adams, 2006; McKenzie et al., 2003; Rasmussen & Bisanz, 2005), we hypothesized a stronger relation between the visuo-spatial WM domain and mathematics among preschoolers than first grades, with an increasing involvement of the verbal WM domain in first grade. Based on previous studies on MLD children (Andersson & Lyxell, 2007; Hitch & McAuley, 1991; Peng & Fuchs, 2014; Peng et al., 2016; Siegel & Ryan, 1989), we also expected a crucial contribution of the numerical-verbal WM domain in predicting early math knowledge in both age groups.

Secondly, we sought to unravel the contribution of different WM processes (i.e., low-control and high-control) to early mathematical knowledge, with the expectation of a greater role of low-control processes among preschoolers, i.e., prior to children's exposure to formal schooling, and an increasing involvement of high-control processes among first graders as compared to preschoolers. This hypothesis is rooted in evidence on the development of Executive Functions (EFs), generally associated to the parallel maturation of the frontal lobes, in children at around age six, at the beginning of exposure to formal education (Anderson, 2001; Engle, Tuholski, Laughlin, & Conway, 1999).

3.2 Method

3.2.1 Participants

Participants were 176 children (66 preschoolers: M_{age} = 51.82 months, *SD* = 5.02, age range: 42-61 months, 30 females; 110 first graders: M_{age} = 80.09 months, *SD* = 3.68, age range: 72-89 months, 57 females), recruited through five schools located in different urban areas of north-eastern Italy serving middle socioeconomic background families. All children were Caucasian and fluent Italian speakers, and none had a diagnosis for a developmental disorder or reported vision or hearing problems.

3.2.2 Procedure

Formal consent was provided by the headmasters of the schools involved in the research and from children's teachers and parents/guardians. Children also gave verbal assent before being assessed. Testing was carried out over a two-month period, involving the assessment of WM skills and early mathematical knowledge. Each child was tested individually in a quiet room at school without distracting stimuli on two separate sessions lasting approximately 15 min each. The order of administration of the tasks was counterbalanced across participants.

3.2.3 Measures

3.2.3.1 Working memory. Six tasks were used to assess WM skills:

Verbal low-control WM. To assess verbal low-control WM skill, we administered the *word forward recall task* (Lanfranchi, Cornoldi, & Vianello, 2004). Participants were presented with a series of familiar two-syllable words and required to recall and repeat them in the same order of presentation. There were two word-lists for each span length (from two to five), for a total of eight trials. The children's answer was considered correct when all items were recalled in the right order (expected range 0-8).

Verbal high-control WM. Verbal high-control WM skill was tested using the *verbal dual task* (Lanfranchi, Baddeley, Gathercole, & Vianello, 2012; Lanfranchi et al., 2004; Lanfranchi, Jerman, & Vianello, 2009). Children were presented with a list of two to five two-syllable words and asked to both remember the first word on the list and tap on the table when the target word *palla* (ball) was pronounced by the researcher. The task had four different levels of difficulty depending on the list's length (two, three, four, or five words), for a total of eight trials. A score of one was given when both the initial word of the series was remembered correctly and the secondary task (i.e., tapping) was performed (expected range 0-8).

Numerical-verbal low-control WM. To measure numerical-verbal low-control WM skill, we used the *digit forward recall task* (from TEMA; Reynolds & Bigler, 1994). Children were presented with a series of single digits and required to recall and repeat them in the same order of presentation. The test was composed by 18 trails, two for each of the nine levels of difficulty (two- to 10-digit spans). A score of one was given for each number recalled in the correct position (expected range 0-108).

Numerical-verbal high-control WM. Numerical-verbal high-control WM skill was assessed using the *digit backward recall task* (from TEMA; Reynolds & Bigler, 1994). Participants were presented with a series of digits and required to recall them in reverse order. The test was composed by 16 lists, two for each of the eight levels of difficulty (two- to nine-digit spans). A score of one was given for each number recalled in the correct position (expected range 0-88).

Visuo-spatial low-control WM. To evaluate visuo-spatial low-control WM skill, we used the *pathway forward recall task* (Lanfranchi, Carretti, Spanò, & Cornoldi, 2009; Lanfranchi et al., 2004). Children were shown a path taken by a small frog on a matrix and asked immediately afterwards to recall the pathway by moving the frog from square to square, reproducing the experimenter’s moves. There were four levels of difficulty depending on the number of jumps along the frog’s path and the size of the chessboard (3 × 3 in the first level with two jumps and 4 × 4 in the other levels, with three, four, and five jumps, respectively), for a total of eight trials. There was one point awarded for each path recalled correctly (expected range 0-8).

Visuo-spatial high-control WM. Visuo-spatial high-control WM skill was tested using the *visuo-spatial dual task* (Lanfranchi et al., 2004, 2009a). Participants were shown a path taken by a small frog on a 4 × 4 matrix containing one red square. Children had to remember the frog's starting position along each path and they also needed to tap on the table when the frog moved onto the red square. The task had four different levels of difficulty depending on the number of times the frog jumped (i.e., two, three, four, or five), for a total of eight trials. A score of one was given when both the first position of the pathway was remembered correctly and the secondary task (i.e., tapping) was performed (expected range 0-8).

All six WM tasks were administered using a classic self-terminating procedure whereby, starting with the easiest trials, the tasks became progressively more difficult and participants continued as long as they were not able to correctly perform the two trials of the same level of difficulty.

3.2.3.2 Early mathematical knowledge. To assess early mathematical knowledge, we used the *Early Number Concepts* subtest from the British Ability Scales (BAS3; Eliot & Smith, 2011). This task consisted of 30 items evaluating different aspects of children's early mathematical competence, such as counting abilities, number concepts, quantitative understanding, and simple arithmetic. The items were scored by awarding one point for a correct answer and no points for a wrong answer (expected range 0-35). The subtest was administered using a self-terminating procedure, whereby the task was interrupted after five consecutive errors.

3.3 Data analyses

Univariate descriptive statistics and bivariate correlations among the study variables were calculated using SPSS 25. A multigroup path analysis was then conducted with Mplus 8.3 to compare the patterns of relations between different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) and early mathematical knowledge among preschoolers and first graders. Specifically, the multigroup approach allows to determine whether the contribution of each WM domain and process to math knowledge (i.e., verbal low-control, verbal high-control, numerical-verbal low-control, numerical-verbal high-control, visuo-spatial low-control, and visuo-spatial high-control) differs across the two age groups. The analysis consisted of three steps. In the first step (Model 1) we estimated a model in which all the paths linking single high-and low-control WM processes to math knowledge were allowed to freely vary between the two groups (i.e., fully variant model). In the second step (Models 2 to 7) we then estimated a set of partially invariant models, in which we constrained one path at a time to be equal across age groups, and evaluated how such constraints affected model fit. If fit indices remained unchanged, the more constrained model could be retained as equally informative (but more parsimonious) than the baseline model, and the path could be assumed to be invariant across the two age groups. If constraining a path to equality resulted in poorer fit, then the path should be assumed as differing significantly between groups. In case more than one path emerged as invariant across groups from Models 2 to 7, we would estimate a further partially invariant model (Model 8) in which all the potentially invariant paths were simultaneously fixed to be equal for preschoolers and first graders. Finally, in the third step of analysis (Model 9), we forced all paths to be equal across preschoolers and first graders (i.e., fully invariant model).

To evaluate the goodness of fit of the models, the χ 2 statistic, the Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA) were taken into account. Non significant χ 2 values are retained as indicative of acceptable fit. As for CFI, values >.90 and >.95 are associated with acceptable and good fit, respectively (Schermelleh-Engel, Moosbrugger, & Müller, 2003). As regards RMSEA, values <.06 can be considered as a good fit, whereas values between .06 and .08 are thought to reflect an adequate fit (Schermelleh-Engel et al. 2003). Akaike Information Criterion (AIC) can be interpreted only comparatively, with lower values suggesting better fit. To assess differences in model fit between the tested models (i.e., fully variant, partially invariant, and fully invariant), the ΔCFI and the ΔRMSEA criterion (Cheung, 2007) were adopted. In addition, we also compared the AIC values of the more restrictive and the less restrictive models. Although χ 2 values were reported, we gave priority to differences in CFI, RMSEA, and AIC to evaluate competing models, as the χ 2 statistics is sensitive to violations of normality assumptions and sample size (Chen, 2007). A lowering of .010 or more in CFI, an increase of .015 or more in RMSEA, and an increase of 2 points or more in AIC, would indicate that the more restrictive model (i.e., the model in which more parameters are fixed to be equal across groups) fits the data significantly less well than the less constricted model (Chen, 2007; Schermelleh-Engel et al. 2003).

3.4 Results

Descriptive statistics, reliability measures, and intercorrelations among study variables are presented in Tables 3.1 and 3.2, separately for preschoolers and first graders. It should be noticed that, at the bivariate level, all the investigated WM skills were significantly correlated with early mathematical knowledge in both age groups, except for verbal low-control WM in preschoolers and visuo-spatial low-control WM in first graders.

Table 3.1 Descriptive statistics, reliability measures, and inter-correlations between all variables for preschoolers (*n* = 66).

	Descriptive statistics							*Zero-order correlations*						
	M	*SD*	Min	Max	Skewness	Kurtosis	Reliability	2.	3.	4.	5.	6.	7.	8.
1. Age (in months)	51.82	5.02	42	61	-0.13	-0.99	-	.15	.07	.36**	.26*	.23	.38**	.44***
2. Verbal low-control WM	4.05	0.92	2	6	0.28	-0.49	.88	-	.16	.23	.10	.57***	.29*	.21
3. Verbal high-control WM	1.91	1.73	0	6	0.61	-0.39	.84	-	-	.37**	.38**	.27*	.32**	.29*
4. Visuo-spatial low-control WM	4.73	1.57	0	8	-1.02	2.07	.79	-	-	-	.28*	.24	.35**	.49***
5. Visuo-spatial high-control WM	2.52	2.14	0	8	0.53	-0.61	.81	-	-	-	-	.23	.49***	.35**
6. Numerical-verbal low-control WM	11.20	4.51	2	24	0.59	0.60	.87	-	-	-	-	-	.51***	.49***
7. Numerical-verbal high-control WM	2.39	3.65	0	14	1.58	1.78	.85	-	-	-	-	-	-	.68***
8. Early mathematical knowledge	14.52	5.80	2	27	0.09	-0.75	.84	-	-	-	-	-	-	-

Note. *M* = mean; *SD* = standard deviation; Min = minimun; Max = maximum.

**p*≤.05, ***p*≤.01, ****p*≤.001.

Table 3.2 Descriptive statistics, reliability measures, and inter-correlations between all variables for first graders (*n* = 110).

	Descriptive statistics							*Zero-order correlations*						
	M	*SD*	Min	Max	Skewness	Kurtosis	Reliability	2.	3.	4.	5.	6.	7.	8.
1. Age (in months)	80.09	3.68	72	89	0.14	-0.76	-	.16	.14	.09	.17	.13	-.04	.11
2. Verbal low-control WM	5.13	1.12	0	8	-0.82	3.59	.89	-	.26**	.19*	.14	.62***	.27**	.46***
3. Verbal high-control WM	2.50	2.22	0	8	0.68	-0.76	.86	-	-	.19*	.48***	.26**	.31***	.28**
4. Visuo-spatial low-control WM	6.26	1.77	0	8	-1.74	3.44	.77	-	-	-	.24*	.21*	.31***	.18
5. Visuo-spatial high-control WM	3.14	2.59	0	8	0.39	-1.29	.80	-	-	-	-	.13	.26**	.32***
6. Numerical-verbal low-control WM	22.33	8.11	2	50	0.76	0.80	.87	-	-	-	-	-	.36***	.47***
7. Numerical-verbal high-control WM	10.40	4.67	1	24	0.34	0.16	.83	-	-	-	-	-	-	.48***
8. Early mathematical knowledge	28.76	3.35	17	35	-0.79	1.45	.94	-	-	-	-	-	-	-

Note. *M* = mean; *SD* = standard deviation; Min = minimun; Max = maximum.

*$p \leq .05$, **$p \leq .01$, ***$p \leq .001$.

3.4.1 Multigroup analyses

Fit indices for all the estimated models are reported in Table 3.3. In the first step of analysis we estimated a fully variant model (Model 1), in which all the paths were free to vary across age groups. The model was saturated, and was kept as the reference point for model comparisons.

Table 3.3 Fit indices and comparison of multigroup path models with different equality constraints in predicting early mathematical knowledge for preschoolers (*n* = 66) and first graders (*n* = 110).

	Fit indices					Model comparison (vs. Model 1)		
	χ2(*df*)	*p*-value	CFI	RMSEA [90%CI]	AIC	ΔCFI	ΔRMSEA	ΔAIC
Fully variant model								
Model 1 – all free	0.000	1.000	1.000	0.000 [0.000-0.000]	5707.558	-	-	-
Partially variant models								
Model 2 – verbal low-control WM	4.874(1)	.027	0.965	0.210 [0.057-0.411]	5711.582	0.035	0.210	4.024
Model 3 – verbal high-control WM	0.013(1)	.907	1.000	0.000 [0.000-0.418]	5705.571	0.000	0.000	-1.987
Model 4 – visuo-spatial low-control WM	8.835 (1)	.003	0.928	0.298 [0.141-0.492]	5715.823	0.072	0.298	8.335
Model 5 – visuo-spatial high-control WM	1.190(1)	.275	0.998	0.046 [0.000-0.292]	5706.654	0.002	0.046	-0.904
Model 6 – numerical-verbal low-control WM	2.625 (1)	.105	0.985	0.136 [0.000-0.348]	5708.546	0.015	0.136	0.988
Model 7 – numerical-verbal high-control WM	12.581(1)	<.001	0.894	0.363 [0.203-0.553]	5715.107	0.106	0.363	7.549
Model 8 – verbal and visuo-spatial high-control WM	4.874(2)	.027	1.000	0.000 [0.000-0.158]	5704.821	0.000	0.000	-2.737
Fully invariant model								
Model 9 – all constrained	66.288 (6)	<.001	0.457	0.310 [0.245-0.381]	5752.768	0.543	0.310	45.210

Note. *df* = degrees of freedom; CFI = Comparative Fit Index; RMSEA = Root Mean Square Error of Approximation; CI = Confidence interval; AIC = Akaike Information criterion.

As evident from Table 3.3, results for partially invariant models (Models 2 to 7) vary across WM skills. Constraining to equality across groups the path linking verbal high-control WM (Model 3) to math knowledge did not result in poorer model fit. As regards visuo-spatial high-control WM (Model 5), the equality constrain lead to a difference that might be indicative of non invariance (i.e., >.015) in RMSEA (.046), but not in CFI (<.010) and AIC (<2). Moreover, all the fit indices of the constrained model indicated good-to-excellent fit, thus suggesting that the parameter may be regarded as invariant across groups. To the contrary, all the remaining models displayed inadequate fit indices when the relative paths were constrained, thus suggesting that verbal low-control WM (Model 2), visuo-spatial low-control WM (Model 4), numerical-verbal low-control WM (Model 6), and numerical-verbal high-control WM (Model 7) contribute to math knowledge to a different extent depending on whether children attended to preschool or first grade. Based on these findings, we also estimated a further partially invariant model (Model 8), in which both verbal and visuo-spatial high-control WM were simultaneously set as equally contributing to math knowledge for both groups. The resulting model had an excellent fit to the data, and fit indices did not worsen as compared to the saturated fully variant model.

In the final step of analysis, we estimated a fully invariant model (Model 9). However, as predictable given the numerous differences emerged in the previous steps of analysis, fit indices for the fully invariant model, in which all the paths from different WM skills to math knowledge were forced to be equal across the two groups, were non acceptable, thus indicating that the assumption that different WM domains and processes equally contribute to math knowledge among preschoolers and first graders is not tenable. In sum, results show that a partially invariant model (Model 8) should be retained as the best fitting and more parsimonious representation of the data.

Final estimates from Model 8 are presented in Table 3.4 and highlight that whereas visuo-spatial low-control and numerical-verbal low-control WM predict early math knowledge among preschoolers, but not among older students, verbal low-control WM emerged as significant predictor only among first graders, but not among preschoolers. Numerical-verbal WM was found to predict math knowledge to a much larger extent among preschoolers than among first graders. Among the latter group, for instance, the association between numerical-verbal low-control WM and math fell slightly short of significance. Finally, as regards the paths constrained to be equal across groups, verbal high-control WM was found to have a null relation with math knowledge, whereas the contribution of visuo-spatial high-control WM emerged as positive and significant for both preschoolers and first graders.

Table 3.4 Multigroup path model estimates for paths linking WM domains and processes to early mathematical knowledge for preschoolers (*n* = 66) and first graders (*n* = 110) (Model 8).

