Executive Function in Preschool Children: Working Memory as a Predictor of Mathematical Ability at School Age

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Abstract:

This paper attempts to provide a synthesis and appraisal of the field of executive functions (EF). In a moment in which early education is a very important issue in Romania, the purpose of this study is to emphasize the importance of early development of EF and EF correlation with school readiness (Ionescu and Benga, 2007). Core EF skills are (i) inhibitory control, (ii) working memory (WM), and (iii) cognitive flexibility. According to empirical studies, the model of WM proposes a multicomponent architecture, including specialized subsystems, considered important in developing children's language skills and mathematics. The WM model comprises four subcomponents. Two domain-specific limited capacity slave systems, the phonological loop (Baddeley, 1986), and the visuo-spatial sketchpad assume responsibility for storing and manipulating verbal or visuo-spatial information. These are coordinated by a domain-general limited capacity system, the central executive, which commands a number of functions including planning, inhibition, switching attention, and monitoring the processing of temporarily held information. The recently added fourth subcomponent, the episodic buffer (Baddeley, 2000), is considered to be responsible for the integration of information from the subcomponents of WM and long-term memory (LTM). Research has suggested that that independent contribution of the different working memory components and functions suggests that the relationship between individual differences in working memory and arithmetic is mediated by a number of resources, not only processing efficiency but also storage capacity and (central) executive ability. In conclusion, the present study shows strong evidence regarding implications of WM for mathematical development and mathematic curricula.

Keywords:

executive function, preschool development, math abilities, assessment.

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Executive Function and Development

During the past decade, the role of executive functions (EF) in relation to children's skills came to the attention of many researchers. This construct, which in the past was related to cortical networks involving the prefrontal cortex (Hopkins, 2000), includes a number of cognitive processes that are integral to the emerging self-regulation of behavior and developing social and cognitive competence in young children. These cognitive processes include the maintance of information in working memory store (Baddeley, 1996), the inhibition of prepotent response (Diamond, 1996) and the appropriate shifting and sustaining of attention for the purposes of goal-directed action (Posner and Rothbart, 1998; Stuss, Floden, Alexander, Levine and Katz, 2001; Stuss et al., 1999).

High interestat in the early development of EF has increased, firstly because researchers have shown that the development of EF is associated with prefrontal cortex, an area of mature brain around adolescence and its development is accelerated during early childhood (Diamond, 2002; Zelazo, 2002). Secondly, it was observed that EF is crucial in situations involving new, detection or removal of many constraints and ambiguities of tasks (Shall and Burgess, 1991). Thirdly, research indicating that EF is implicated in a variety of developmental disorders, and early developing psychopathologies (Barkley, 1997; Diamond, Prevor, Callendar and Druin, 1997; McLean and Hitch, 1999; Pennington and Ozonoff, 1996). Additionally, numerous studies on populations, including children with learning difficulties, language and comprehension problems, mathematical problems, autism, impaired attentional and hyperactivity (ADHD) and conduct disorder (Willis, 1998; Bull, Johnston and Roy, 1999; Cornoldi, Barbieri, Gaiani and Zocchi, 1999; Gathercole and Pickering, 2000a , 2000b, Hughes and Richards, 1998; Lehto, 1995; Lorsbach and Wilson, 1996; McLean and Hitch, 1999; Lehto, 1995; Lorsbach and Reimer, 1996, McLean and Hitch, 1999, Ozonoff and Jensen, 1999; Russell, Jarrold, and Henry, 1996; Swanson, 1993, 1999 ; Swanson, Ashbaker and Lee, 1996) found that EF are predictors of performance, some studies indicating these results even after a review of factors involved, and the withdrawal of MLD, phonological processing and information processing speed.

Functions, broadly, are essential behavioral constructs, defined in terms as outcome. In a narrow sense, the tasks are characterized by complex functions, and EF is a matter of describing its hierarchical structure, characterizing its subfunctions, and organizing these subfunctions around their constant common outcome (Zelazo and Müller, 2002). In the case of EF, the outcome is deliberate problem solving, and functionally distinct phases of problem solving can be organized around the constant outcome of solving a

