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Development and longitudinal relationships between children's executive functions, prospective memory, and metacognition

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ABSTRACT

Though theoretically and neurobiologically related, little is known about the developmental relationships between executive functions, prospective memory, and metacognition. As knowledge about potential relations would help to better understand the mechanisms of cognitive development, we investigated the development of, and the longitudinal relationships between executive functions, prospective memory, and metacognition. Eight-year-old children ($N = 119$) carried out the same test battery twice with a delay of eight months. In general, results revealed significant improvement in executive functions, prospective memory, and metacognition. Structural equation modeling revealed a significant longitudinal link from executive functions to prospective memory, but not to metacognition. These findings are discussed within a broader developmental framework.

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1. Introduction

For children, everyday life can be utterly cognitively demanding. Imagine an 8-year-old performing a math test which requires to solve different mathematical problems – additions, subtractions, divisions, multiplications – all mixed up on one piece of paper. Before starting with the test, the child is told to remember to get a book from the library before heading home. Upon completion of the test, the teacher encourages the child to check the answers again and to revise if necessary. In terms of cognitive processes, this short episode requires the child to activate a certain arithmetic rule, process the calculation, occasionally switch the rule, maintain or update an intermediate result, inhibit other task-irrelevant thoughts (executive functions). Furthermore, the child has to monitor and maybe revise a given answer while engaging in the test (metacognition). Finally, the child has to form the intention to go to the library, remember it and execute it at the appropriate moment (prospective memory).

This example illustrates that various cognitive processes are simultaneously in action and required in order to succeed in purposeful and goal-directed daily activities. Especially during the early school years, children face a wide range of changes and they will encounter more and more challenges that are predominantly cognitive in nature. These cognitive demands increase gradually as children grow older, because both the environment and the (school) tasks children are confronted with become more complex. In order to master these challenges, children's abilities have to improve substantially within a relatively short period of time. For developmental progression, not only environmental factors such as for example school

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entry which puts new demands on cognitive abilities (Schneider, 2015) might be crucial, but also internal factors such as the neurobiological basis associated with the abilities addressed in this study, namely, executive functions, prospective memory, and metacognition (Fuster, 2002). Moreover, when different cognitive abilities are associated with the same brain structures, it is probable that they not only develop concurrently, but that they are also longitudinally related. Empirically, however, relatively little is known about the extent to which different cognitive abilities are interrelated and how they influence each other in the course of development. A previous study revealed that although clearly empirically differentiable on the latent level, the three theoretically related cognitive abilities do share a substantial amount of variance (Spiess, Meier, & Roebers, 2015). That is, executive functions, prospective memory, and metacognitive control were found to be cross-sectionally linked in a sample of 119 seven- to eight-year-olds, with executive functions and prospective memory being particularly and significantly related, sharing 26% of the variance. The longitudinal links, however, remained unexplored. Therefore, the present study aimed to further investigate the development of, and the longitudinal relationships between executive functions, prospective memory, and metacognitive control within a narrow time frame of one school year. Combining developmental and relational aspects is central for a better understanding of young children's cognitive development. Therefore, we addressed the following research questions: To what extent do executive functions, prospective memory, and metacognitive control develop in the course of one elementary school year? And how do they influence each other during this period?

1.1. Development of executive functions, prospective memory, and metacognitive control

Executive functions as an umbrella term reflect higher-order cognitive processes that govern conscious, deliberate, and goal-directed actions (Diamond, 2013), encompassing updating, inhibition, and shifting (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). *Updating* stands for the maintenance and manipulation of relevant information (Alloway, Gathercole, & Pickering, 2006; Pickering & Gathercole, 2001). *Inhibition* is the ability to resist to habits or distractions (Friedman & Miyake, 2004; Johnstone et al., 2007). *Shifting* is defined as the ability to adjust to change of, for instance, mental sets or task rules (Wendelken, Munakata, Baym, Souza, & Bunge, 2012; Zelazo, 2006). Miyake et al. proposed this three component structure in adults. In children, however, these three components seem to be very closely intertwined and processes of differentiation that occur in childhood have been proposed instead (Brydges, Fox, Reid, & Anderson, 2014). Moreover and according to the so-called *task-impurity problem*, the three components can hardly be assessed in isolation. This is because the targeted cognitive processes must be embedded in a certain task context that is very likely to also trigger other executive functions and non-executive functions processes (Miyake & Friedman, 2012). In this sense, findings regarding the exact factorial structure in children are still dissenting. Some studies support a one-factor in younger children, for example, in 5-year-olds (Willoughby, Wirth, & Blair, 2012), in 2.5- to 6-year-olds (Wiebe, Espy, & Charak, 2008), or in 7- to 9-year-olds (Brydges, Reid, Fox, & Anderson, 2012). Others found a two-factor-solution for example in 3- to 5-year-olds (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012) or in 5- to 13-year-olds (Lee, Bull, & Ho, 2013; van der Sluis, de Jong, & van der Leij, 2007). A more differentiated three-factor-solution is found in older children, for example in 8- to 13-year-olds (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003) or 15-year-olds (Lee et al., 2013). Based on a literature review, Brydges et al. (2014) suggested that a one-factor solution in children younger than 9-years of age is most appropriate. Although the three executive functions components are suggested to follow differential trajectory trends (Anderson, 2002), the overall picture emerging from numerous studies suggests that executive functions develop strongly from 4/5 years to 8/9 years, and even continue to improve into adolescence (e.g. Best, Miller, & Naglieri, 2011). Responsible for the development of executive functions are neuronal and neurophysiological changes, especially structural and functional changes in the prefrontal cortex (Dumontheil, Burgess, & Blakemore, 2008; Stuss & Alexander, 2000). Even though the overall picture regarding the development in executive functions during childhood is unambiguous, longitudinal studies are still needed to gain more detailed quantitative and qualitative information on the intra-individual development of young children's executive functions.

Prospective memory is the ability to plan an intention, to retain it in memory, and to retrieve it at the appropriate moment without an explicit reminder to carry it out. Typically, a prospective memory task is embedded in an ongoing task. Retrieval can either be time-based, when an intention has to be carried out after a certain period of time, e.g. in 15 min, or event-based when an intention has to be carried out when a certain event occurs, e.g. when a specific cue appears (Einstein & McDaniel, 1996). The present study used an event-based task. With respect to prospective memory development, studies demonstrated that performance follows an inverted U-shaped function across the lifespan (Mattli, Schnitzspahn, Studerus-Germann, & Zöllig, 2014; Zimmermann & Meier, 2006, 2010), implying considerable improvement during childhood. Although most prospective memory studies have included adults, there is evidence that children's prospective memory performance increases gradually over the childhood years (Guajardo & Best, 2000; Passolunghi, Brandimonte, & Cornoldi, 1995; Yang, Chan, & Shum, 2011; Zimmermann & Meier, 2006). However, most findings are based on age-group comparisons in cross-sectional studies, with older participants typically outperforming younger participants (Kliegel et al., 2013). Furthermore, many studies investigated the impact of ongoing task specific or prospective memory task specific features such as ongoing task difficulty or prospective memory cue salience (Mahy, Moses, & Kliegel, 2014b). Yet, longitudinal studies that uncover intra-individual development are very rare.

Metacognition represents higher-order self-reflective cognitive processes that are used to regulate information processing. It has been subdivided into declarative metacognition (the knowledge about one's own cognitive processes) and procedural metacognition (Flavell & Wellman, 1977), with the latter being further divided into monitoring and control

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