	Preschoolers				First graders			
	Estimate (*SE*)	95%CI [lower/upper]	β	*P*	Estimate (*SE*)	95%CI [lower/upper]	β	*p*
Verbal low-control WM	-0.927 (0.766)	[-2.428/0.574]	-0.146	.226	0.736 (0.307)	[0.134/1.338]	0.247	.017
Verbal high-control WM	**-0.021** **(0.109)**	**[-0.235/0.194]**	**-0.006**	**.850**	**-0.021** **(0.109)**	**[-0.235/0.194]**	**-0.014**	**.850**
Visuo-spatial low-control WM	1.054 (0.269)	[0.527/1.581]	0.284	<.001	-0.080 (0.147)	[-0.368/0.207]	-0.043	.584
Visuo-spatial high-control WM	**0.215** **(0.092)**	**[0.034/0.395]**	**0.079**	**.020**	**0.215** **(0.092)**	**[0.034/0.395]**	**0.166**	**.020**
Numerical-verbal low-control WM	0.334 (0.142)	[0.055/0.613]	0.258	.019	0.081 (0.042)	[-0.001/0.163]	0.198	.052
Numerical-verbal high-control WM	0.722 (0.121)	[0.485/0.959]	0.451	<.001	0.228 (0.065)	[0.101/0.354]	0.319	<.001
*R*2	.400			<.001	.573			<.001

Note. Bold indicates paths constrained to be equal across age groups.

In a nutshell, while visuo-spatial low-control WM significantly predicted early math knowledge only among preschoolers, verbal low-control WM was a significant predictor only among first graders. Instead, the contribution of visuo-spatial high-control WM emerged as significant for both age groups, as well as numerical-verbal WM was found to predict math knowledge in both preschoolers and first graders, although to a greater extent among the first ones. Overall, the partially invariant models accounted for 57.3% of variance for math knowledge among preschoolers, and 40.0% among first graders. A summary of the significant predictors in the two age groups from Model 8 is given in Table 3.5.

Table 3.5 A summary of the significant predictors in the two age groups from Model 8.

Predictors	**Preschoolers**	**First graders**
Verbal low-control WM	-	X
Verbal high-control WM	-	-
Visuo-spatial low-control WM	X	-
Visuo-spatial high-control WM	X	X
Numerical-verbal low-control WM	X	-
Numerical-verbal high-control WM	X	X

3.5 Discussion

The current study examined the role of WM skills in predicting early mathematical knowledge, by comparing a group of children in the final year of preschool to a group of first graders. More in detail, we investigated the contributions of different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) to early mathematics before and after the onset of formal education.

Overall, our results showed a variation in the role of both WM domains and processes in predicting early mathematical knowledge depending on children’s developmental stage.

Specifically, in line with our hypothesis, we found that visuo-spatial WM domain was more strongly associated to mathematics in preschoolers than in first graders. In fact, while both low- and high-control visuo-spatial WM skills significantly predicted math performance among preschoolers, only high-control visuo-spatial WM was predictive of early mathematical knowledge among first graders. Moreover, in line with what was expected, as regards verbal WM domain, low-control verbal WM skill emerged as a significant predictor of math only among first graders, but not among preschoolers. These age-related differences may suggest that children in the final preschool year heavily rely on visuo-spatial representations of number and quantity (e.g., finger counting or number line) when performing math tasks (Hitch, Halliday, Schaafstal, & Schraagen, 1988; Rasmussen & Bisanz, 2005), while children in primary school may rather rely more on verbal WM strategies (e.g., verbally retrieve arithmetic facts or memorize the associations between math problems and their solutions) (De Smedt et al., 2009; Hecht, Torgesen, Wagner, & Rashotte, 2001; Rasmussen & Bisanz, 2005; Roussel et al., 2002; Swanson & Kim, 2007). The fact that only low-control verbal WM (and not the high-control one) emerges as a significant predictor of first graders' math knowledge could be due to the specific math domain examined in our study (e.g., performing additions and subtractions) (for the *math domain specificity* explanation see Van de Weijer-Bergsma et al., 2015).

As expected, the numerical-verbal WM domain played a significant role in both age groups, but it was found to predict early mathematical knowledge to a much larger extent among preschoolers than among first graders. This finding adds to the existent body of research by providing new insight into the specific contribution of numerical-verbal WM skills, suggesting that the ability to remember and manipulate numerical information while performing mathematical tasks is crucial not only in children with MLD, as already highlighted by prior research (Andersson & Lyxell, 2007; Hitch & McAuley, 1991; Passolunghi &

Cornoldi, 2008; Passolunghi & Siegel 2004; Peng et al., 2016; Siegel & Ryan, 1989) but also in typically developing children, before and after the onset of formal education. This evidence further supports the theory of “domain specificity” of WM (Ericsson & Kintsch, 1995; Peng et al., 2016; Unsworth & Engle, 2007), according to which the operation of WM depends on the specific domain of knowledge considered. Although we do recognize that in both numerical-verbal WM and math tasks children process the same type of material, that is numerical stimuli, we believe that numerical-verbal WM domain, integrating domain-specific skills, knowledge, and procedures to meet the demands of numerical WM tasks, is very specific and, as such, should be distinguished from the verbal one (see also Oakhill, Yuill, & Garnham, 2011; Peng et al., 2017).

Concerning the relationship between different WM processes and early mathematical knowledge, in line with what was assumed, our results revealed on the one hand a significant contribution of both low- (i.e., passive) and high-control (i.e., active) WM skills among preschoolers, and, on the other hand, a leading role of high-control WM, supported by the central executive component, over that of low-control WM among first graders. More specifically, both visuo-spatial high- and low-control WM processes and numerical-verbal high- and low-control WM processes significantly predicted preschoolers’ math performance, while significant predictors of first graders’ early mathematical knowledge were verbal low-control and both visuo-spatial and numerical-verbal high-control WM processes. In brief, then, the contribution of visuo-spatial and numerical-verbal high-control WM skills emerged as positive and significant for both preschoolers and first graders, whereas verbal high-control WM was found to have a null relation with early mathematical knowledge in neither of the two age groups. The latter result could be due to the type of task used to assess verbal high-control WM skills (i.e., a verbal dual task) which may still have been too difficult for both preschoolers and first graders. Taken together, these findings are in line with previous research suggesting the separability of low-control and high-control WM skills as distinct precursors of early mathematical learning (Cowan, 1995; Passolunghi et al., 2007; Shah & Miyake, 2005; Swanson, 2006), and also reflect the development of EFs, generally associated to the parallel maturation of the frontal lobes, in children at around age six, when it starts the exposure to formal education (Anderson, 2001; Engle et al., 1999).

The present study, however, is not without limitations. Firstly, it provides a cross-sectional perspective on the relations between different WM domains and processes and early mathematical knowledge. A longitudinal design would be needed to dynamically investigate changes in these links in response to children's cognitive development and level of education. Secondly, in the current research we assessed only WM skills and math performance, without taking into account the potential role of either children's other cognitive abilities such as domain-general intelligence level or other EFs or environmental factors like parents' education. Moreover, we tested early mathematical knowledge through a subtest that simultaneously taps into different aspects of math competence, thus providing a measure of general math achievement. In this respect, future studies might consider introducing more fine-grained measures to assess specific children's abilities related to early mathematical knowledge (e.g., number line or Approximate Number System tasks) in order to better account for the complexity of numerical processing and draw a clearer and more complete picture of the relations between WM and different mathematical skills before and after the onset of formal education.

From an educational point of view, our results provide useful information for the development of age-appropriate and effective training interventions that, already from preschool onwards, could be aimed at promoting early enhancement of WM skills and, at the same time, preventing the onset of difficulties in math learning. For example, a WM training mainly focused on both low- and high-control visuo-spatial WM skills could be more effective in the final preschool year, while activities tapping primarily high-control WM processes might be more useful in first grade. Moreover, numerical-verbal WM skills, especially the high-control ones, could represent a fruitful target for training interventions and early detection of children at risk for mathematical difficulties already in preschool years.

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Chapter 4

Executive Functions and math abilities in highly deprived contexts

Pellizzoni, S., Apuzzo, G. M., De Vita, C., Agostini, T., Ambrosini, M., & Passolunghi, M. C. (under review). Exploring EFs and math abilities in highly deprived contexts. *Frontiers in Psychology*.

Abstract

Executive Functions (EFs)' development is critically affected by childhood adversity exposure. Although recent studies underlined the deleterious effects of early life stresses on Working Memory (WM) and inhibitory control, they were scarcely investigated in war context especially in relation with learning abilities.

In order to fill this gap, we designed a research with the aim to evaluate EFs together with early math skills. In particular, we conducted a study involving 150 children divided into three groups: 48 Yazidis (M_{age} = 71 months, *SD* = 6.59), 47 Syrian refugees (M_{age} = 68.77 months, *SD* = 7, age), and 55 Italians (M_{age} = 68.65 months, *SD* = 2.88) attending the third year of kindergarten in Italy or inserted in Psyco-Social-Support activities in Iraq. The children were evaluated with a variety of tasks assessing WM, inhibition, counting, digit-quantity mapping, and digit naming skills.

The results indicated substantial differences both in EFs and early numerical abilities between the deprived groups and the Italian children. Data are discussed in terms of implications for children both exposed to mainstream school environments and living in socio-economically disadvantaged and deprived contexts.

4.0 Introduction

Early exposure to deprived environments, deviating considerably from the care that is typical for children, may represent a risk factor for negative longer-term outcomes and lasting alterations at both cognitive, social-emotional, and behavioral level (Merz, Harlé, Noble, & McCall, 2016). Experience-expectant models of development suggest that, for typical neural development to proceed, expected environmental input, such as the presence of a sensitive and responsive attachment figure, adequate physical resources (e.g., nutrition) as well as social and linguistic stimulation matched to child's developmental stages and needs, must be provided at certain sensitive periods (Marshall & Kenney, 2009). A recent review of the literature confirms that early adverse experiences get "under the skin" with specific effects on hypothalamic-pituitary-adrenal axis, level of inflammation and brain functioning (Danese & McEwen, 2012). More specifically, in relation to the brain activities, literature shows the deleterious effects of maltreatment (McCrory, De Brito, & Viding, 2011) and toxic early life stresses during childhood (see Shonkoff, Boyce, & McEwen, 2009) on the development and functioning of three areas known to be highly sensitive to psychosocial stress: amygdala, hippocampus, and prefrontal cortex (PFC). PCF, in particular, is considered the neural substrate of Executive Functions (EFs) (McEwen & Morrison, 2013).

EFs are defined as a set of interrelated top-down mental processes crucial for goal-directed activities. These functions allow individual to 1) hold, update, and actively manipulate information in mind, 2) inhibit inappropriate responses, 3) show flexibility in strategies, ideas, and activities (see Miyake & Friedman, 2012; Miyake & Shah, 1999; Zelazo & Müller, 2002). These cognitive functions start to emerge relatively early in life with rapid development during the preschool years and early school-age (Best & Miller, 2010; Garon, Bryson, & Smith, 2008; Zelazo, Blair, & Willoughby, 2016). EFs are described referring to specific developmental stages and trajectories involving first "low level EFs" (working memory - WM - and inhibition), then “intermediate level EFs” (cognitive flexibility) ending up with “high level EFs” (reasoning, problem solving, and planning) (see Diamond, 2013) and they seem to differentiate as separate skills around the end of the preschool period (e.g., Clark et al., 2014; Fuhs & Day, 2011). Considering this progression of development, WM and inhibition skills, developing earlier compared to other EFs abilities, seem to be particularly vulnerable to early deprivation (Garon et al., 2008; Jurado & Rosselli, 2007).

EFs have been extensively investigated in children (for a review see Garon et al., 2008), resulting significantly related to learning abilities on both reading and math, overall school achievement (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm 2009; Bull, Espy, & Wiebe, 2008; Bull & Lee, 2014; Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010), as well as to later academic outcomes (e.g., McClelland et al., 2014). By means of a cascade effect, EFs are broadly considered fundamental for the acquisition and mastering of more complex skills, such as early mathematical abilities (e.g., Bull et al., 2008; Bull & Scerif, 2001; Espy et al., 2004). More specifically, previous studies conducted on typically developing children showed that both high-control and low-control WM skills predicted numerical competence in preschool and primary school both directly (e.g., Bull et al., 2008; Passolunghi & Lanfranchi, 2012) and indirectly (e.g., Krajewski & Schneider, 2009). Similarly, inhibition during the preschool years accounted for variability in children's early math achievement one year after school entry (see Clark et al., 2010).

Taken together, these pieces of information seem to indicate that early adversity crucially undermines domain-general skills (i.e., EFs) which, in turn, are associated with achievement abilities. Studies on the field confirm that institutionalized children show poorer levels of inhibition and WM (Merz et al., 2016), as well as children diagnosed with maltreatment-related Post-Traumatic Stress Disorder[4] (PTSD) reveal more distractibility and lower sustained visual attention (Beers & De Bellis, 2002). Furthermore, familial trauma is found to have an effect on EFs'composite score, including performance in WM, inhibition, auditory attention and processing speed tasks (DePrince, Weinzierl, & Combs, 2009). Moreover, a growing number of studies has investigated the specific effects of living conditions characterized by disadvantaged or deprived socio-economic contexts and poverty on EFs' development in children (e.g., Blair et al., 2011; Evans & Fuller-Rowell, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010).

Likewise, previous research has showed that low-income children, living in more disadvantaged socio-economic contexts, and thus receiving less stimuli for mathematical development, perform worse and progress at a slower rate than their middle-income counterparts in mathematics achievement during both preschool and primary school (e.g., Bowman, Donovan, & Burns, 2001; Denton & West, 2002; Natriello, McDill, & Pallas, 1990; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Starkey, Klein, & Wakeley, 2004). This socioeconomic-related gap in children's numerical cognition is already evident very early, during the pre-kindergarten year (Ginsburg & Russell, 1981; Jordan, Huttenlocher, & Levine, 1992, l994; Sarama & Clements, 2009). In this regard, a series of studies on the home learning environment suggest that there are socio-economic status (SES) - related differences in both the frequency and breadth of parental activities and number-related experiences directed at supporting early mathematical development, thus impacting on preschool children's math competence (Baker, Street, & Tomlin, 2006; Berkowitz et al., 2015; Ramani & Siegler, 2008, 2014; Siegler & Ramani, 2008).

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[4] Post-Traumatic Stress Disorder is the most prevalent psychopathological consequence of exposure to traumatic events, characterized by the persistence of intense reactions to reminders of the triggering event, a pervasive sense of imminent threat, hypervigilance, disturbed sleep, and alteration of mood and cognition (see Shalev, Liberzon, & Marmar, 2017).

However, literature on EFs and mathematical development is surprisingly lacking on children living in war-affected contexts, and related refugee conditions, despite the enormous relevance and topicality of these issues in contemporary society. According to a recent survey, in fact, approximately one in six children today lives in a war context (Save the Children International, 2018), characterized by inadequate physical resources, life-threatening conditions, lack of social and cognitive stimulation, and in some cases loss of close family members and continuous violence, as well as a huge number of children (seventy-one million, UNHCR, 2019) is currently displaced in the world and at a potential risk of cognitive disadvantage and mental illness. Considering this state of art, it is critical to organize evidence-based interventions targeted for specific deprived life conditions.

A recent study on Yazidi children indicated that preschoolers, living in a critically adverse context, show lower scores in hot and cool EFs tasks, in particular in delay of gratification and inhibition abilities, with a specific effect on motor (Circle Drawing task) and prevalent response (Day and Night Stroop task) control (Pellizzoni, Apuzzo, De Vita, Agostini, & Passolunghi, 2019), thus confirming previous developmental research (Mertz et al., 2016). On the other hand, a study conducted by Chen and colleagues (2019) underlines a specific effect of poverty, but not violence, on WM. These findings highlight the importance of carefully distinguishing between types of childhood adversity exposure (e.g., violence and poverty) in order to identify the specific relevant neurocognitive pathways underlying children’s cognitive functioning as well as their psychosocial well-being.

4.1 The present study

In the light of this state of art, showing the disrupting effects that stressful experiences have on the development of EFs as well as the direct and indirect influences of EFs on early mathematics achievement, the aim of this study was to explore the signature of living in highly deprived environments (i.e., war context and refugee condition) on children’s EFs and early mathematical abilities, by comparing three groups of preschoolers coming from different socio-cultural and economic backgrounds (i.e., Yazidis, Syrian refugees, and Italians). In particular we expected to: (a) confirm the relation between deprived living environments, specifically focusing on war context and refugee condition, and poor EFs, already found in literature (e.g. Merz et al., 2016; Pellizzoni et al., 2019; Welsh et al., 2010); (b) observe lower early mathematical skills in children exposed to specific deprived environments (i.e., war context and refugee condition) at an early age.

4.2 Method

4.2.1 Participants

Participants were 150 children divided into three groups: 48 Yazidis (M_{age} = 71 months, *SD* = 6.59, age range: 62-80 months, 24 females), 47 Syrian refugees (M_{age} = 68.77 months, *SD* = 7, age range: 60-80 months, 24 females), and 55 Italians (M_{age} = 68.65 months, *SD* = 2.88, age range: 62-72 months, 28 females). Yazidis are a Kurdish religious minority found primarily in northern Iraq, southeastern Turkey, and northern Syria; the majority of Yazidis live in northern Iraq and they have suffered numerous atrocities perpetrated by ISIS that are described as genocide (United Nations Human Rights Council, 2016, June 15, 32nd session); most of them are currently internally displaced people (IDPs). On the other hand, the sample of refugees included children from different areas of Syria living in refugee camps specifically organized to accommodate them.

The data were collected in the HARSHAM Camp, close to the city of Erbil, that hosts mainly Syrian refugees together with IDPs, and in the Bajid Kandala Camp, closed to the city of Dohuk, hosting mainly IDPs belonging to Yazidis’ community, who survived the genocide. Both Camp facilities include tents and prefabricated shelters and containers, and they offer internal activities destined to preschoolers focused on promoting aggregation and socialization among the children and including playing together, respecting simple roles, painting, and enhancement of motor abilities. Some activities are led by adults while others are freely organized by the children. Participation is spontaneous, and, generally, children attending activities are the most favourably disposed to participate, play and stay together with other children. Italian children were recruited from three preschools located in different urban areas of northern Italy, serving middle SES families. None of the participants displayed developmental delay or reported learning difficulties.