problem. For example, consider the Dots task (Diamond et al., 2007) for children beginning at age 4 years. In all conditions of the task, a red heart or flower appeared on the right or left. In the congruent condition, one rule applied ("press on the same side as the heart"). Dots-Incongruent also required remembering a rule ("press on the side opposite the flower") plus it required inhibition of the tendency to respond on the side where the stimulus appeared. In Dots-Mixed, incongruent and congruent trials were intermixed and preschoolers have an unlimited time available to train their executive skills. In other words, to perform correctly on the Dots task, the preschooler children first construct a representation of the problem space, which includes identifying the relevant dimensions. Then, one must choose a promising plan—for example, sorting according to shape. After selecting a plan, one must keep the plan in mind long enough for it to guide one's thought or action and actually carry out the prescribed behavior. Keeping a plan in mind to control behavior is referred to as intending; translating a plan into action is rule use. Finally, after acting, one must evaluate one's behavior, which includes both error detection and error correction.

According to cognitive complexity and control theory (Frye, Zelazo and Burack, 1998; Zelazo and Frye, 1998), rules constructed by the children and problem solving differs and depending on age. On this account, rules are formulated in an ad hoc fashion in potentially silent and self-directed speech. These rules link antecedent conditions to consequences, as when we tell ourselves, "If I see a mailbox, then I need to mail this letter." When children reflect on the rules they represent, they are able to consider them in contradiction to other rules and embed them under higher order rules, in the same way that we might say, "If it's before 5 p.m., then if I see a mailbox, then I need to mail this letter, otherwise, I'll have to go directly to the post office." Therefore, according to CCC theory, dissociation of an acquaintance and the use of information happen immediately as the incompatible knowledge fits into a single complex rule through a rule subordinate to a higher level. Recently empirical studies on development of the EF indicate significant advances in children between 3-6 years (Diamond, Prevor, Callender and Druin, 1997; Hughes, 1998a; Kochanka, Murray and Coy, 1997; Zelazo, Carter, Reznick and Frye, 1997). This period coincides with the emergence of children theory of mind, the ability to attribute mental states such as beliefs, desires and intentions. Therefore, the healthy development of EF, tend to play an important key in developing social competence (Hughes, 1998 Hughes , Dunn , and White, 1998), academic and school readiness (Blair, 2002; Blair, Granger and Rance, 2005; Riggs, Blair and Greenberg, 2004 ; Ionescu and Benga , 2007) .

Working Memory and Mathematical Skills

Recent studies found most frequently articulated constructs of EF are those that reflect prepotent response inhibition and WM, described as the ability to keep information online, flexibility and fluency in response (Holmes and Adams, 2006). WM is a limited capacity system responsible for handling and storage of information during cognitive tasks (Baddeley, 1986). Several models of working memory are available (eg Cowan, 1999), including those that view WM as a unitary, limited capacity system where processing and storage operations that compete with a pool of limited resources (eg Case, Kurland and Goldberg, 1982) and that conceptualize WM as a multicomponent system comprising specialized subsystems. The multi-component model of WM proposed by Baddeley (1986, 2000) is arguably the most widely cited. In its current form (Fig. 1), the model includes four subcomponents: two domain-specific limited capacity slave systems, the phonological loop and the visuo-spatial sketchpad assume responsibility for storing and manipulating verbal or visuo-spatial information. These are co-coordinated by a domain-general limited capacity system, the central executive, which commands a number of functions including planning, inhibition, switching attention, and monitoring the processing of temporarily held information. The recently added fourth subcomponent, the episodic buffer (Baddeley, 2000), is considered to be responsible for the integration of information from the subcomponents of WM and long-term memory (LTM) (Towse and Cowan, 2005).