4.2.2 Procedure

Consent to participate in the research was obtained from children' teachers and parents and participants also gave verbal assent before being tested. Children's assessment was conducted in a single session, lasting approximately 30 minutes, involving the evaluation of EFs skills (i.e., low-control and high-control WM, and inhibition) and early mathematical abilities (i.e., forward and backward counting, digit-quantity mapping, and digit naming). Children were tested individually in a quiet room without distracting stimuli. The order of tasks presentation was counterbalanced across participants. In the Italian sample, evaluation was carried out by two experimenters (female Italian master students), while in the other two cases (i.e., Yazidis' and Syrian refugees' groups) testing was guided by two social workers (one male and one female) in Arabic (for Syrian refugees) and Kurdish Badini (for Yazidis).

In math-related use of words, the Arabic and Italian languages have a very similar structure: for example, the term naming the number 11 (eleven) includes both components, ten+one; therefore, in these two cases, the use of the number words has a quite regular structure. Yazidi minority group use - both as spoken and written language - the Kurdish Badini, though they know and speak both Arabic and other variants of Kurdish. Given the fact that children were less familiar with Arabic than with Badini, and in order not to create other potentially confounding factors associated with less frequent use of Arabic language, Yazidi children were tested in Badini. The latter has completely novel words for eleven and fifteen while the other number words have a regular structure.

The data collectors were from the same language/cultural background of the children, and native speakers of the participants' language. In order to guarantee a reliability between data collectors, we provided a training on the consequences of trauma on behavior and cognitive abilities, specifically on EFs, also clarifying the importance of such skills for children's development, and we described tools that could provide a specific cognitive evaluation. Moreover, data collectors were trained directly in the field, supervised by an expert researcher, on how to evaluate a child and how to report the results.

4.2.3 Measures

4.2.3.1 Executive Functions.

Low-control working memory. To assess low-control WM skills, we used the forward word span task (Lanfranchi, Cornoldi, & Vianello, 2004). Children were presented with sequences of two to five words and were asked to repeat each list immediately after the presentation in the same order as the examiner. The test included four difficulty levels, for a total of eight trials. A score of one was given for each sequence correctly recalled (expected range 0-8). The test-retest reliability was .87.

High-control working memory. High-control WM skills were measured using the backward word span task (adapted from Lanfranchi et al., 2004). Participants were read lists of two to five words and were required to recall each sequence in reverse order to that used by the examiner. The test included four difficulty levels, for a total of eight trials. A score of one was given for each sequence correctly recalled (expected range 0-8). The test-retest reliability was .84.

Inhibition. Inhibition skills were tested using the Day and night stroop task (Gerstadt, Hong, & Diamond, 1994), comprising a congruent and an incongruent (or stroop) condition.

In each condition children were shown a sequence of 16 pictures presented one at a time, eight depicting the sun and eight depicting the moon. In the congruent condition, children were asked to say either “day” or “night” whenever a picture of the sun or the moon was presented respectively. In the incongruent condition, participants were required to say “day” for the picture of the moon and “night” for the picture of the sun. One point was given for each correct response in each condition (expected range 0-16). The test-retest reliability was .97 for the incongruent condition.

4.2.3.2 Early mathematical abilities.

***Forward counting*.** To measure forward-counting skills, we used a task adapted from the forward sequence subtest of the Numerical Intelligence Battery (BIN; Molin, Poli, & Lucangeli, 2007). Children were asked to recite aloud the numerical sequence from 1 to 50 and obtained one point for each correct response. Considering the differences between the number word systems of Italians and Syrians on the one hand, and Yazidis on the other, in order to examine distinctly performance for single digits and two-digit numbers, we analyzed forward counting separately for 1-10 and 11-50 (expected ranges 0-10 and 0-40, respectively). The test-retest reliability was .83 for counting from 1 to 10 and .82 for counting from 11 to 50.

***Backward counting*.** Backward-counting skills were tested using a task adapted from the backward sequence subtest of the BIN (Molin et al., 2007). Participants had to recite the numerical sequence backwards from the largest number correctly counted in the forward counting task to one, obtaining one point for each correct response. As well as for forward counting, also in this case we conducted separate analyses from 10 to 1 and from 50 to 11 (expected ranges 0-10 and 0-40, respectively). The test-retest reliability was .82 for counting from 10 to 1 and .81 for counting from 50 to 11.

Digit-quantity mapping. Digit-quantity mapping was assessed using the digit-dots correspondence subtest from the BIN (Molin et al., 2007). In this task, children were asked to match a presented digit ranging from one to nine with the corresponding set of dots among three different visually presented sets, receiving one point for each correct answer (expected range 0-9). The test-retest reliability was .79.

Digit naming. Digit naming skills were measured using a task adapted from the number naming subtest of the BIN (Molin et al., 2007), in which participants were shown digits from one to sixteen and had to read aloud them. One point was given for each digit correctly recognised and named. Analogously to forward and backward counting, we analyzed also digit naming separately for 1-10 and 11-16 (expected ranges 0-10 and 0-6, respectively). The test-retest reliability was .86 for naming from 1 to 10 and .83 for naming from 11 to 16.

4.3 Results

Means and standard deviations of scores of the three groups of children are presented in Table 4.1. Preliminary analysis indicated no difference between the groups in terms of chronological age, $F(2, 147) = 2.67$, $p = .07$, $\eta_p^2 = .035$ and gender, $X^2(2, 150) = 0.013$, $p = .994$. Therefore, these parameters were not further included as covariates in the analysis.

Bivariate correlations between all measured variables are reported in Table 4.2 for Yazidi and Syrian refugee children and in Table 4.3 for Italian children. It should be noticed that in all three groups EFs and early math abilities were significantly related.

Table 4.1 Mean scores and standard deviations in the different measures of the three groups of children (Syrian Refugees, Yazidis, and Italians).

	Syrian Refugees Group (*n* = 47)		Yazidi Group (*n* = 48)		Italian Group (*n* = 55)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Low-control WM	5.45	0.97	5.40	1.20	5.00	1.20
High-control WM	1.96	1.76	1.54	1.60	2.49	2.30
Inhibition	10.13	2.04	10.10	2.00	13.67	2.44
Forward counting (1-10)	8.89	2.06	8.29	2.90	9.98	0.14
Forward counting (11-50)	6.04	8.95	2.73	6.84	24.24	12.06
Backward counting (10-1)	1.70	3.59	1.83	3.86	5.40	4.93
Backward counting (50-11)	0.28	1.02	0.17	0.72	3.93	10.94
Digit-quantity mapping	4.47	1.92	3.63	2.04	7.16	2.01
Digit naming (1-10)	5.62	2.32	4.50	2.13	9.15	2.11
Digit naming (11-16)	0.21	0.69	0.13	0.53	2.55	2.38

Table 4.2 Bivariate correlations between all variables considered in the study for Yazidi (*n* = 48) and Syrian refugee (*n* = 47) children.

	Zero-order correlations										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Age (in months)	-	.42**	.38**	.31*	.44**	.03	.21	-.05	.38**	.33*	.18
2. Low-control WM	.39**	-	.56***	.36*	.16	.31*	.38**	.27	.29*	.32*	.16
3. High-control WM	.31*	.01	-	.76***	.58***	.67***	.71***	.44**	.74***	.72***	.47***
4. Inhibition	.24	.12	.86***	-	.59***	.64***	.76***	.49***	.76***	.78***	.46***
5. Forward counting (1-10)	.33*	.19	.60***	.46***	-	.24	.29*	.14	.60***	.57***	.14
6. Forward counting (11-50)	.20	-.10	.90***	.88***	.37**	-	.62***	.77***	.66***	.61***	.68***
7. Backward counting (10-1)	.07	-.14	.84***	.75***	.26	.89***	-	.50***	.70***	.70***	.51***
8. Backward counting (50-11)	-.17	-.15	.48***	.37*	.15	.58***	.64***	-	.46***	.50***	.44**
9. Digit-quantity mapping	.24	.10	.79***	.77***	.42**	.78***	.77***	.26	-	.93***	.67***
10. Digit naming (1-10)	.12	.01	.73***	.72***	.42**	.75***	.71***	.33*	.91***	-	.62***
11. Digit naming (11-16)	.34*	.21	.55***	.51***	.17	.50***	.51***	.10	.70***	.60***	-

Note. *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$.

Yazidis' results are reported in the upper right part of the table, while Syrian refugees' results are shown in the lower left part of the table.

Table 4.3 Bivariate correlations between all variables considered in the study for Italian children (*n* = 55).

	Zero-order correlations									
	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Age (in months)	-.02	-.06	-.03	-.12	-.06	.06	-.13	-.07	.04	-.13
2. Low-control WM	-	-.07	-.12	.00	.05	.03	.11	.11	.05	.09
3. High-control WM	-	-	.52***	.60***	.58***	.76***	.61***	.60***	.30*	.58***
4. Inhibition	-	-	-	.63***	.44***	.51***	.49***	.57***	.68***	.47***
5. Forward counting (1-10)	-	-	-	-	.42**	.66***	.39**	.91***	.41**	.57***
6. Forward counting (11-50)	-	-	-	-	-	.55***	.76***	.51***	.44***	.60***
7. Backward counting (10-1)	-	-	-	-	-	-	.56***	.68***	.52***	.65***
8. Backward counting (50-11)	-	-	-	-	-	-	-	.44***	.50***	.72***
9. Digit-quantity mapping	-	-	-	-	-	-	-	-	.43***	.60***
10. Digit naming (1-10)	-	-	-	-	-	-	-	-	-	.57***
11. Digit naming (11-16)	-	-	-	-	-	-	-	-	-	-

Note. **p*≤.05, ***p*≤.01, ****p*≤.001.

4.3.1 Group comparisons

Differences between the three groups of children were investigated through a multivariate analysis of variance (MANOVA) with the group (Syrian Refugees Group - SRG -, Yazidi Group -YG -, and Italian Group - IG -, respectively) used as the fixed factor, and the measures of EFs (i.e., low- and high-control WM and inhibition) and early mathematical abilities (i.e., forward and backward counting, digit-quantity mapping, and digit naming) as the dependent variables. Bonferroni-adjusted post-hoc pair-wise comparisons of scores were also carried out. We decided to include all the variables (i.e., EFs and early mathematical abilities) in the same MANOVA because in this way the analysis is more conservative than multiple comparisons.

To compare differences between groups, η_p^2 was used as a measure of effect size. Cohen's (1988) criteria were used to classify the effect sizes: small effect: $\eta_p^2 =.01$; medium effect: $\eta_p^2 = .06$; and large effect: $\eta_p^2 = .14$. Cohen's (1988) *d* for post hoc pairwise comparisons were used as a measure of effect size: small effect $d = .20$; medium effect $d = .50$; large effect $d = .80$. Univariate test results and Bonferroni's adjusted post-hoc pair-wise comparisons from MANOVA between the three groups of children are reported in Table 4.4.

Table 4.4 Univariate Test results and Bonferroni’s adjusted post-hoc pair-wise comparisons from MANOVA between the three groups of children (SRG, YG, and IG).

	F	Effect sizes	*Groups*		M_{diff}	p	d
Low-control WM	F (2, 147) = 2.42, $p = .09$	.03	YG	IG	.40	.24	.33
			SRG	IG	.45	.15	.41
			YG	SRG	.05	1	.05
High-control WM	F (2, 147) = 3.14, $p = .046$	.04	YG	IG	-.095	.04	.48
			SRG	IG	-.053	.50	.26
			YG	SRG	-.042	.89	.25
Inhibition	F (2, 147) = 46.16, $p \leq .001$	.39	YG	IG	-3.57	≤ .001	1.60
			SRG	IG	-3.55	≤ .001	1.57
			YG	SRG	0.02	1	.01
Forward counting (1-10)	F (2, 147) = 9.73, $p \leq .001$	.12	YG	IG	-1.71	≤ .001	.83
			SRG	IG	-1.11	.02	.76
			YG	SRG	.60	.43	.24
Forward counting (11-50)	F (2, 147) = 74.93, $p \leq .001$	.51	YG	IG	-21.51	≤ .001	2.19
			SRG	IG	-18.19	≤ .001	1.71
			YG	SRG	-3.31	.29	.42
Backward counting (10-1)	F (2, 147) = 12.97, $p \leq .001$	.15	YG	IG	-3.57	≤ .001	.81
			SRG	IG	-3.70	≤ .001	.86
			YG	SRG	.13	1	.03
Backward counting (50-11)	F (2, 147) = 5.39, $p = .006$	.07	YG	IG	-3.76	.02	.49
			SRG	IG	-3.65	.02	.47
			YG	SRG	-.11	1	.12
Digit-quantity mapping	F (2, 147) = 44.81, $p \leq .001$	.38	YG	IG	-3.54	≤ .001	1.74
			SRG	IG	-2.70	≤ .001	1.37
			YG	SRG	0.84	.12	.42
Digit naming (1-10)	F (2, 147) = 64.20, $p \leq .001$	.47	YG	IG	-4.65	≤ .001	2.19
			SRG	IG	-3.53	≤ .001	1.59
			YG	SRG	-1.12	.04	.50
Digit naming (11-16)	F (2, 147) = 42.49, $p \leq .001$	.37	YG	IG	-2.42	≤ .001	1.40
			SRG	IG	-2.33	≤ .001	1.34
			YG	SRG	-.09	1	.13

The MANOVA results revealed a significant main effect for group factor (Wilks’ Lambda = .31, $F(20, 276) = 11.19$, $p = \leq .001$, $\eta_p^2 = .45$), since the three groups (SRG, YG, and IG) significantly differed from each other.

Overall, univariate test results established significant differences between the three groups in all measures considered in the study (i.e., EFs and early mathematical abilities), except for low-control WM skills. More specifically, children living in contexts characterized by various conditions of deprivation (i.e., Yazidis and Syrian refugees) showed a lower level of both EFs (i.e., high-control WM and inhibition skills, except for low-control WM abilities) and early mathematical abilities (i.e., forward and backward counting, digit-quantity mapping, and digit naming) than children coming from not deprived sociocultural contexts (i.e., Italians). Regarding both EFs and early math skills, except for digit naming (1-10), no significant differences were found between the two deprived groups.

4.4 Discussion

The present study grounds on two main aspects enucleated from the previous research: on the one hand, EFs provide a crucial foundation for learning in school settings and early school achievement (see Zelazo et al., 2016), predicting a wide range of important outcomes, such as early math abilities (e.g., Blair & Razza, 2007; Bull et al., 2008; Clark et al., 2010); on the other hand, EFs' development is critically affected by the levels of stress, disadvantage, or deprivation that children experience early in their lives (Shonkoff et al., 2009). In the light of this analysis, we expected to (a) confirm the association between living in deprived environments (i.e., war context and refugee condition) and showing lower EF skills, as well as (b) observe lower early mathematical skills in children early exposed to specific deprived living conditions (i.e., war context and refugee condition).

Regarding the first point, overall our results revealed that Yazidi and Syrian children, both coming from highly deprived backgrounds characterized by genocide context and refugee condition respectively, showed poorer EFs skills than Italian preschoolers, thus confirming the link between EFs deficit and exposure to stressful living conditions previously found in other disadvantaged contexts (e.g., Merz et al., 2016). More in detail, inhibition abilities resulted more impaired in both Yazidi and Syrian children than Italians, while high-control WM skills emerged as worse only in the sample of Yazidis compared to Italian group. The greater impairment of high-control WM in the Yazidis may be attributed to the fact that the genocide suffered by this latter group represents a condition of extreme and violent deprivation (United Nations Human Rights Council, 2016). There was no significant difference between the three samples of children in low-control WM, in line with recent findings suggesting that low-control WM skills (or Short-Term Memory) may not be so strongly affected by socio-economic background (Alloway et al., 2017) and deprivation.

Concerning the second hypothesis of the study, the results confirmed the relationship between EFs and early mathematical abilities, already found in typically developing children. Indeed, the two groups of deprived children (i.e., Yazidis and Syrian refugees) not only showed lower EFs skills but also revealed significantly poorer early mathematical abilities than Italians, by performing worse all four mathematical tasks used in the study. In summary, although all three groups of participants, being preschoolers, had not yet had access to formal mathematical education and therefore to a systematic approach to the concept of number, it is possible to observe that, already at this early developmental and educational stage, more deprived children showed significantly lower EFs and poorer early math performance.

Our study is limited in several ways. First of all, we must acknowledge that, although we found correlations between EFs and early math abilities, this does not preclude the possibility that other bio-psycho-social variables could mediate or moderate this relationship. Genetic background (Brett, Humphreys, Fleming, Kraemer, & Drury, 2015), age differences related to the degree of PFC vulnerability to stressors (McEwen & Morrison, 2013), severity, timing, and duration of deprivation (Beckett, Castle, Rutter, & Sonuga-Barke, 2010) may have contributed to determine our results. Likewise, we have no information regarding certain potentially relevant aspects, such as children’s family composition, difficulties and/or traumas related to prenatal and/or perinatal status, and the possibilities to access to medical care. Furthermore, at a psychological level, differences in domain general cognitive abilities (e.g., intelligence), number words system used, and specific educational stimulations could have driven the data. Lastly, the level of poverty experienced in the specific geopolitical context may have had an impact on the differences we observed in preschool children involved in our study (see Chen et al., 2019).