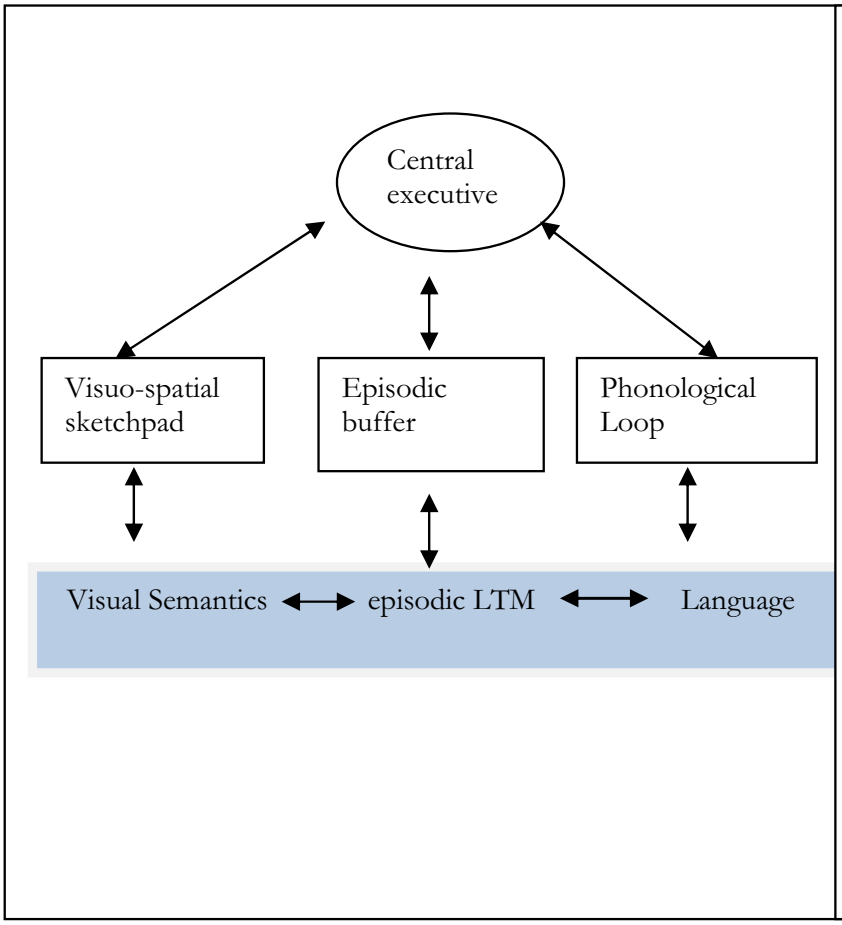


Fig. 1 The current version of WM model (Baddeley, 2000).

The episodic buffer is assumed to be capable of storing information in a multi-dimensional code. It thus provides a temporary interface between the slave systems (the phonological loop and the visuospatial sketchpad) and LTM. It is assumed to be controlled by the central executive, which is responsible for binding information from a number of sources into coherent episodes. Such episodes are assumed to be retrievable consciously. The buffer serves as a modelling space that is separate from LTM, but which forms an important stage in longterm episodic learning. Shaded areas represent 'crystallized' cognitive systems capable of accumulating long-term knowledge, and unshaded areas represent 'fluid' capacities (such as attention and temporary storage), themselves unchanged by learning.

Now that the components have been defined, we will examine the role of ML in cognitive tasks by studying each component separately as it's written below:

Central executive

Arguably the least understood, the central executive system is involved in a variety of functions. After Baddeley et al. (1984), central executive coordinates activities within working memory and controls the transmission of information between other parts of the cognitive system. The author suggests that the central executive has a limited capacity, and thus tasks that seem to deal specifically with either of the slave systems require processing by the central executive (see Figure 1). Additionally, they propose that some cognitive tasks suggested to involve the central executive include mental arithmetic and the recollection of events from long-term memory, logical reasoning and recall of lengthy lists of digits random letter generation, and semantic verification.

Norman and Shall (Potts, 1996), in their work showed that central executive include a model of the attentional control of human action, referred to as the Supervisory Attentional System. Instead, Baddeley, through its work supports the possibility that the alert system of supervision is just central executive. Thus, Baddeley has combined with that of Norman and Shallice assign many roles to the central executive assigning multiple roles to the central executive. They include:

1. Allocation of attention.
2. Controlling communication between the phonological loop and the visuo-spatial sketchpad.
3. Controlling communication between working memory and other memory stores.
4. Generation of random numbers and letters.
5. Mental arithmetic.
6. Logical reasoning.

Phonological loop

The loop was assumed to have two components, namely, a store that is capable of holding phonological information over a matter of seconds before the memory trace fades or is refreshed by the second component. This is assumed to involve sub vocalization, whereby inner speech is used to rehearse the items, successively retrieving them from the store and feeding them back by means of articulation, hence the term "articulatory loop." (Pickering, 2006). For example, typically, the child retains retains three numbers less than one second, but if you retain the latest issue delivered and the first number does not

disappear, performance can be maintained indefinitely. Baddeley et al. (1984) argued that the best way to blur the evocation of late is the long word. As the length of sequence increases, a point is reached whereby it is impossible to rehearse all the digits rapidly enough to avoid losing one or more as the result of reducing memory trace. This process provides a simple account of why we have a limited digit span.