Secondly, we compared three different situations: Yazidi, Syrian refugee and Italian preschoolers. The specific environmental and political situation experienced by Yazidi children may not be representative of other different forms of deprivation, such as war and refugee experience, and both the analyzed deprived conditions are substantially dissimilar from the Italian one. In this sense, it would be more methodologically correct to use a sample from the same population but not affected from the crucial political and social events in question (Bos, Fox, Zeanah, & Nelson, 2009; Lan, Legare, Ponitz, Li, & Morrison, 2011). In this specific study, anyway, given the extended and complex social situations in the territory, it was not possible to recruit non-affected samples. Alternatively, the use of a low SES control group (notoriously characterized by lower math skills), not afflicted by a situation of severe deprivation such as war, would have been useful to disambiguate the role of the SES from living in a toxic stress situation (see Jordan, Kaplan, Nabors Olahá, & Locuniak, 2006; Jordan et al., 2009; Starkey et al., 2004).

Thirdly, we tested only WM and inhibition among EFs, since these skills, developing earlier compared to other EFs, seem to be particularly vulnerable to early deprivation (Garon et al., 2008; Jurado & Rosselli, 2007). Further research could also focus on other EFs, such as updating, shifting, or planning abilities (see Diamond, 2013; Miyake et al., 2000), investigating their link with early mathematics in children living in deprived contexts.

Moreover, future studies could use more tools instead of just one to measure the different EF skills.

Finally, our work used a cross-sectional design which shows only an association between levels of EFs and early mathematical abilities. Further longitudinal studies could provide useful information with respect to the complexity of this relationship.

Even acknowledging these limitations, it is our belief that the present research contributes to the literature in numerous ways: firstly, it represents a first attempt to evaluate cognitive consequences of genocide and deprivation providing important insight into the effects of these types of experience on both EFs and numerical abilities in early childhood. Secondly, and consistently with the literature, deprivation seems to have an effect on basic abilities, thereby confirming the importance of school-based activities for specific interventions programs. The possibility not only to evaluate but also to apply tailored trainings in these contexts and in other migration-related situations may be crucial for helping future adults deal with the scourge of war. This study could therefore be considered a starting point for implementing intervention strategies that may early promote and provide concrete tools to base achievement abilities, preventing an entire cohort of children from becoming a "lost generation".

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Chapter 5

Evaluation and training of Executive Functions in genocide survivors

Pellizzoni, S., Apuzzo, G. M., De Vita, C., Agostini, T., & Passolunghi, M. C. (2019). Evaluation and training of Executive Functions in genocide survivors. The case of Yazidi children. *Developmental science*, e12798. doi: 10.1111/desc.12798

Abstract

Executive Functions (EFs) development is critically affected by stress and trauma, as well as the socio-economic context in which children grow up (Welsh, Nix, Blair, Bierman, & Nelson, 2010). Research in this field is surprisingly lacking in relation to war contexts. This study represents a first attempt at addressing this topic by evaluating EFs in Yazidi children. The Yazidi community is an ethnic and religious minority living in Iraq. From August 2014 onwards, the Yazidi community has been the target of several atrocities perpetrated by ISIS and described as genocide by the international community at large.

The University of Trieste, thanks to a program financed by the Friuli Venezia Giulia Region, developed a study aimed at (a) evaluating hot and cool EFs in children living in a war context and (b) developing a specific training method to enhance hot and cool EFs in Yazidi children of preschool age (N= 53) and assessing its effectiveness. Data related to this group of children were compared with a sample of typically developing Italian children randomly assigned to either an EFs training group (N=55) or a passive control group (N= 51).

Results indicate different baselines in hot EFs in Yazidi and Italian samples and a significant effect of the program on both trained groups, especially in tasks measuring hot EFs.

Data are discussed in terms of hot and cool EFs in children growing in adverse environments, as well as the evaluation of educational and developmental opportunities to prevent children who survived genocide from becoming a "lost generation".

5.0 Introduction

According to recent surveys, approximately one in six children today lives in a war context (Save the Children International, 2018) characterized by continuous life-threatening conditions, loss of close family members, violence, lack of social and cognitive stimulation, and, in some cases, inadequate physical resources. Their experience may severely compromise these children's adaptive, cognitive and healthy development.

Executive Functions (EFs) are a set of abilities involved in the regulation of thoughts, emotions, and behaviors (Diamond, 2013) that are profoundly altered in children that experience prolonged stressful conditions, such as trauma (DePrince, Weinzierl, & Combs, 2009), maltreatment (Rogosch, Dackis, & Cicchetti, 2011), and institutionalization, with specific repercussions on inhibition and working-memory (WM) abilities (Merz, Harlé, Noble, & McCall, 2016). Surprisingly, studies on EFs in children growing up in war contexts are quite scarce and focus exclusively on emotional control and trauma (Betancourt et al., 2012; Pat-Horenczyk et al., 2013).

This state of art call for an urgent need to reach a deeper understanding of EFs development in adverse contexts. To the best of our knowledge, this work represents the first attempt at evaluating hot and cool aspects of EF s in a group of preschool Yazidi children, whose community is constantly exposed to extreme trauma and violence, defined by the UN as genocide (United Nations Human Rights Council, 2016, June 15, 32nd session). Given the lack of literature on these extreme forms of vexation, the aim of this study was twofold: (a) evaluating hot and cool EFs (with specific reference to WM and inhibition) in a sample of children who survived genocide, and (b) developing a training to increase these functions, given their relevance for development, and assessing its effectiveness.

Development in critical environmental conditions, and the relevant increased risk of long-term negative repercussions, is a broad theme that has profoundly influenced developmental psychology, psychiatry, public health, and education. Increased knowledge of the effects of war on specific abilities related to EFs may promote a better understanding of how and to what extent toxic and prolonged stress conditions are associated with crucial developmental skills that support flexible, goal-directed behavior controlled by areas of the Prefrontal Cortex (PFC) (McEwen & Morrison, 2013). Furthermore, investigation of specific aspects of EFs may help design effective and targeted interventions on the above-mentioned skills that could promote positive outcomes in children growing in critical contexts. Finally, and in specific relation to the Yazidi genocide, this research may provide a significant contribution to preventing Yazidi children that survived genocide from becoming a "lost generation", and to supporting specific actions in countries hosting Yazidi refugees.

5.0.1 EFs: the hot and cool model

EFs are a set of cognitive abilities (Miyake & Friedman, 2012) that allow individuals to control thoughts and actions when new or complex situations must be processed. In other words, they serve to: inhibit inappropriate responses (inhibitory control); show flexibility in strategies, ideas, and activities (shifting); hold, update, and actively manipulate information in one’s mind (working memory). These functions have been extensively investigated in children (Garon, Bryson, & Smith, 2008), showing their connection with developmental outcomes related to children’s learning abilities in terms of both literacy and math achievement (Blair & Razza, 2007; Clark, Pritchard, & Woodward, 2010). As highlighted by Wass (2015), the effect of such developmental outcomes may even extend to an individual’s academic life and relevant achievements. Furthermore, the development of these abilities seems to be associated with social success with peers (Eisenberg, et al., 2003). Although EFs are traditionally defined through a purely cognitive perspective, Zelazo and Müller (2002) have further developed existing views, proposing the distinction between “hot” emotional and “cool” cognitive aspects of EFs. Cool EFs are involved in abstract and context-free tasks, while hot EFs are involved in situations requiring the regulation of motivations and affective challenges.

5.0.2 Development of hot and cool EFs in differential stressful environments

Research shows that stress, experienced early in life, has deleterious effects on the development and functioning of the prefrontal cortex, namely the brain system that mediates EFs (McEwen, 2008; McEwen & Morrison, 2013). Shonkoff and colleagues (2009) identify three levels of stress that may be experienced during childhood. The first level of stress concerns normative and routine life challenges, that include the need to face daily problem-solving tasks and promote positive coping skills. The second level of stress concerns time-limited stressful situations experienced within a context of protective factors. The third level of stress concerns toxic stress conditions in which children are exposed to severe, chronic, and prolonged stress and in the total absence of protective factors. Possible examples are abuse and family violence, neglect, parental substance abuse, or growing up in a war zone. This classification has been applied to a variety of conditions that range from lesser forms of deprivation, such as disadvantaged socio-economic positions (Welsh et al., 2010), to extreme forms of deprivation such as trauma (DePrince et al., 2009), institutionalization (Merz et al., 2016), and maltreatment (Rogosch et al., 2011). The present study focuses on the third level of stress.

Current research on children diagnosed with maltreatment-related Post-Traumatic Stress Disorder (PTSD) indicate that they perform poorly on several EFs measures, for example distractibility and sustained visual attention tasks, compared to the control sample (Beers & De Bellis, 2002). Furthermore, a moderate effect size was observed between familial trauma and EFs’ composite score, including WM, inhibition, auditory attention, and processing speed tasks (DePrince et al., 2009). A recent review of the studies on formerly institutionalized children shows that they are at greater risk of EFs deficiency: analyses confirm that EFs difficulties mainly affect inhibitory control and WM, but have limited repercussions on planning and, to a certain extent, shifting (Merz et al., 2016). These differences in the effects of stress on single EFs processes could be due to differential developmental trajectories related to specific components. More specifically, inhibitory control and WM are thought to develop at an earlier stage with respect to the other components, which may be the reason why they are susceptible to early deprivation (Garon et al., 2008). While studies on cool EFs seem more consistent, research on specific effects of hot EFs on development is still limited. In this regard, McIntyre and colleagues (2006) showed that high hot EF such as the ability to delay gratification upon school entry predicts teacher-reported prosocial skills and more positive overall student-teacher relationships in children with and without intellectual disability in kindergarten. Moreover, hot EF has been found to be uniquely related to inattentive-overactive behaviors in low-income preschoolers aged 3-5 years old (Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011). From a more clinical perspective, a recent study shows a specific relation between hot EFs and emotional dysregulation in adolescents (Poon, 2017), as well as hyperactivity/inattention symptoms and conduct problems in extremely pre-term children (Walczk & Chrzan-Dętkoś, 2018). Since EFs are central to many developmental tasks children need to perform - from navigating peer relationships to tackling setting- and behavioral control (Jacobson, Williford, & Pianta, 2011), the development of systematic studies on EFs in children exposed to war trauma is crucial and deserves the undivided attention of the scientific community.

5.0.3 EFs training in preschool children

There are various types of training aimed at promoting EFs. In particular, Table 5.1 summarizes the results obtained with training specifically targeted at EFs in typically developing preschool children from middle-class, low-income backgrounds. Previous studies have consistently recorded positive effects of EFs training on cool EFs in preschoolers. However, there are no consistent data concerning their effects on inhibition skills: while some studies (e.g., Diamond, Barnett, Thomas, & Munro, 2007; Dowsett & Livesey, 2000; Lillard & Else-Quest, 2006; Raver et al., 2011) report positive effects, others yielded little (e.g., Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2011; Traverso, Viterbori, & Usai, 2015) or no effect at all (e.g., Domitrovich, Cortes, & Greenberg, 2007; Rueda, Checa, & Còmbita, 2012; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). Moreover, training programs including hot EFs are still under-researched, and there are only two cases in the relevant literature that provide evidence of positive effects of these programs on EFs in children’s delay gratification ability. Existing training methods developed in war contexts tend to focus mainly on first aid support (Kar, 2009) and emotional control (Pat-Horenczyk et al., 2009), but, to the best of our knowledge, no training method specifically focusing on EFs has been developed yet.

Table 5.1 Training interventions on EFs in typically developing preschoolers from middle-class, low-income backgrounds.

Authors	**Sample**	**Training program (duration, materials and activities, and setting)**	**Investigated EFs skills**	**Results: Training Effect**	**Effect size**
Dowsett & Livesey (2000)	N = 49 lower-to-middle income preschoolers, M_{age} = 3.98 years	*Duration:* A short-term intervention with 3 sessions lasting approximately 15-20 min on 3 successive days of the child's attendance at the preschool. *Materials and Activities:* The training program involves the use of pencil paper materials (e.g., cards, coins, and sheets of cardboard), and includes a modified version of the Wisconsin Card Sorting task, and a semplified version of the Stop Signal paradigm, that is the change task. *Setting:* Individualized intervention.	- Inhibition	Inhibition: Positive effect	Not reported
Kloo & Perner (2003)	N = 44 (22 F), M_{age} = 3.76 years (SD = 0.41)	*Duration:* A short-term intervention with 15-min sessions, for approximately 8 days. *Materials and Activities:* The Card Sorting Task training involves the use of pencil paper materials and each session consists of a card-sorting task with three dimension switches and two transfer-sorting tasks. *Setting:* Individualized intervention.	- Shifting	Shifting: Positive effect	Not reported
Rueda et al. (2005)	1° and 2° Exps. N = 49 (25 F), M_{age} = 4.33 years (SD = 0.18) 3° Exp. N = 24 (12 F), M_{age} = 6.42 years (SD = 0.27)	*Duration:* A short-term intervention lasting 5 days over a 2- to 3- week period. *Materials and Activities*: A total of 9 (Exps. 1 and 2) or 10 (Exp. 3) computerized exercises designed to train attention in general, with a special focus on executive control. *Setting*: Individualized intervention.	- Inhibition	Inhibition: No effect	Not reported

Lillard & Else-Quest (2006)	*N* = 55, M_{age} = 5 years	*Name:* Montessori curriculum for infancy to grade 12 (0-18 years). *Duration*: A long-term education program implemented in primary level (3- to 6- year-olds). *Materials and Activities*: The curriculum-based program is characterized by a special set of educational materials, student-chosen work in long time blocks, collaboration, the absence of grades and tests, and individual and small groups instruction in both academic and social skills. *Setting*: Both individualized and group-based program in multi-age classrooms.	- WM - Inhibition - Shifting - Delay of gratification (Hot EF)	WM, Inhibition, and Shifting: Positive effect Delay of gratification (Hot EF): No effect	Not reported
Diamond et al. (2007)	*N* = 147 low-income preschoolers, M_{age} = 5.1 years	*Name*: Tools of the Mind (Tools) curriculum for preschool and kindergarten. *Duration*: A long-term intervention provided for 1 or 2 years of preschool. *Materials and Activities*: The classroom curriculum-based program improves EFs through 40 EF-promoting daily activities, including telling oneself out loud what one should do (17), dramatic play (18), and aids to facilitate memory and attention (19). Games targeted to teach reflective thinking and self-regulation comprise inhibitory control, turn-taking, and reminding and carrying out pre-planned behaviors. A central part of Tools is social pretend play, during which children must remember their own and others' roles, inhibit acting out of character, and flexibly adjust as their friends improvise.	- WM - Inhibition - Cognitive flexibility (Shifting)	WM, Inhibition, and Cognitive flexibility (Shifting): Positive effect	Not reported

		Setting: A group-based intervention in regular public school classes with regular teachers.			
Domitrovich et al. (2007)	*N* = 246 (126 F) disadvantaged preschoolers, M_{age} = 4.28 years (*SD* = 0.49)	*Name*: Preschool "PATHS" (Promoting Alternative Thinking Strategies) Curriculum for preschool to grade 6 (3-12 years). *Duration*: A long-term curriculum-based program across a 9-month period. *Materials and Activities*: It is a social-emotional curriculum-based on the ABCD (Affective-Behavioral-Cognitive-Dynamic) model of development and designed to improve children's competencies in self-control, managing and recognizing feelings, and social, behavior, emotional, and interpersonal problem-solving. It includes weekly lessons and extension activities integrated effectively with common early childhood programs. *Setting*: A classroom-based teacher-taught program that intends to complement existing curriculum.	- Inhibition	Inhibition: No effect	Not reported
Bierman et al. (2008)	*N* = 356 (192 F) socioeconomically disedvantaged preschoolers, M_{age} = 4.49 years (*SD* = 0.31)	*Name*: Head Start REDI (Research-Based, Developmentally Informed) program. *Duration*: A long-term intervention delivered over the course of the prekindergarten year. *Materials and Activities*: It included curriculum-based lessons, center-based extension activities, and training in "coaching strategies" to promote language/emergent literacy and social-emotional skills associated with school readiness. More specifically, it comprises an interactive reading program	- WM - Inhibition (cognitive and behavioral) - Shifting	WM, cognitive Inhibition, and Shifting: Positive effect Behavioral Inhibition: No effect	WM, cognitive Inhibition, and Shifting 0.20

		targeted to four skills: vocabulary, sintax, phonological sensitivity, and print knowledge. Regarding social-emotional skill enrichment, it is used a 33-lesson curriculum targeted four domains: prosocial friendship skills, emotional understanding and expression skills, self-control, and social problem-solving skills. *Setting*: A group-based interactive intervention, delivered by classroom teachers.			
Thorell et al. (2009)	$N = 65$ (33 F), $M_{age} = 4.17$ years	*Duration:* A short-term intervention for a total of 15-min sessions carried out every school day over a period of 5 weeks. *Materials and Activities:* The computerized intervention comprises two different types of training: the inhibition and WM training programs. Each training includes five different computer games but only three tasks are administered to the child daily using a rotating schedule. The WM training focuses specifically on visuo-spatial WM (remember location and order of visuo-spatial stimuli), when the inhibition program is related to inhibition of a prepotent motor response, stopping an ongoing responce, and interference control. *Setting:* Individualized intervention.	- WM - Inhibition	WM: Positive effect Inhibition: No effect	Spatial WM 0.89 Verbal WM 1.15
Bergman Nutley et al. (2011)	$N = 112$ (68 F), $M_{age} = 4.27$ years ($SD = 0.25$)	*Duration:* A short-term intervention lasting around 15 minutes/day, 5 days/week for 5-7 weeks, until 25 sessions have been performed. *Materials and Activities:* It is a computerized training of either non-verbal reasoning, WM,	- WM	WM: Positive effect	Not reported

		a combination of both, or a placebo version of the combined training. The WM program is the same described in Thorell *et al.* (2009) and it includes seven visuo-spatial tasks, out of which three are trained daily on a rotating schedule. *Setting:* Individualized intervention.			
Raver et al. (2011)	*N* = 543 low-income preschoolers, M_{age} = 4.12 years (*SD* = 0.67)	*Name*: Chicago School Readiness Project (CSRP) for preschool (3-5 years). *Duration*: A long-term intervention implemented from fall to spring of the Head Start year. *Materials and Activities*: The curriculum-based program provided teachers with training in new techniques and strategies (e.g., reward positive bahevior and redirect negative bahevior, apply clearer routines and rules) that they could employ to improve children's school readiness by increasing their emotional and behavioral adjustment. *Setting*: A group-based intervention implemented in classroom that intends to complement existing curriculum.	- WM - Inhibition - Delay of gratification (Hot EF)	WM and Inhibition: Positive effect Delay of gratification (Hot EF): No effect	WM and Inhibition 0.37
Röthlisberger et al. (2011)	1° Exp. (prekindergarten) *N* = 71 (33 F), M_{age} = 5.04 years (*SD* = 0.30) 2° Exp. (kindergarten) *N* = 64 (24 F), M_{age} = 6.08 years (*SD* = 0.32)	*Duration:* A short-term intervention including a sequence of 30 daily sessions of approximately 30 min carried out twice a week spread over 6 weeks. *Materials and Activities:* Each training session includes three different tasks: one task for the whole intervention group, one for a couple of children, and one individual task. Regarding the content, the program comprises	- WM - Cognitive flexibility (Shifting) - Inhibition	WM and cognitive flexibility (Shifting): Partially positive effect in pre-kindergarten children	WM 0.42 Cognitive flexibility (Shifting) 0.59

		pencil paper activities and games based on well-known EFs tasks to improve specifically working memory, inhibition (interference control), and cognitive flexibility processes. *Setting:* A mixed individual and small group training (individual, couple, and group setting) implemented in regular prekindergarten and kindergarten settings.		Inhibition: Partially positive effect in kindergarten children	Inhibition 0.43
Rueda et al. (2012)	*N* = 37 (17 F), M_{age} = 5.39 years (*SD* = 0.27)	*Duration*: A short-term intervention for a total of 10 45-min sessions carried out over a period of 5 weeks (2 sessions per week). *Materials and Activities*: A total of 11 computerized exercises divided in 5 general categories: (1) Tracking/Anticipatory; (2) Attention Focusing/Discrimination; (3) Conflict Resolution; (4) Inhibitory Control; (5) Sustained Attention. *Setting*: Individualized intervention.	- Inhibition - Delay of gratification (Hot EF)	Inhibition: No effect Delay of gratification (Hot EF): Partially positive effect	Not reported
Traverso et al. (2015)	*N* = 75 (40 F) lower-to-middle income preschoolers, M_{age} = 5.72 years (*SD* = 0.29)	*Duration:* A short-term intervention including a total of 12 sessions of approximately 30 min, carried out three times a week over about 1 month during the regular kindergarten day. *Materials and Activities:* It is a play-based group training including a series of small group (five children) game activities which require incresing levels of active participation and cognitive control on the part of each child. More specifically, the children are asked to help Chicco and Nanà, two little goblin friends attending kindergarten, in order to face 10 different challenges (intervention	- Delay of gratification (Hot EF) - Inhibition - Shifting - WM	Delay of gratification (Hot EF): Partially positive effect Inhibition, Shifting, and WM: Partially positive effect	Delay of gratification (Hot EF) 0.70 Inhibition 0.35, 0.45, 0.61 Shifting 0.53 WM 0.43, 0.65

		activities) that involve EFs. In this way, children will help Chicco and Nanà become more regulated and finally attend primary school. Each activity requires progressively higher levels of inhibitory control, cognitive flexibility, and WM. Moreover, each game requires that children resolve conflicts respecting the rules and the roles they are assigned in order to reach the fixed goals. Every training session finishes with a metacognitive activity in which children have to report their self-perception of their EFs and to share with the whole group strategies that they retain useful in facing the challenges. The training involves low-cost and readily available pencil paper and physical materials (without using either computers or other technical equipment). *Setting:* A small- group school-based intervention implemented within the daily schedules of standard preschool setting.			

5.1 The study

Considering the crucial role of EFs in development, our study focuses on EFs abilities in children from war contexts through two different evaluations: (a) assessment of EFs cool and hot components in children living in a war context, (b) implementation of a training program to improve these children's EFs and assessment of its effectiveness. This study, in particular, evaluates hot and cool EFs in a group of five-year-old Yazidi children living in refugee camps in Kurdistan, comparing them to a sample of Italian preschoolers living in a typical environmental context.

As regards the training, we referred to the literature confirming the importance of school-based training methods in relation to war contexts (Pat-Horenczyk et al., 2009), by designing a tailored intervention that may contribute to the still limited number of programs involving scientifically valid methods, such as randomized assignment and blind evaluators.

In line with previous studies, our rationale is based on the assumption that child survivors of genocide show worse EFs competence compared to their peers in the control group (i.e. typically developing five-year-old children). More specifically, we intend to verify the following hypotheses: (a) children that live in a traumatic context show impairment of cool components of EFs, specifically in relation to inhibition and WM; (b) war contexts have an impact on hot EFs, in line with research indicating that socio-economic contexts may affect the development of delayed gratification; (c) specific training target at both cool and hot EFs can have a positive impact on the participants of both groups.

5.2 Method

5.2.1 Participants

Participants are five-year-old children, divided into two groups, Yazidi and Italian respectively. Yazidis are a minority group living in an Islamic cultural surrounding. Since

August 3, 2014, they have been targeted by militants of the Islamic State of Iraq and the Levant as part of a religious campaign to rid Iraq of non-Islamic influences. ISIS' assaults resulted in the death of 5,800 Yazidis, while another 4,000 were displaced, with numerous atrocities perpetrated against children, as described by Salloum (2016). In March 2015, the Office of the United Nations High Commissioner for Human Rights identified the atrocities perpetrated against the Yazidi minority as genocide (United Nations Human Rights Council, 2016, June 15, 32nd session). The training method applied in this study was part of an international cooperation program implemented by the Friuli Venezia Giulia Region and developed in collaboration with local NGOs' partners. One hundred and twenty-six Yazidi children in the care of four different NGOs took part in the study, but only 53 of them attended at least 80% of the program and could therefore be evaluated. A multivariate analysis of variance (MANOVA) was conducted on the total sample of Yazidi children taking part in the preliminary evaluation phase, to exclude the presence of a possible selection bias related to EFs in those who completed the program. Table 5.2 shows that there are no differences in hot and cool EFs between the two groups of Yazidi children at this stage.

Italian children were selected among attendees of four different kindergartens located in Northern Italy. Consent to participate in the training was obtained by both the schools and the parents of 112 children. Three children displaying developmental delay were preventively excluded from the initial sample, while other three attended less than 80% of the program. The remaining, typically-developing 106 Italian children were randomly assigned either to the training group (*n*=55) or to the control sample (*n*=51). The participants were divided into the following three groups: 53 Yazidi children taking part in informal activities in the refugee camps in Sinjar (Kurdistan region, Iraq) (M_{age} = 64.67 months, SD = 2.9, 26 girls, age range: 61.77-67.57 months), who were administered the cognitive training; 55 Italian children (M_{age}

= 65.8 months, *SD* = 2.1, 24 girls, age range: 63.7-67.9 months), who were administered the cognitive training; 51 Italian children (M_{age} = 64.4 months, *SD* = 3.2, 29 girls, age range: 61.2-67.6 months), who were assigned to a passive control group and performed usual classroom activities. No passive control group was formed in the Yazidi sample due to the extremely difficult situation these children were living in. The extremely urgent need to provide an intervention program to enhance emotional control and cognitive abilities prevailed over methodological issues.

Table 5.2 Mean Pre-test scores in the different tasks and Univariate Test results (from MANOVA) on total Yazidi sample.

	total Yazidi sample (pre training)						
	Training (*n* = 53)		no Training (*n* = 73)		*F*		Effect size
	M	*SD*	*M*	*SD*			
Delay of gratification							
Delay time	37.2	16.4	35.9	15.6	*F* (1, 124) = 0.17, *p* = .68	ns	.08
Gift Wrap time	23.5	11.3	21.8	11.1	*F* (1, 124) = 0.34, *p* = .56	ns	.15
Gift Wrap violations	1.8	1.4	2.1	1.5	*F* (1, 124) = 2,07, *p* = .15	ns	.21
Inhibition							
Circle Drawing time	0.3	0.2	0.3	0.2	*F* (1, 124) = 0.35, *p* = .56	ns	.00
Day and Night Stroop accuracy	10.1	1.9	9.8	2.2	*F* (1, 124) = 0.33, *p* = .57	ns	.15
STM and WM							
Forward word span (sequences)	2.0	1.3	2.1	1.1	*F* (1, 124) = 0.02, *p* = .89	ns	.08
Backward word span (sequences)	1.5	1.0	1.4	1.0	*F* (1, 124) = 0.35, *p* = .55	ns	.10

The MANOVA results for hot EFs do not show a significant main effect for group factor (Wilks' Lambda = .98, *F*(3, 122) = .75, *p* = .53, η_p^2 = .02), since the two groups did not significantly differ from each other.

The MANOVA results for cool EFs do not show a significant main effect for group factor (Wilks' Lambda = .99, *F*(5, 120) = .23, *p* = .95, η_p^2 = .01), since the two groups did not significantly differ from each other.

To verify the relative magnitudes of the differences, effect sizes were calculated using Cohen's (1988) effect size formula (*d*). Based on Cohen's effect size formula (*d*), an effect size of 0.20 is considered small, an effect of 0.50 is considered medium, and an effect of 0.80 is considered large.

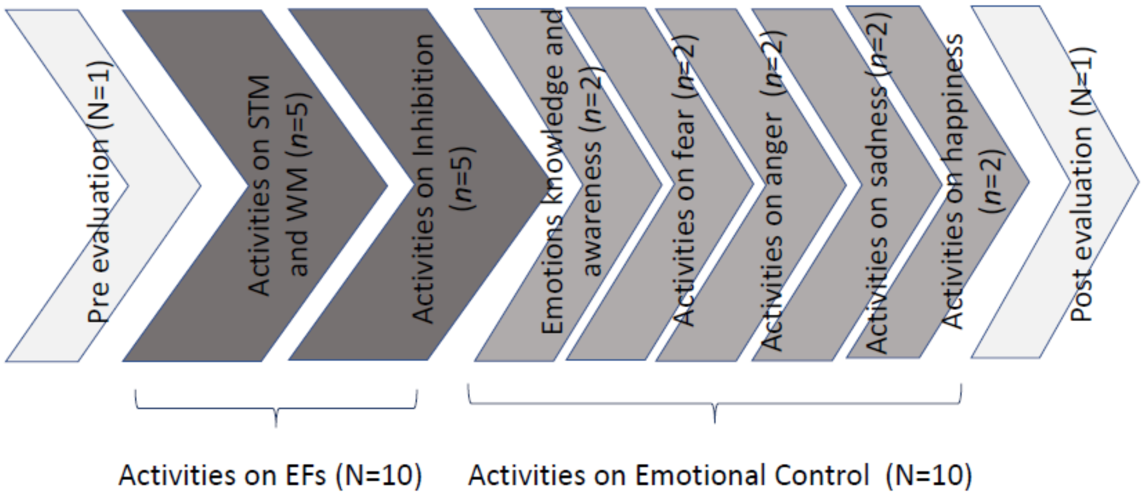
5.2.2 Training program

Intervention focused on cognitive strategies to recognize and control emotions, a well-established intervention method that has already been extensively tested in war environments (Pat-Horenczyk et al., 2009), in combination with a specific training targeting EFs as crucial aspects of children's cognitive development. The program was administered in class with a game-like approach for a total of 20 sessions (10 weeks of sessions taking place twice a week, each with a duration of about 40 minutes). Ten activities were related to EFs and ten related to emotional control. Pre- and post-assessment took place individually in a quiet room inside the schools or camps, and each assessment session lasted about 30 minutes.

The first set of activities (*n*=10) involved cognitive tasks administered in the form of games. These were based on the test battery developed by Usai and colleagues (2017) and concern short-term memory (STM) and WM (*n*=5), and Inhibition (*n*=5) abilities. WM- and STM-related activities required children to memorize poetries, song lyrics, and sequences of objects, and then repeat them forward and backward. The five games on Inhibition required children to switch behavior following suggestions (e.g., modulating their voice volume or facial movements), sometimes applying the dominant or habitual response pattern (e.g., the color red indicating "stop" and the color green indicating "move"), and sometimes changing the response pattern they have previously learned (e.g., the color green for "stop" and the color red for "move").

The second group of activities (*n*=10) was based on the approach pertaining to Rational Emotional Behavioral Therapy (Di Pietro, 2014). These tasks promote self-regulation, identification and verbalization of emotions. The activity set included two games related to knowledge and awareness of emotions and two tasks for each primary emotion (fear, anger, sadness, and happiness). At the end of each activity, applied strategies were shared and discussed by children and teachers. A schematic representation of the intervention protocol is illustrated in Figure 5.1.

Figure 5.1 Study design: representation of the intervention protocol



5.2.3 Procedure

The training for teachers, social workers, or master students, both in Kurdistan and in Italy, was organized in the form of a workshop that lasted one day and a half, and it addressed the following topics: effects of trauma on emotional and cognitive development, impact of school-based training activities on development, methods to assess EFs, and activities promoting emotional and cognitive control. In Kurdistan, the trainer illustrated all activities in English, with simultaneous translation into Kurdish. Activities involving training and assessment were illustrated in the local language spoken by the two educators involved, one male and one female, and training sessions were guided by two social workers, one male and one female. Training implementation was monitored via video connection. Pre- and post-assessment in the Italian sample was carried out by two experimenters (female Italian master students), while a third blind experimenter was in charge of the evaluation of both Italian programs. Fidelity of implementation was ensured by requiring all trainers to prove their knowledge of the program's aims, activities organization and performance, and situation management through the training schedule.

5.2.4 Pre- and post-test assessments

5.2.4.1 EFs tasks

Hot EFs

Delay task. Children were presented with a gift box and were asked to wait as long as they could before opening it, while latency was recorded. This task (adapted from Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996) is a version of the standard delay paradigm used to assess the ability of children to delay gratification (Delay Task Time, expected range 0-no limit). The test-retest reliability is .99.

Gift Wrap Delay. This task is used to evaluate the ability to delay gratification and inhibit undesirable behaviors in children (Carlson & Moses, 2001). Children were told that the examiner would wrap a present behind their back and that they should not peek until the examiner says they were allowed to do so. The examiner spent 60 seconds wrapping the gift. Latency to the first peek (Gift Wrap Task Time, expected range 0–60s) and the total number of peeks during the 1-min interval were recorded (Gift Wrap Violations, expected range 0-no limit). The test-retest reliability is .97 for the latency, and .88 for the violations.

Cool EFs

Inhibition

Circle drawing task. This task (Bachorowski & Newman, 1985) measures inhibition of on-going responses and is typically used for childhood assessments. Children must use their finger to trace a circle with a 17-cm diameter from a given starting point to a given ending point. The task was administered twice. The first time the researcher provided neutral instructions, such as "trace the circle"; the second time, inhibition instructions were provided, such as "trace the circle again but this time as slowly as you can". Larger time differences indicate better inhibition (slowing down) on the part of the participant in continuous tracing response. Time in seconds was recorded for each trial. Scores were calculated as the speed relative to the total time using the following formula: T2−T1/T2+T1, where T1 and T2 are the times recorded for the first and second trials (Circle drawing task, expected range negative to positive values-no limit). The test-retest reliability is .93.

Day and night stroop task. This task (Gerstadt, Hong, & Diamond, 1994) consists of a congruent and an incongruent (or stroop) condition. In each condition children were presented with a sequence of 16 pictures: six of them depicted the sun and the other six depicted the moon. In the congruent condition, children were required to say either "day" or "night" whenever a picture of the sun or the moon was presented. In the incongruent condition, they were required to say "day" for the picture of the moon and "night" for the picture of the sun. The pictures were always presented one at a time in a pseudo-random order. Scores were based upon the total number of trials correctly performed in each condition (expected range 0-16). The test-retest reliability is .96 for the incongruent condition.

Short-term memory and Working Memory

STM and WM are two distinct temporary memory systems. More specifically, whereas WM refers to the capacity of information storage and processing, STM involves purely temporary storage of material without any form of manipulation (Alloway, Gathercole, & Pickering, 2006).