A second function of the articulatory process is to convert visually presented material into a phonological code by sub vocal naming (Pickering, 2006). Thus there is little difference in memory span for digits that are presented visually or auditorily because participants tend to covertly speak the visual digits and convert them into a phonological code. This process of sub vocal naming can be prevented by requiring the participant to continuously repeat some irrelevant utterance, such as the word "the" a process known as articulatory suppression -a simple but very useful methodological tool.

The phonological loop model assumes that forgetting is a result of simple trace decay within the store. Despite some lively and intriguing controversy, the phonological loop model seems to be surviving well and providing a simple and robust account of a wide range of studies and denotes phonologic contribution to a range of children's mathematical skills necessary at school age.

Visuo-spatial sketchpad

The visuo-spatial sketchpad is a system that parallels the phonological loop but has proved less easy to study; "we do not have a rich and standardized set of stimuli such as those provided by language, nor have robust phenomena such as the phonological similarity and word-length effects been identified" (Pickering, p.13, 2006). It seems likely that the system will play an important role in the acquisition of our visual and spatial knowledge of the world: What color is an apple? How does a car work? How do you play a DVD? How can I find my way around my hometown? Whereas we have many tests of language at the levels of phonology, individual word meaning, and text comprehension, we appear to lack well-developed measures of visuo-spatial world knowledge.

Baddeley and Lieberman (Potts, 1996) tested these aspects of the WM used pegword mnemonics (association of a number with a phonologically similar word; one - gun, two - stew, etc.) for generation of visual imagery. Given a list of words, the subjects had to visualize an image which contained the word (in object form) and the pegword representing the number of the word in the list. If the first word is chair, then the subject was to imagine a chair with a gun, etc. Other subjects were simply asked to rote memorize the list. When subjects performed spatial tracking tasks during recall, those subjects using the pegword mnemonics did much poorer than those who did rote learning of the list. This

supports the notion that the visuo-spatial sketchpad is used in the generation of images, as well as storage and refreshing.

According Baddley's and Logie's (Potts, 1996) visuo-spatial sketchpad is concerned by:

1. Providing temporary storage of visual and spatial information
2. Refreshing images in the sketch pad as needed
3. Generating images

Episodic buffer

The episodic buffer is assumed to be a limited-capacity temporary storage system that is capable of integrating information from multiple of sources (Baddeley, 2000). It is assumed to be controlled by the central executive, which is capable of retrieving information from the store in the form of conscious awareness, of reflecting on that information and, where necessary, manipulating and modifying it. The buffer is episodic in the sense that it holds episodes whereby information is integrated across space and potentially extended across time.

From this point of view, resembles Tulving's concept on episodic memory. But also differs in that it is assumed to be a temporary store that can be preserved in densely amnesic patients with grossly impaired episodic LTM.

WM model incorporates episodic buffer as illustrated in Fig .1. As such, the buffer provides not only a mechanism for modeling the environment, but also for creating new cognitive representations, which in turn might facilitate problem solving.

The multicomponential model of WM provides a general framework of how children learn and play an important role in the acquisition of language skills (eg Gathercole and Baddeley, 1989). However, ML is involved in understanding how their children distribute effective strategies to solve arithmetic problems (Menon et al. 2008), the development of the cognitive processes that support retention of information in WM has rarely been directly studied in children during the performance of simple mental arithmetic tasks. Davis and Bamford (Pickering, 2006) examined children's (aged 4-5 years) use of visual imagery in arithmetic performance, examining the solution of both simple problems (e.g., 1+1, 2 - 1) and more difficult problems (e.g., 6 + 2, 8 - 1). Children were presented with arithmetic problems that had contextual support- that is, concrete representations (in the form of small toys) for each number involved in the calculation or had no visible concrete support, instead referring to hypothetical toys. Some of the children also were prompted to use an imagery strategy- that is, imagining a mental picture of the concrete representations. The authors found that concrete contextual support led to the production of more correct answers. Therefore, they suggested that, visual imagery does provide a

useful resource in solving simple arithmetic problems, at least for young children.

Many studies have examined the relationship between working memory subsystems, executive functioning, and arithmetic or mathematics ability. Some studies have attributed individual differences in mathematical problem solving (particularly arithmetic) to inefficiencies in the utilization of the phonological system (Bull et all, 2008), with the role of the phonological loop being to encode and retain verbal codes used for counting and retain solutions. However, a number of studies of children with poor mathematical skills emphasized the important role of the visuo-spatial sketchpad in children's early arithmetical skills. Visual-spatial skills may impact math at various levels—number inversions and reversal, misalignment of column digits, problems in visual attention and monitoring such as ignoring signs or changing operation part-way through completion of problem, and acquiring concepts of borrowing and carrying. The visual- spatial system also supports other aspects of non-verbal numerical processing such as number magnitude, estimation, and representing information in a spatial form, as in a mental number line (Casey, Nuttall and Pezaris, 1997 Geary, Saults Liu and Horde, 2000).

McKenzie, and Gray Bull (Bull and Scerif, 2001) examined the cognitive mechanisms involved in arithmetic performance in children between 6 to 8 years old. The authors have split the two subcomponents of WM model, phonological loop from visuospatial sketchpad, in order to show interference on different sections of arithmetic performance in the two groups. If at the age of 6, children's WM had based more on vizuo-spatial strategies to solve simple arithmetic computation (supported by visu-ospatial sketchpad), then those around 8 years old depended more on verbal strategies in carrying out computations (supported by phonological loop). Authors' hypothesis seems to be in contradiction with the research carried out by Palmer (2000), which argues that the strategies submitted by vizuo-spatial system aren't dependent on the verbal task, but rather may be influenced by a general phenomenon that could be applied to a wide range of tasks that store and manipulate information in the WM. In the first study of McKenzie's the two systems were separated by interference of two passive tasks: irrelevant speech and dynamic visual noise. Even if was predicted that the 6-year-old's WM is based on vizuo-spatial representation and they could solve simple arithmetic computations, their arithmetic performance was disrupted by dynamic noise (McConnell and Quinn, 2000). In contrary, those of 8 years old WM is based on both subcomponents phonological loop and visuo-spatial sketchpad, consistent with speculation of Palmer's (2000), which argues that the cognitive mechanisms involved during arithmetic tasks vary depending on age. Therefore, the relationship of the two

systems should become the target of future studies in order to analyze their contribution in developing mathematical skills.

In the context of Baddeley 's multicomponential model have been shown that measurements of central executive functions are strongly correlated with the prediction of mathematical abilities in children (Anderson, 2008; Holmes and Adams , 2006 ; Fuchs et al., 2005, 2000 ; Gathercole et al. , 2004 ; Noel Seroni and Trovarelli, 2004 , Swanson and Beebe - Frankenberger, 2004; Lee and Lim, 2004 ; Henry and MacLean , 2003 ; Keeler and Swanson 2001; Lehto , 1995 ; Swanson , 1994) . Most of these studies have appreciated the central executive functions in the memory tasks, showing that the coordination and monitoring of simultaneous processing and storage of information are important during the performance of arithmetic and mathematical tasks. Additionally, this component of the WM plays an important role in decision making and attentional resources in the selection and implementation strategies. Therefore, the central role of the executive may be critical to children of grade 2 or 3rd and require a more costly process. If an answer can be extracted from the LTM, then central executive should follow the following steps: encoding, maintenance and handling in both episode numbers (vizuospatial and phonological loop) .

While most authors of these studies have given attention to central executive, Anderson, in particular, has concluded that independent contribution of WM components and functions are mediated by more resources as those of age, fluid IQ (Raven color test) and four working memory tasks (counting span, verbal fluency, trail making, digit span) .

Conclusions

This paper proposed a synthesis of theoretical knowledge about FE, in particular, the study of working memory, to our understanding how children perform in educational setting.

Although research in this area has been carried out for some years now, there has recently been a significant increase in the number of research groups that investigate working memory with respect to educational attainment. During the last decade, many papers have been published in academic journals on this topic, each one providing further important details about working memory and children's academic functioning. Journal papers are an extremely important source of knowledge for many;

As a final note I offer a brief of the paper:

- EF in early childhood is essential for the advancement of the study of developing self-regulation; EF are cognitive skills, maintaining information in working memory store, prepotent response and some aspects of attention ;

- EF predictions are strongly correlated with children's mathematical skills because executive processes of memory, organization, flexibility, prioritization and control are important in mathematical success; EF convert words into mathematical logic, provides relevant information, keep the words and numbers in WM ;
- The multicomponential model of WM provides a general framework on how to teach children; math skills acquisition depends on vizuospatial abilities, age and phonological memory, and central executive functioning.

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