Short-Term Memory

Forward word span task. In this task (Lanfranchi, Cornoldi, & Vianello, 2004) children were read sequences of two to five words and were then asked to repeat each list immediately after the presentation and in the same order as the examiner. The task included four different difficulty levels, depending on the length of the lists. Each level comprised two different lists, for a total of eight trials. The span was considered correct if the child could recall all the items of a sequence in the right order. A score of one was given if one of the two lists of the same difficulty level was recalled correctly (expected range 0-4). The task was administered with a self-terminating procedure, whereby it was interrupted when participants were not able to correctly perform the two trials of the same difficulty level. The test-retest reliability is .88.

Working Memory

Backward word span task. In this task, adapted from Lanfranchi and colleagues (2004), children were once again asked to memorize a list of spoken words (uttered approximately once per second), but were then required to recall it in reverse order. The test included an illustration trial and it began with two trials of two words. The number of words increased by one every two trials until two lists of the same difficulty level were recalled incorrectly. The task comprised a total of eight trials. A score of one was given if one of the two lists of the same difficulty level was recalled correctly (expected range 0-4). The test-retest reliability is .85.

5.3 Results

Means and standard deviations of pre-test and post-test scores of the three groups are presented in Table 5.3. There was no difference between the three groups in terms of chronological age, $F(2, 156) = 1.06$, $p = .35$, $\eta_p^2 = .04$, and gender, $X^2(2, 159) = 0.196$, $p = .907$, nor there was a significant difference between the two training groups in the amount of intervention sessions received, *F*(1, 106) = 0.70, *p* = .41, η_p^2 = .02. Therefore, these parameters were not further included as co-variates in the analyses.

Table 5.3 Mean Pre- and Post-test scores in the different tasks and Univariate Test results (from MANCOVA) for gain differences between the conditions.

		Yazidi Training Group				Italian Training Group				Italian Control Group				
		Pre Training		Post Training		Pre Training		Post Training		Pre Training		Post Training		*F*
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Delay gratification														
	Delay time	37.2	16.4	60.0	21.9	55.8	37.5	75.1	46.4	57.3	33.1	56.7	37.7	*F*(2, 153) = 6.74, *p* = .002
	Gift Wrap time	23.5	11.3	31.9	11.4	33.0	12.2	40.7	10.9	30.4	15.1	33.6	10.6	*F*(2, 153) = 5.35, *p* = .006
	Gift Wrap violations	1.8	1.4	0.8	0.6	0.9	0.9	0.5	0.6	1.0	1.9	0.9	1.0	*F*(2, 153) = 4.69, *p* = .012
Inhibition														
	Cicle Drawing time	0.3	0.2	0.4	0.2	0.4	0.2	0.5	0.2	0.4	0.2	0.4	0.2	*F*(2, 150) = .94, *p* = .39
	Day and Night Stroop accuracy	10.1	1.9	10.4	1.8	12.1	2.7	13.6	2.1	11.5	2.6	11.8	2.6	*F*(2, 150) = 18.32***, *p* ≤ .001
STM and WM														
	Forward word span (sequences)	2.01	1.3	2.6	1.1	2.4	1.3	2.9	1.1	2.1	1.5	2.9	1.3	*F*(2, 150) = 1.18, *p* = .30
	Backward word span (sequences)	1.5	1	1.6	0.9	1.7	1.0	1.6	1.0	1.7	1.0	1.6	1.2	*F*(2, 150) = .06, *p* = .94

Note *p < .05, **p < .01, ***p < .001

5.3.1 Pre-training evaluation

A review of the topic of hot and cool EFs in preschoolers shows that both Exploratory and Confirmatory factorial analyses distinguishes between these two aspects, thus indicating that hot and cool EFs tasks allow for the assessment of two different sets of abilities (Garon et al., 2008). In order to evaluate possible differences in the sample, therefore, we run two different MANOVAs with the three groups (Yazidis Training, Italian Training, and Italian Control) as fixed factors, and the hot EFs (Delay and Gift Wrap Delay tasks) or cool EFs factors (Inhibition and STM and WM tasks) as dependent variable.

To compare pre-test score differences between groups, η_p^2 was used as a measure of effect size. The criteria of Cohen (1988) were used to classify the effect sizes: small effect: $\eta_p^2 = .01$; medium effect: $\eta_p^2 = .06$; and large effect: $\eta_p^2 = .14$. Effect sizes (Cohen's *d*) for post hoc pairwise comparisons are also reported; small effect $d = .20$; medium effect $d = .50$; large effect $d = .80$.

Pre-training: Hot EFs

As shown in Table 5.3, mean differences emerged between the Yazidi children and the two Italian groups (training and control) in a number of hot EFs tasks. More specifically, the MANOVA results reveal a significant main effect for group factor (Wilks' Lambda = .75, $F(6, 308) = 5.21$, $p = .000$, $\eta_p^2 = .99$), since the three groups (Yazidi training group - YTG - , Italian training group - ITG - , and Italian control group - ICG -) significantly differ from each other.

Univariate test results show significant differences in the Delay Task, $F(2, 156) = 4.94$, $p = .009$, $\eta_p^2 = .79$. Bonferroni's adjusted post-hoc pair-wise comparisons indicate that the YTG waited less time before opening the present compared to the ITG ($M_{diff} = -18.66$, $p = .033$, $d = .64$) and the ICG ($M_{diff} = -20.09$, $p = .024$, $d = .77$). No difference was recorded between the two Italian groups (M_{diff} = - 6.32, p = .43, d = .04). Significant differences emerged from the Gift Wrap task - latency, F(2, 156) = 5.70, p = .005, η_p^2 = .85. Bonferroni's adjusted post-hoc pair-wise comparisons indicate that the YTG committed the first violation before the ITG (M_{diff} = - 9.48, p = .002, d = .81), but not before the ICG (M_{diff} = - 6.9, p = .07, d = .52). No difference was recorded between the two Italian groups (M_{diff} = 2.57, p = .42, d = .19). Differences related to the Gift Wrap task also concern the number of violations in the three groups, F(2, 156) = 10,70, p = 0.00, η_p^2 = .98. The YTG was statistically different from both the ITG (M_{diff} = 0.92, p = .000, d = .76) and the ICG (M_{diff} = - .85, p = .001, d = .48). No difference was observed between the two Italian samples (M_{diff} = 0.076, p = 1, d = .07). In brief, as regards hot EFs, results indicated that the YTG waited less time before opening the present and committed more violations earlier in time in the Gift Wrap Delay task, particularly compared to the ITG.

Pre-training: Cool EFs

The MANOVA results show a significant main effect for group factor (Wilks' Lambda = .81, F(10, 304) = 3.14, p = .001, η_p^2 = .95), since the three groups (YTG, ITG, and ICG) significantly differ from each other. As regards the univariate test, the Circle Drawing MANOVA analysis showed a significant difference between the groups, F(2, 156) = 4.13, p = .018, η_p^2 = .72. Bonferroni's adjusted post-hoc pair-wise comparisons indicate that YTG's slowdown time was shorter than of the ITG (M_{diff} = - 0.09, p = .016, d = .50) and ICG (M_{diff} = - 0.1, p = .011, d = .50). Again, no difference was observed between the two Italian groups (M_{diff} = 0.006, p = .88, d = .00).

In relation to the Day and Night task, significant differences were found between the groups in the number of correct answers in the stroop condition, F(2, 156) = 9.16, p = .000, η_p^2 = .97. Bonferroni's adjusted post-hoc pair-wise comparisons indicate that the YTG provided a lower number of correct answers than the ITG (M_{diff} = -2.03, p = .000, d = .86) and the ICG (M_{diff} = -1.38, p =.02, d = .61). No difference was found between the two Italian groups (M_{diff} = -0.65, p =.17, d = .23). As regards STM and WM, no significant difference was found between the three groups, either in the forward word-span task, $F(2,156) = 1.06$, $p = 0.34$, $\eta_p^2 = .23$, or in the backward word-span task, $F(2, 156) = 1.07$, $p = 0.35$, $\eta_p^2 = .24$.

In short, concerning cool EFs, the YTG provided a lower number of correct answers in the Day and Night stroop condition and, in the Circle Drawing Task, the YTG's slowdown time was shorter. Moreover, no significant difference was found between the groups with respect to STM and WM.

5.3.2 Training evaluation

Hot EFs

After the preliminary comparisons between the three experimental conditions, performance gains between the pre- and post-test sessions of all tasks were examined. Use of the gain parameter to compare pre- and post-training evaluations is a common procedure, as witnessed by various studies (e.g., Alloway, Bibile, & Lau, 2013; Brehmer, Westerberg, & Bäckman, 2012; Passolunghi & Costa, 2016). In particular, we conducted multivariate analyses of covariance (MANCOVA), with the Group (either YTG, ITG, or ICG) used as factor, pre-test scores used as covariate, and gain scores (post-test minus pre-test scores) examined as the dependent variable. Bonferroni's adjusted post-hoc pair-wise comparisons of gain scores were also applied. For the comparison of gain differences between groups, η_p^2 and effect sizes (Cohen's d) for post- hoc pair-wise comparisons were used.

MANCOVA results reveal a significant main effect for group factor (Wilks' Lambda = .72, F (6, 302) = 4.8, p = .000, ηp2 = .98), since the three groups (YTG, ITG, and ICG) significantly differ from each other. More specifically, the univariate analysis carried out on the Delay task indicate a significant difference between the groups, *F*(2, 153) = 6.74, *p* = .002, ηp2 = .90, reflecting differential treatment effects. Indeed, the YTG (*Mdiff* = 19.89, *p* = .02, *d* = .11) and ITG (*Mdiff* = 27.45, *p* = .002, *d* = .44) show better ability to delay gratification in this task compared to the ICG. No difference was observed between the YTG and the ITG in this task (*Mdiff* = .02, *p* = 1, *d* = .09).

The analysis performed on the Gift Wrap task latency shows a significant difference between the groups, *F*(2, 153) = 5.35, *p* = .006, ηp2 = .82, reflecting differential training effects. Bonferroni's adjusted post-hoc pair-wise comparisons indicate a significant effect of the training on the latency performance in the ITG compared to the ICG (*Mdiff* = 8,4, *p* = .005, *d* = .66), but not compared to the YTG (*Mdiff* = 3.7, *p* = .42, *d* = .79). No differences were found between the YTG and the ICG (*Mdiff* = 4.6, *p* = .16, *d* = .15).

The MANCOVA analysis also shows a difference between the groups in Gift Wrap task violations, *F*(2, 153) = 4.69, *p* = .012, ηp2 = .77. Bonferroni's adjusted post-hoc pair-wise comparisons indicate a lower number of violations in the ITG compared to the YTG (*Mdiff* = -.25, *p* = .029, *d* = .50) and the ICG (*Mdiff* = -.27, *p* = .022, *d* = .49). No difference was observed between the YTG and the ICG (*Mdiff* = .018, *p* = 1, *d* = .12).

In short, as regards hot EFs training in relation to the Delay Task, our results indicated an increase in waiting time before opening the gift in both trained groups (YTG and ITG). Furthermore, in the Gift Wrap Delay task, latency time before the first violation was longer and the number of violations lower in the ITG, particularly compared to the ICG.

Cool EFs

The MANCOVA results reveal a significant main effect for group factor (Wilks' Lambda = .77, *F*(10, 292) = 3.09, *p* = .000, ηp2 = .99), since the three groups (YTG, ITG, and ICG) significantly differ from each other. The univariate analysis does not show any significant difference between the groups in the Circle Drawing task, *F*(2, 150) = .94, *p* = .39, ηp2 = .21. In relation to the Day and Night task, univariate analysis shows a sizeable difference between the groups in the number of correct answers given in the stroop condition, *F*(2, 150) = 18.32, *p* = .000, ηp2 = 1. Bonferroni's adjusted post-hoc pair-wise comparisons indicate that the ITG displayed a significant improvement in the task, with considerable increase in the number of correct answers in the stroop condition, higher than the ICG (*Mdiff* = 1.39, *p* = .000, *d* = .76) and the YTG (*Mdiff* = 2.2, *p* = .000, *d* = 1.64). There is no significant difference between the YTG and the ICG (*Mdiff* = -.81, *p* = .44, *d* = .63). In relation to STM and WM no difference was found between the three groups, either in STM, *F*(2, 150) = 1.18, *p* = .30, ηp2 = .25, or in WM, *F*(2, 150) = .06, *p* = .94, ηp2 = .06.

In a nutshell, with respect to cool EFs training, the ITG showed significant improvements in the number of correct answers in the Day and Night stroop condition. No other differences were observed. A summary of the effects of the training program and related effect sizes is reported in Table 5.4.

Table 5.4 A summary of the effects of the training program and related effect sizes.

	Group effect			
	F	Groups	Direction	Effect size (*d*)
Delay of gratification				
Delay time	6.74**	YTG ICG	YTG > ICG	0.11
		ITG ICG	ITG > ICG	0.44
		YTG ITG	*No difference*	0.09
Gift Wrap time	5.35**	YTG ICG	*No difference*	0.15
		ITG ICG	ITG > ICG	0.66
		YTG ITG	*No difference*	0.79
Gift Wrap violations	4.69*	YTG ICG	*No difference*	0.12
		ITG ICG	ITG > ICG	0.49
		YTG ITG	YTG < ITG	0.50
Inhibition				
Circle Drawing time	*ns*	YTG ICG	*No difference*	0.36
		ITG ICG	*No difference*	0.23
		YTG ITG	*No difference*	0.12
Day and night Stroop accuracy	18.32***	YTG ICG	*No difference*	0.63
		ITG ICG	ITG > ICG	0.76
		YTG ITG	YTG < ITG	1.74
STM and WM				
Forward word span (sequences)	*ns*	YTG ICG	*No difference*	0.20
		ITG ICG	*No difference*	0.25
		YTG ITG	*No difference*	0.03
Backward word span (sequences)	*ns*	YTG ICG	*No difference*	0.14
		ITG ICG	*No difference*	0.00
		YTG ITG	*No difference*	0.15

Note. *ns* = not significant, *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$.

5.4 Discussion

The present work focuses on specific cognitive aspects known as EFs. A careful literature review indicates that this study may be the first research effort aimed at (a) evaluating hot and cool EFs in five-year-old children living in a critically adverse context (Yazidi minority group) compared to children living in a typical context (Italian children); and (b) estimating the effect of a cognitive training method on hot and cool EFs in children that survived genocide.

Concerning the first aspect, hot and cool EFs in child survivors of genocide is still an under-researched topic in literature, to which we intend to contribute. Our data indicate that five-year-old children living in a critically adverse context show lower scores in tasks concerning delay of gratification. This outcome corroborates results presented in previous studies indicating the impact of low socioeconomic status (SES) environmental contexts on the development of the hot aspects of EFs (Raver et al., 2011). This is a crucial evidence when considering the link between EFs, specific educational achievement, and emotional regulation later in life (Poon, 2017). Furthermore, Yazidi children show lower ability in tasks requiring both motor inhibition (Circle Drawing) and the control of prevalent response (Day and Night Stroop) compared to their Italian counterpart. This aspect seems to confirm previous research carried out on the effect of trauma and institutionalization on cool EFs (DePrince et al., 2009; Merz et al., 2016).

It is worth noticing that tests on both STM and WM (measured as forward and backward word span) yielded equal results from the three groups. These data are consistent with recent findings showing that WM does not seem to depend on financial background/SES and mothers’ educational level (Alloway et al., 2017).

Our research provides for a significant contribution to the literature on cool (in particular inhibition-related) and hot (delay of gratification) EFs, clearly indicating that both are affected by the extremely violent environmental situation Yazidi children were exposed to when they were about one year old, confirming possible stress-related neuro-cognitive effects on brain areas connected with the control of EFs (McEwen & Morrison, 2013). In this critical situation, Yazidi children are at risk of social, educational, psychological, and behavioral problems. Our data highlight the need to implement programs to reduce the risk of long-term cognitive damage, while enhancing resilience in children who live in contexts of war and terrorism.

Our preliminary survey showed an extremely difficult starting-point situation, requiring the development of a targeted training program. This training method was specifically designed to address the development of hot and cool EFs, promoting their enhancement through specific games illustrated in the relevant literature (Traverso et al., 2015). The program focused on cognitive aspects of EFs, but it also included activities related to cognitive strategies to control emotions (Di Pietro, 2014; Ellis & Bernard, 2006). Compared to the control sample, Yazidi and Italian training groups showed a significant improvement in hot EFs (delay of gratification). This particular finding is pivotal, as hot EFs abilities appeared to be impaired during our preliminary assessment. More specifically, by the end of the program, Yazidi children's performance has reached the mean levels of their Italian peers belonging to the control sample. The current literature suggests that EFs are strong predictors of school readiness, academic achievement, and behavioral and social competence (Jacobson et al., 2011), showing that hot EFs components may be relevant in daily life activities, academic performance, social relationships, and psychological well-being (Poon, 2017). Therefore, we consider a very encouraging result the fact that, after training, Yazidi children improved their ability to delay gratification.

Contrary to the training proposed by Traverso and colleagues (2015), that showed mixed results on hot EFs, our data on Italian children yielded evidence of the positive effect of our program on these aspects. This may be related to the program's specific sections devoted to the cognitive management of feelings during the training. These emotional control activities, together with a specific tailoring of the program to the development of EFs and a higher number of sessions (N=12 in Traverso et al., 2015, N=20 in the present training), may have been the main factors promoting the improvement of delayed gratification abilities. Only one study conducted in this field and involving a purely cognitive computer-based training indicated permanent improvements of hot EFs without a specific training on emotional control (Rueda et al., 2012).

In line with other studies that promote basic components of EFs, our program showed improvements in inhibition abilities (Bierman et al., 2008; Raver et al., 2011; Röthlisberger et al., 2011), but not in STM and WM abilities in Italian children. The same could not be observed in the Yazidi children, whose impaired inhibition abilities did not benefit from the training. We think this result could be attributed to both the highly traumatic experience suffered by Yazidi children and the adverse conditions in which they are living. Perhaps a longer training could prove more effective in improving EFs in these particular conditions. Our data, however, seem to point to a specific effect of the training on inhibition in salient emotional contexts.

Our study is limited in several ways. First of all, from a methodological point of view, the absence of a Yazidi control group may represent a problem. Research in this field underlines the need to recruit a control sample in the same country of the training sample (Bos, Fox, Zeanah, & Nelson, 2009), based on the differences emerged in studies that compare EFs in different countries (Lan, Legare, Ponitz, Li, & Morrison, 2011). However, as mentioned above, the situation we observed and the context in which we were working called for immediate intervention. Secondly, the specific environmental and political situation experienced by Yazidi children may not be representative of other different forms of deprivation. A third limit of this study concerns duration: while an increment in hot EFs was observed immediately after the training, it was not possible to verify the program's long-term effects, or its repercussions on school performance once children enter formal education. Future longitudinal perspectives could provide further insight into these matters. As a last point, Yazidi children that could follow the entire program may be living in a better family environment than those who could not, which could have been the reason why they were more motivated and less affected by the traumatic consequences of war. However, our analysis revealed no differences in hot and cool EFs between the Yazidi children who completed the training program and those who interrupted it, thus excluding the presence of a possible selection bias. Furthermore, developmental trajectories of EFs may vary on the basis of various mediating and moderating factors that we have not taken into account: genetic background (Brett et al., 2015), age-related differences involved in the degree of PFC vulnerability to stressors, individual neuronal resilience, recovery-related plasticity mechanisms (McEwen & Morrison, 2013), severity, timing, and duration of deprivation (Beckett, Castle, Rutter, & Sonuga-Barke, 2010).

It is our belief that this study contributes the literature in numerous ways: firstly, it is a first attempt to evaluate cognitive consequences of war trauma, providing important insight into EFs current knowledge through the close observation of specific detrimental consequences of war on EFs. Secondly, and consistently with the literature, this research shows a higher level of hot cognitive control, in both the Italian and the Kurdish educational setting, thereby confirming the importance of school-based activities for specific interventions. Considering the specificity of our program, follow-up research is required in order to test its validity in other, different cultural contexts, or in the case of migrant children fleeing their home countries with their families after experiencing traumatic events there. The possibility of exporting and applying our training in contexts related to other current social phenomena may validate its usefulness as research tool in the investigation of cool and hot EFs, to acquire a more comprehensive perspective on child development, while helping future adults deal with the scourge of war.

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Chapter 6

General Discussion

6.0 Discussion

The general aim of the present dissertation was to provide a cognitive-environmental approach to understanding and promoting the development of early numerical skills from preschool to the beginning of primary school. This purpose was rooted in the knowledge that mathematical learning is a very complex and articulated process in which many factors come into play during a child's development. Therefore, referring to Bronfenbrenner's ecological multi-systemic model (1979) and Rubinsten and colleagues' developmental bio-psycho-social model (2018), we decided to adopt a multifactorial approach, which takes into account the impact of both cognitive abilities (i.e., domain-general and domain-specific precursors of math knowledge) and environmental aspects (i.e., the political, socio-economic, and cultural context in which a child lives in) on the development of early mathematical skills at a very early age, that is from the beginning of preschool to entry into primary school.

In pursuing the general purpose of the dissertation, we focused the first part of the thesis on the role of cognitive factors involved in early math knowledge (Chapters 2 and 3) and the second part on the impact of environmental conditions on the development of early numerical skills (Chapters 4 and 5). More in detail, we addressed the following questions: a) the investigation of the domain-general and domain-specific cognitive predictors of growth in typically developing children's early numerical competence as well as the developmental dynamics between different specific mathematical skills through the first two years of preschool (Chapter 2); b) the examination of the relative contributions of Working Memory (WM) domains and processes to typically developing children's math performance before and after the transition to primary school (Chapter 3); c) the exploration of the signature of living in highly deprived environments (i.e., war context and refugee condition) on children's Executive Functions (EFs) and early mathematical skills (Chapter 4); d) the assessment of hot and cool EFs in children living in a war context who survived genocide and the implementation of a training program to improve these children's EFs as well as the evaluation of its effectiveness (Chapter 5).

6.0.1 Cognitive predictors of growth in early numerical competence and developmental dynamics between different math skills in preschoolers.

In the last few years, extensive research showed the significant role of both domain-general and domain-specific cognitive precursors in predicting preschoolers' mathematical knowledge (e.g., Geary et al., 2018; Geary, vanMarle, Chu, Hoard, & Nugent, 2019; Gray & Reeve, 2014, 2016; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; LeFevre et al., 2010; Passolunghi, Lanfranchi, Altoè, & Sollazzo, 2015; vanMarle et al., 2016; Xenidou-Dervou, Molenaar, Ansari, van der Schoot, & van Lieshout, 2017). However, previous studies examining the predictors of early numerical development at the beginning of preschool education (e.g., Geary et al., 2018; Geary et al., 2019; vanMarle et al., 2016) have focused on the factors underlying the level of acquisition of emergent math skills at a given time point, whereas no study thus far has sought to determine which factors predict the rate of change or growth (i.e., the development) of early mathematical skills from age 3 to age 4, that is through the first two years of preschool. Moreover, regarding the predictive role of domain-specific cognitive precursors (i.e., subitizing ability and ANS acuity), empirical evidence is quite scarce and in part inconsistent, with a shortage of studies focusing on subitizing (e.g., Gray & Reeve, 2014; Hannula-Sormunen, Lehtinen, & Räsänen, 2015; Hannula, Räsänen, & Lehtinen, 2007; Kroesbergen et al., 2009; LeFevre et al., 2010), and contradictory findings regarding the relationship between ANS acuity and mathematical knowledge in preschoolers. In fact, such association emerged in some studies (e.g., Libertus, Feigenson, & Halberda, 2011; vanMarle et al., 2016) but not in others (e.g., Negen & Sarnecka, 2015; Sasanguie, Defever, Maertens, & Reynvoet, 2014). Furthermore, it is surprising that only one study (vanMarle et al., 2016) to date has examined the relative contributions to early mathematical skills of subitizing and ANS acuity in combination. In addition to that, to the best of our knowledge, no previous research explored the developmental dynamics between different specific early math skills, and the sequential order in which they develop over time at such an early age. Most research with preschoolers, in fact, used global measures of mathematics achievement including a wide range of numerical skills (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Kroesbergen et al., 2009; Passolunghi et al., 2015; Xenidou-Dervou et al., 2017), without giving the possibility of understanding how the different early-emerging math skills are intertwined with each other.

In the light of the gaps described above, our research findings (Chapter 2) extend previous literature in several ways, enriching knowledge about the contribution of domain-general (i.e., verbal intelligence, visuo-spatial WM, and processing speed) and domain-specific (i.e., subitizing and ANS acuity) cognitive precursors to the emergence of different early mathematical skills (i.e., counting ability, symbol-quantity mapping, and cardinality proficiency) in the first year of preschool, and to the improvement in each of these skills between age 3 and age 4, as well as the developmental changes occurring in math learning through the first two years of preschool. Taken together, our results suggest that both domain-general and domain-specific cognitive precursors support the acquisition and the development of early mathematical skills through the preschool years. However, it is worth noticing that the precursors of starting points of each math skill were not the same as those predicting subsequent ability gains.

More in detail, as regards initial levels of math abilities, processing speed emerged as a significant predictor of counting, symbol-quantity mapping, and cardinality as well as verbal intelligence exerted a direct influence in predicting both counting and cardinality skills. On the other hand, the role of visuo-spatial WM resulted more limited, as it only predicted the initial level of cardinality proficiency. Among domain-specific precursors, subitizing emerged as a significant predictor of counting, symbol-quantity mapping, and cardinality at age 3, whereas ANS acuity did not. Results regarding the growth in early mathematical skills over time further highlight the pivotal role of subitizing as a critical precursor. In fact, subitizing emerged as a unique predictor of improvement in both counting and cardinality, whereas neither ANS acuity nor domain-general cognitive abilities predicted any change in early math skills from age 3 to age 4. For the first time, this result emphasizes that subitizing not only underlies punctual levels of math knowledge at very young ages, but also influences the pace at which children improve their emerging abilities through the preschool years. This finding may have relevant implications at both educational and practical level, since the rate of growth in early math skills prior to school entry has emerged as the best predictor of high-school math achievement – above and beyond the level of mastery of such skills at a given time point (see Watts, Duncan, Siegler, & Davies-Kean, 2014). In this perspective, it is worth developing and implementing training interventions focused on subitizing in order to foster the improvement of early math skills through the preschool years.

Concerning the dynamic interrelations between simpler and more complex mathematical skills, our findings indicate that early acquisition of simpler math skills plays a crucial role in setting children’s developmental learning trajectories related to more advanced mathematical knowledge. This means that children with higher levels of basic skills at the beginning of preschool (i.e., at age 3), not only show higher levels of more complex skills concurrently, but also improve their mastery of those skills over time (i.e., between the age of 3 and 4) at higher rates than children with lower levels of basic skills at the beginning. Consequently, it would be very relevant from an educational point of view to invest in training programs for the early improvement of basic mathematical skills in order to develop a cumulative advantage and trigger a virtuous circle in support of the development of mathematical learning as early as the beginning of preschool. Going in the same direction, more research is needed to explore the role of other cognitive predictors, such as EFs (e.g., inhibition), attention, or phonological abilities, as well as the verbal component of WM, in predicting early math knowledge through the first two preschool years. Moreover, further studies ideally covering the transition into primary school, when math learning becomes the object of formal education and evaluation, could provide more useful information in order to develop increasingly targeted, age-appropriate and effective interventions to enhance early mathematical abilities.

6.0.2 The contributions of different WM domains and processes to preschoolers' and first graders' early mathematics.

Investigating the cognitive foundations of mathematical competence, previous studies showed that WM plays a crucial role in supporting children's mathematical learning, influencing both the acquisition of more basic numerical skills and subsequent development of more complex math abilities (e.g., Alloway & Alloway, 2010; De Smedt et al., 2009; DeStefano & LeFevre, 2004; Menon, 2016). However, there is still an absence of shared consensus on the relative contributions of different WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., high-control and low-control) to math performance at different developmental stages of mathematical learning, specifically before and after the onset of formal education.

Regarding the role of WM domains in the development of mathematical learning (for a review see Peng, Namkung, Barnes, & Sun, 2016), to date the results are still inconsistent and unconclusive. More in detail, visuo-spatial WM measures have been found to be strongly related to mathematics in both preschool (e.g., De Smedt et al., 2009; Holmes & Adams, 2006; Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015) and primary school (e.g., Mammarella, Caviola, Giofrè, & Szűcs, 2017; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014; Trbovich & LeFevre, 2003). Concerning the contribution of verbal WM domain, the results are particularly controversial. Indeed, on the one hand, some studies suggested an increasing involvement of verbal WM skills in mathematical cognition as children grow older (De Smedt et al., 2009; Rasmussen & Bisanz, 2005; Roussel, Fayol, & Barrouillet, 2002); on the other hand, other research has showed that the contribution of verbal WM is typically more evident during very early stages of mathematical skills acquisition (i.e., ages 4-5), with an increasingly critical role of visuo-spatial WM skills during later stages of math learning (Menon, 2016; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Soltanlou, Pixner, & Nuerk, 2015). Moreover, with reference to the verbal WM domain, research investigating the different role played by numerical and non-numerical verbal WM measures with respect to the development of math skills focused only on children with Mathematical Learning Disability (MLD), not reporting any data on typically developing children.

Also regarding the contributions of different WM processes to early math knowledge, results are still not conclusive. More in detail, previous literature highlighted a contribution of high-control WM processes to mathematics both in preschool (e.g., Espy et al., 2004; Passolunghi & Lanfranchi, 2012) and in primary school (e.g., De Smedt et al., 2009; Geary, Hoard, & Nugent, 2012; Imbo & Vandierendonck, 2007; Passolunghi, Vercelloni, & Schadee, 2007). Concerning the link between low-control WM processes and math knowledge, results are more inconsistent. On one side, some studies did not find a significant relation between low-control WM skills and mathematical achievement neither in preschoolers (e.g., Passolunghi & Lanfranchi, 2012) nor in primary school (e.g., Imbo & Vandierendonck, 2007). On the other side, other research showed that low-control WM skills are involved in specific tasks, such as counting (Logie & Baddeley, 1987) and calculations without carrying or borrowing operations (Fürst & Hitch, 2000) as well as in primary school children’s problem-solving ability (Fung & Swanson, 2017). In the light of the inconsistent results described above, we were interested in uncovering the relations between different WM domains and processes and early mathematical knowledge at different developmental stages, specifically before and after the onset of formal education (Chapter 3), since no previous study had specifically focused on this particular transitional education phase.

In sum, our results showed a variation in the role of both WM domains and processes in predicting early mathematical knowledge depending on children’s developmental stage. Specifically, visuo-spatial WM domain was more strongly associated to mathematics in preschoolers than in first graders, while verbal WM domain emerged as a significant predictor of math only among first graders, but not among preschoolers. Regarding numerical-verbal WM domain, it played a significant role in both age groups, but it was found to predict early mathematical knowledge to a much larger extent among preschoolers than among first graders. Concerning the relations between different WM processes and early mathematical knowledge, our results revealed on the one hand a significant contribution of both low-control and high-control WM skills in preschoolers, on the other hand a leading role of high-control WM over that of low-control WM in first graders.

Overall, these findings add to the body of research by providing new insights into the relations between WM domains and processes and early mathematical knowledge at different developmental stages of math learning. In particular, our study suggests new information about the specific contribution of numerical-verbal WM skills to early mathematics, suggesting that the ability to remember and manipulate numerical information while performing mathematical tasks is crucial not only in children with MLD, as already suggested by former research (Andersson & Lyxell, 2007; Hitch & McAuley, 1991; Passolunghi & Cornoldi, 2008; Passolunghi & Siegel, 2004; Peng et al., 2016; Siegel & Ryan, 1989), but also in typically developing children, before and after the onset of formal education. These results provide useful suggestions for the development of age-appropriate and effective training programs aimed at promoting early enhancement of WM skills and, at the same time, preventing the onset of difficulties in math learning already from preschool age onwards. In this regard, numerical-verbal WM skills could represent a fruitful target for both the implementation of training interventions and early detection of children at risk for mathematical difficulties. However, further longitudinal studies are needed to extend our results and investigate developmental changes and differences in the relations between different WM domains and processes and early mathematical knowledge in response to children's cognitive development and level of education, considering also the role of other cognitive abilities as well as the developmental trajectories of specific children's math abilities.

6.0.3 EFs and early mathematical skills in children living in highly deprived environments.

A considerable amount of research has highlighted a robust relationship between children's EFs and their learning abilities and academic outcomes (e.g., Blair & Razza, 2007; Bull & Lee, 2014; Clark, Pritchard, & Woodward, 2010; McClelland et al., 2014). In particular, by means of a cascade effect, EFs resulted fundamental for the acquisition and mastering of more complex skills, such as early mathematical abilities (e.g., Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Clark et al., 2010; Passolunghi & Lanfranchi, 2012). Moreover, moving from a purely cognitive to an environmental point of view, recent studies underlined the deleterious effects of early life stresses on the development of EFs (see McEwen, 2008; Shonkoff, Boyce, & McEwen, 2009), suggesting that WM (both high-control and low-control) and inhibition skills, developing earlier compared to other EFs abilities, seem to be particularly vulnerable to early deprivation (Garon, Bryson, & Smith, 2008; Jurado & Rosselli, 2007). Consequently, a growing number of studies has explored the effects of environmental conditions characterized by disadvantaged or deprived contexts, trauma, maltreatment, or abuse on EFs' development in children (e.g., Blair et al., 2011; Evans & Fuller-Rowell, 2013; Merz, Harlé, Noble, & McCall, 2016; Welsh, Nix, Blair, Bierman, & Nelson, 2010).

However, to date, literature on EFs is surprisingly lacking on children living in war-affected contexts, and related refugee conditions, and no previous study specifically focused on the development of learning abilities, in the case in point early math skills, in children living in these highly deprived conditions. In order to fill this gap and considering the disrupting effects of stressful experiences on the development of EFs as well as the influences of EFs on early mathematics achievement, our study (Chapter 4) explored the signature of living in highly deprived contexts on EFs and early mathematical abilities, by comparing three groups of preschool children coming from different socio-cultural and economic backgrounds (i.e., Yazidis, Syrian refugees, and Italians), thus representing a first attempt to evaluate these relevant cognitive abilities in highly deprived children. More specifically, it enriches previous research exploring the relation between living in specific deprived environments, namely war context and refugee condition, and showing poor EFs as well as lower early mathematical skills.

In a nutshell, our findings revealed that the two groups of Yazidi and Syrian children, both coming from highly deprived backgrounds characterized by war context and refugee condition respectively, not only showed lower EFs skills but also revealed significantly poorer early mathematical abilities than Italian preschoolers. This means that, although all three groups of participants had not yet had access to formal mathematical education and thus to a systematic approach to the concept of number, already at this early developmental and educational stage, more deprived children showed a disadvantage in the level of development of both domain-general precursors, such as EFs, and more complex skills, like early math abilities, compared to their peers from middle socio-economic background. In other words, children living in socio-economically deprived contexts are a particularly vulnerable population who is likely to develop a further cumulative disadvantage in mathematical learning. In view of this risk, our results may represent a starting point for implementing intervention strategies aimed at providing concrete tools to base achievement abilities, preventing an entire cohort of children from becoming a “lost generation”. From this point of view, our study also takes on a social and human value serving as a basis to offer to all children in the world, regardless of their socio-economic and cultural background, the same opportunities to develop their own learning processes. Anyway, future longitudinal studies are needed to deepen the complexity of the relationship between levels of EFs and early mathematical abilities, exploring how this link change over time, focusing not only on WM and inhibition but also on other EFs, such as updating, shifting, or planning abilities, as well as using more tools instead of just one to measure the different EF skills. Moreover, further research might consider the role of other bio-psycho-social variables that could mediate or moderate the relationship between EFs and early math abilities, such as genetic background, the degree of prefrontal cortex vulnerability to stressors, children’s family composition, difficulties and/or traumas related to prenatal and/or perinatal status, the level of poverty experienced by children or their possibilities to access to medical care. The consideration of all these aspects could shed light on certain risk and protective factors for the development of EFs and mathematical abilities in highly deprived contexts.

6.0.4 Hot and cool EFs in genocide survivors and the implementation of a training program to improve them.

Previous research highlighted that children’s EFs development is profoundly affected by stressful and traumatic conditions, as well as the socio-economic context (e.g., DePrince, Weinzierl, & Combs, 2009; Rogosch, Dackis, & Cicchetti, 2011; Welsh et al., 2010), with critical repercussions especially on inhibition and WM abilities (Merz et al., 2016), since they are thought to develop at an earlier stage with respect to the other EFs components (Garon et al., 2008). In this regard, while studies on cool EFs seem more consistent, research on the effects of hot EFs on development is still limited as well as the relationship between them and early deprivation is still unclear. Moreover, with respect to possible stressful living conditions, surprisingly, studies on EFs in children growing up in war contexts are quite scarce and focus exclusively on first aid support (Kar, 2009), emotional control, and trauma (Betancourt et al., 2012; Pat-Horenczyk et al., 2013). Regarding the interventions on EFs, various types of training aimed at promoting EFs in typically developing preschool children from middle-class and low-income backgrounds were developed. However, while they have consistently shown positive effects on cool EFs in preschoolers, although with some contradictory data on inhibition skills, training programs including hot EFs are still under-researched.

In the face of this lacking literature, our study (Chapter 5) represents a first attempt at evaluating and training both hot (i.e., delay of gratification) and cool (i.e., inhibition, Short-Term Memory [STM] and WM) EFs in a group of five-year-old Yazidi children who survived genocide, comparing them to a sample of Italian preschoolers living in a typical environmental context. Moreover, we also evaluated the effectiveness of our training program in order to assess its potential usefulness in other deprived contexts. Our findings suggested that Yazidi children showed different baselines in delay of gratification as well as inhibition-related abilities compared to their Italian counterpart. These preliminary data highlighted an extremely difficult starting-point situation, requiring the implementation of a targeted training program focused on both cognitive aspects of EFs and cognitive strategies to control emotions (see Di Pietro, 2014; Ellis & Bernard, 2006). After training, both Yazidi and Italian training groups showed a significant improvement in delay of gratification, while, regarding cool EFs, significant improvements in inhibition abilities have been noted in

Italians but not in Yazidis. Since hot EFs have emerged as relevant in daily life activities, academic performance, social relationships, and psychological well-being (see Poon, 2017), we consider a very encouraging and promising result the fact that, after training, Yazidi children, a population at risk of social, educational, psychological, and behavioral problems, improved their ability to delay gratification.

However, in future research, it will be desirable to explore the development of EFs in other conditions of deprivation, such as in migrant children fleeing their home countries with their families after experiencing traumatic events there, possibly also recruiting a control group with a similar background, as well as considering the potential influence of other mediating and moderating factors, such as severity, timing, and duration of deprivation. Moreover, future longitudinal investigations and follow-up research could provide further insight into the impact and the long-term effects of a training intervention such as ours on school performance once children enter formal education. The possibility of exporting and applying our training program in other socio-cultural and political contexts on the one hand may validate its usefulness as research tool in the investigation of cool and hot EFs, reducing the risk of long-term cognitive damage, on the other hand could enhance resilience in children who live in contexts of terrorism, helping them to deal with the scourge of war. These implications represent worthwhile opportunities to prevent Yazidi children who survived genocide from becoming a "lost generation", affirming their inalienable right to enjoy the same educational and developmental opportunities as all other children in the world. A summary of all four studies described in the present dissertation, showing their aims, the characteristics of the samples, and their main findings, is reported in Table 6.1.

Table 6.1 A summary of the four studies described in the present dissertation.

	Aims	Characteristics of the samples	Main findings
Study 1 (Chapter 2) Longitudinal study	**A)** To investigate the contribution of domain-general (i.e., verbal intelligence, visuo-spatial WM, and processing speed) and domain-specific (i.e., subitizing and ANS acuity) cognitive predictors to both the initial level of different early mathematical skills (i.e., counting ability, symbol-quantity mapping, and cardinality proficiency) in the first preschool year and their growth (i.e., change) from age 3 to age 4. **B)** To explore the developmental dynamic relations between these mathematical skills through the first two years of preschool.	354 typically developing preschoolers (168 F) tested at two different moments: Time 1: first year of preschool (M_{age} = 45.67 months); Time 2: second year of preschool (M_{age} = 52.68 months).	**A1)** Processing speed, verbal intelligence, visuo-spatial WM and subitizing emerged as predictors of initial level of early math skills in the first preschool year, whereas ANS acuity did not. **A2)** Subitizing emerged as a unique predictor of growth in early math skills from age 3 to age 4. **B1)** Substantial dynamic interrelations between the initial levels of simpler mathematical skills at age 3 and later improvements in more complex abilities between the age of 3 and 4. **B2)** Processing speed, verbal intelligence and subitizing exerted an indirect effect on change in cardinality, through their positive influence on the initial level of counting and symbol-quantity mapping.
Study 2 (Chapter 3) Cross-sectional/transversal study	**A)** To examine the relative contributions of WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) to early math knowledge before and after the transition to primary school.	176 typically developing children: • 66 preschoolers (final year of preschool): M_{age} = 51.82 months (30 F); • 110 first graders: M_{age} = 80.09 months (57 F).	**A1)** Visuo-spatial WM domain was more strongly associated to mathematics in preschoolers than in first graders. **A2)** Verbal WM domain emerged as a significant predictor of math only among first graders.

			A3) Numerical-verbal WM domain played a significant role in both age groups, although to a greater extent among preschoolers. **A4)** A significant contribution of both low- and high-control WM skills among preschoolers, **A5)** A leading role of high-control WM over that of low-control WM among first graders.
Study 3 (Chapter 4) Cross-sectional/transversal study	**A)** To explore the signature of living in highly deprived environments (i.e., war context and refugee condition) on preschoolers' EFs and early mathematical abilities, by comparing three groups of children coming from different socio-cultural and economic backgrounds (i.e., Yazidis, Syrian refugees, and Italians).	Three groups of preschool children (*n*=150): • 48 Yazidis: M_{age} = 71 months (24 F); • 47 Syrian refugees: M_{age} = 68.77 months (24 F); • 55 Italians: M_{age} = 68.65 months (28 F). Yazidis and Syrians came from highly deprived backgrounds (i.e., war context and refugee condition, respectively), while Italians belonged to middle socio-economic status.	Yazidis and Syrian refugees: **A1)** Showed poorer EFs skills than Italian preschoolers: • inhibition resulted more impaired in both Yazidis and Syrians than Italians; • high-control WM emerged as worse only in the sample of Yazidis compared to Italian group; **A2)** Revealed significantly poorer early mathematical abilities than Italians, by performing worse all four mathematical tasks used in the study.
Study 4 (Chapter 5) Training study	**A)** To further investigate hot and cool EFs in five-year-old children living in a war context who survived genocide (Yazidi minority group), by comparing them to children living in a typical context (Italian children).	Three groups of preschool children: • 53 Yazidis (training group): M_{age} = 64.67 months (26 F);	**Pre-training evaluation:** **A1)** Yazidis showed lower delay of gratification and inhibition abilities compared to Italians; **A2)** The three groups of children did not differ in STM and WM abilities.

	B) To implement a training program to improve these children's hot and cool EFs, also assessing its effectiveness.	- 55 Italians (training group): M_{age} = 65.8 months (24 F); - 51 Italians (control group): M_{age} = 64.4 months (29 F).	**Training evaluation:** **B1)** Both Yazidi and Italian training groups showed a significant improvement in hot EFs (i.e., delay of gratification) compared to the Italian control sample; **B2)** Italians showed improvements in inhibition; **B3)** Yazidis' impaired inhibition abilities did not benefit from the training; **B4)** No improvements in STM and WM were found in any of the three groups.

6.0.5 Educational implications and future directions.

The results of the present dissertation may have several practical implications from the point of view of both early prevention of MLD and promotion of the development of children's numerical competence. More in detail, findings of Chapters 2 highlighted the critical role of both domain-general (i.e., processing speed, verbal intelligence, and visuo-spatial WM) and domain-specific (i.e., subitizing) cognitive precursors in predicting the acquisition of preschoolers' early mathematical knowledge as well as emphasized the unique pivotal role of subitizing as a critical precursor of growth in early mathematical skills over time. Taken together, these data configure subitizing both as a marker, that is a natural foundational basis, and as a catalyst for children's mathematical development through the preschool years. In this regard, children with low-level of subitizing ability at the beginning of preschool may be less likely to acquire basic numerical knowledge from as early as 3 years of age, and, more importantly, may be particularly at risk of developing a cumulative disadvantage in later mathematical learning. Thereby, an early deficit in subitizing ability could be considered a core deficit underlying math difficulties useful to early screen and identify children at risk for MLD. Likewise, early difficulties in processing speed, verbal intelligence, or visuo-spatial WM could serve as indicators of possible future difficulties in math, making children more at risk of experiencing delays or problems in acquiring basic numerical skills. In the face of these results, the other side of the coin is the possibility to develop and implement targeted and appropriate training programs and interventions specifically focused on the significant predictors of both acquisition and growth of early math knowledge during preschool years. In this sense, educational practices and activities aimed at strengthening subitizing, processing speed, verbal intelligence, and visuo-spatial WM may be effective in fostering both the emergence and development of math skills, from the simplest to the most complex ones. However, future studies should further investigate the potential role of other cognitive precursors in predicting early math knowledge, such as EFs, attention, or phonological abilities (e.g., Cragg & Gilmore, 2014; Chu, Hoard, Nugent, Scofield, & Geary, 2019; Kroesbergen et al., 2009; Passolunghi et al., 2015), also monitoring its development through a longer span, ideally covering the transition into primary school, thus adopting a longitudinal perspective.

Similarly, the findings of Chapter 3 showed which are the specific WM domains (i.e., verbal, visuo-spatial, and numerical-verbal) and processes (i.e., low-control and high-control) that contribute to early mathematical knowledge before and after the onset of formal education, suggesting which cognitive components should be focused on both to prevent the onset of difficulties and to promote early mathematical learning. Regarding WM domains, we found that visuo-spatial domain was more strongly associated to mathematics in preschoolers than in first graders, while verbal domain, in particular verbal low-control WM skill, emerged as a significant predictor of math only among first graders, but not among preschoolers. Moreover, numerical-verbal WM was found to predict math knowledge in both preschoolers and first graders, although to a greater extent among the first ones. Concerning WM processes, the results suggest on the one hand a significant contribution of both low-control and high-control WM skills in preschoolers, on the other hand a leading role of high-control WM over that of low-control WM in first graders. As anticipated, these findings provide useful information about which WM domains and processes should be evaluated and monitored, depending on developmental stage, in order to identify children particularly at risk of developing MLD or difficulties. At the same time, our results may suggest effective directions to implement age-appropriate training interventions aimed at strengthening the cognitive bases of mathematical learning from preschool age onwards. In line with our findings, for example, a WM training program mainly focused on both low- and high-control visuo-spatial or numerical-verbal WM skills could be more effective in the final preschool year, while activities tapping primarily high-control WM processes (i.e., the visuo-spatial and numerical-verbal ones) as well as low-control verbal WM skills, might be more useful in first grade. From the point of view of both prevention and promotion, numerical-verbal WM skills, that is WM abilities specifically related to numerical stimuli and material, especially the high-control ones, may represent a fruitful target for both early detection of children at risk for mathematical difficulties and implementation of training interventions, respectively. Anyway, future longitudinal studies are needed to extend our results and to further investigate developmental changes in the relations between different WM domains and processes and specific early math abilities in response to children's cognitive development, level of education, and expertise , in order to better account for the complexity of the development of mathematical learning before and after the onset of formal education.

Regarding findings of Chapter 4, they may have relevant implications for children exposed to mainstream school environments (i.e., Italians) but especially for those living in socio-economically disadvantaged and deprived contexts (i.e., Yazidis and Syrian refugees). Overall, our results revealed that the two groups of Yazidi and Syrian children not only showed lower EFs skills but also revealed significantly poorer early mathematical abilities than Italian preschoolers, thus proving to be a particularly vulnerable population, at risk of developing difficulties in learning processes. Since our study represents a first attempt to evaluate relevant cognitive abilities in highly deprived children, it may be considered a starting point for the implementation of intervention strategies that could early provide concrete tools to base achievement abilities in children living in disadvantaged environmental conditions. More specifically, training programs aimed at promoting early EFs and basic numerical skills in deprived children from pre-school age onwards may provide children with useful tools to juggle in an adequate and efficient way in everyday activities as well as to acquire the fundamental basis for developing increasingly complex learning. However, future longitudinal studies are needed to further explore the associations between EFs and early mathematical knowledge in children living in disadvantaged contexts, also considering other components of EFs, such as updating, shifting, and planning abilities, in the light of their well-known significant role in predicting mathematical abilities in typically developing preschoolers and primary schoolers (e.g., Bull & Lee, 2014; Clark et al., 2010; Simanowski & Krajewski, 2019; see Friso-Van Den Bos, Van Der Ven, Kroesbergen, & Van Luit, 2013 for a meta-analysis). Moreover, further research might focus on other bio-psycho-social variables that can potentially mediate or moderate the relationship between EFs and early math abilities, thus supporting a more complex and comprehensive approach to the object of study.

In line and in continuity with the results of Chapter 4, also findings of Chapter 5 may have substantial practical implications, especially for children growing in adverse environments. Compared with Chapter 4, Chapter 5 provides additional useful information regarding the development not only of cool EFs (i.e., inhibition, STM and WM) but also of hot ones (i.e., delay of gratification), highlighting that delay of gratification and inhibition skills are particularly affected and compromised in children living in a war context, exposed to an extremely violent environmental situation. As a result, the latter skills are configured as the ideal target of training interventions aimed at enhancing them at a very early stage. In this regard, our study represents the first research effort aimed at estimating the effect of a targeted and tailored training program focused on both cognitive aspects of EFs and cognitive strategies to control emotions (see Di Pietro, 2014; Ellis & Bernard, 2006) in children living in war context, involving scientifically valid methods, such as randomized assignment and blind evaluators. This program may enrich previous research, representing a concrete tool potentially exportable and applicable in other socio-cultural and political contexts, thus acting as reference for the implementation of other similar training interventions, for example, in favor of migrant children fleeing their home countries with their families after experiencing traumatic events there. Anyway, follow-up research and future longitudinal studies are needed to test the validity of our pioneering programme as well as verify its long-term effects and repercussions on school performance once children enter formal education, also exploring the potential impact of various mediating and moderating factors, such as genetic background (Brett et al., 2015), severity, timing, and duration of deprivation (Beckett, Castle, Rutter, & Sonuga-Barke, 2010). Considering that, according to recent surveys, approximately one in six children today lives in a war context (Save the Children International, 2018), the practical implications of our study may represent a resource for the improvement of the quality of life of the whole of humanity.

6.0.6 Conclusion

The present dissertation represents the translation in terms of research of a cognitive-environmental approach to understanding and promoting the development of early numerical skills in both typically developing children and children living in deprived environments. Overall, our findings highlight the importance of mathematics in the growth of aware citizens as well as in providing specific tools functional to the acquisition of a political and economic identity to contrast manipulation of minority groups. More specifically, the results of the four studies provide new insights basically on three different fronts. From a theoretical point of view, our findings enrich the previous research with new information on the relationship between domain-general and domain-specific cognitive precursors of mathematical learning and early numerical knowledge at a very early age (i.e., from preschool to the beginning of primary school), with particular focus on certain developmental stages, trajectories and changes. From a practical standpoint, the results represent useful information for the implementation of age-appropriate, targeted, and effective training interventions aimed at the early development of mathematical skills, also describing (in Chapter 5) a training protocol potentially applicable in different socio-cultural and political contexts or modifiable and adjustable according to further research needs. Last but not least, the results of the present dissertation have a significant humanitarian impact, encouraging the possibility that the potential of each child from all over the world, in its peculiarity and uniqueness, can be best expressed and promoted.

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