Executive Function and Metacognition:

Towards a Unifying Framework of Cognitive Self-Regulation

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Abstract

Executive function and metacognition are higher-order cognitive processes that undergo steady improvements throughout childhood. They are highly relevant to daily functioning in various domains, including academic achievement. Both concepts have been intensively researched, but surprisingly little literature has sought to connect them theoretically and empirically. In the present review, I elaborate on the similarities between these concepts from a developmental perspective, including the definitions, developmental timetables, factors that lead to changes over time, and relations to academic achievement and intelligence. Simultaneously, the differences between these two domains of cognitive development are discussed. These include, in particular, the relative neglect of quantifying monitoring within research on executive functions and the disregard for the neuropsychological underpinnings of metacognition. Finally, this paper presents several avenues for future research and proposes a possible unifying framework of cognitive self-regulation that integrates executive function and metacognition and may lead to a better understanding of the emergence of cognitive self-regulation in development.

Keywords: executive function, metacognition, development, review

Introduction

One of the major milestones of a child`s cognitive development is the ability to intentionally regulate his or her own behavior and thinking. This includes the ability to stop performing an action when asked to do so (e.g., clapping one`s hands, talking, kicking the ball) and act in a goal-directed manner (e.g., getting out the right utensils for playing a certain game; remembering to do something at a certain time or place; selecting the best-suited strategy for solving a task). Further striking and far-reaching developments—for both the child and those in his/her environment (e.g., parents, teachers)—include the ability to stay focused despite distractions (e.g., going to fetch an object; finishing a task despite decreasing motivation) and to detect and correct errors.

This literature review focuses on so-called "higher-order cognitive processes," which play an important role in children's development of self-regulating behavior and mental operations. Such processes include the monitoring, steering, controlling, and adapting of "lower- or first-level information processes," such as encoding, storage, and retrieval of information. Two different bodies of the literature will be integrated: that focusing on "executive function" (EF) and that on "metacognition" (MC). In a previous brief report, some practically relevant similarities between EF and MC were outlined (Roebers & Feurer, 2016). The current paper aims to provide a more detailed review of the literature and a critical discussion of the avenues for future research. This review has been organized into two major sections: the first addresses the conceptual and theoretical issues related to EF and MC, while the second focuses on the developmental progression of these concepts, as well as their links to other variables and each other. The major aims of the present review are (a) to bring together two distinct bodies of cognitive and developmental literature related to the regulation of behavior and thinking, and (b) to elaborate on the many similarities and few differences between the concepts described therein. It is important to note that this review is not intended to be exhaustive; rather, the content was selected based on its subjective relevance to developmental theory and practice.

I. Conceptual and Theoretical Issues

Historical Background

In 1971, John Flavell introduced the concept of "*metamemory*," and from the beginning linked it to developmental psychology. In discussing the potential factors that promote memory development in children, he referred to the concept of metamemory as "monitoring and knowledge of (memory) storage and retrieval operations" (p.277). The essential aspects of metamemorial knowledge, nowadays commonly referred to as declarative metamemory, were described in detail by Flavell and Wellman (1977), and include an individual's knowledge about various person, task, and strategy-related variables. Concerning the procedural aspects of MC, Hart (1967) might have been the first to directly relate monitoring to performance by introducing a calibration curve. Such a calibration approach (still used today in metacognitive research) allows researchers to estimate the degree to which monitoring is commensurate with actual performance; in other words, it enables researchers to assess the realism of on-task monitoring. Calibration curves are determined by plotting subjective estimates of correctness (i.e., monitoring judgments) against the objective proportion of correct responses, revealing either over- or under-confidence in individuals.

Around the same time, Butterfield and colleagues (Butterfield, Wambold, & Belmont, 1973) suggested that memory improvements rely on two main factors: Namely, an individual's spontaneous and conscious access to memory monitoring and a task-unspecific executive control that allows for coordination of memory and memory monitoring. Together, these factors can improve memory performance—if applied in a sensible way during information processing. In a similar vein, Ann Brown (1975) explicitly added the concept of "knowing *how* to know" (i.e., "the ability to monitor and control," p. 146), which allowed a child to deliberately learn and memorize information, as well as to use self-initiated, goal-directed strategies. Later, Flavell (1979) proposed the broader concept of "metacognition" as the constant interplay between metacognitive knowledge, metacognitive experiences (i.e., essentially momentary to longer-lasting monitoring experiences), and metacognitive actions (e.g., selecting the best mode for learning, executing the best-suited strategy).

Conversely, researchers only became interested in *EF* in the late 1980s, with the emergence of various neuroanatomical, neurophysiological, and behavioral approaches to frontal lobe functioning in clinical neuropsychology (Welsh & Pennington, 1988). Initially, heterogeneous sets of behavioral deficits in adult patients with frontal lobe lesions were pooled under the term "executive function." This term captured patients' inability to inhibit a prepotent behavioral response, to mentally represent a plan, and to act in a goal-directed, self-determined, and flexible way in a variety of situations. Despite knowing of the rapid growth of the frontal lobes in primates' brain evolution (Fuster, 2008), researchers underestimated the impact of EF for typical development for a long time. The concept of executive function made a detour via developmental psychopathology before entering the field of developmental psychology: Pennington and colleagues (Pennington & Ozonoff, 1996; Welsh & Pennington 1988), in outlining the pronounced executive deficits in children with developmental disorders (especially those with attention deficit hyperactivity disorder [ADHD]), argued that EF is distinct from other information processing domains. Thus, as a "higher-order cognitive process," EF came to be seen as a primary driving force for typical development. Overall, despite being rooted in different research traditions, EF and MC are both factors now assumed to govern improvements in children's deliberate, goal-directed, and self-regulated information processing (Blair & Diamond, 2008; Kuhn, 1999).

Contemporary Conceptualizations

Executive function. In the literature, “executive function” has been defined as a set of heterogeneous, higher-order cognitive processes involved in goal-directed, flexible, and adaptive behavior and the top-down regulation of cognition and behavior, that are particularly triggered in novel, challenging, and complex situations (Miyake et al., 2000). Zelazo (2015) noted that the situations in which top-down regulation through EF is necessary vary on a continuum from purely cognitive challenges (calling for “cool EFs”) to motivationally significant situations (calling for “hot EFs”). Based on clinical observations of developmental disorders, the ability to inhibit automated responses and switch mental sets was also included in the concept of EF (Baddeley, 2000; Barkley, 1997). Although most researchers would agree that these different aspects of EF operate together and that a separation of the different processes is mostly impossible (Miyake & Friedman, 2012); separately measuring and investigating the various EF components can nevertheless shed light on differences in developmental timetables as well as the relative importance of the different EF components for various outcomes (Lee, Bull, & Ho, 2013).

Note that there is some conceptual overlap between research on EF and Mischel’s framework of “hot” and “cool” “self-control” (Metcalfe & Mischel, 1999) and also with temperament-based approaches to children’s self-regulation (Rothbart & Bates, 1998). According to Mischel, there is a hot, emotional system that urges individuals to approach a desirable stimulus and a cool, cognitive system that executes top-down control over the hot system. Ideally, the cool system helps individuals resist temptations, postpone gratification, maintain pursuit of her/his initial goal, etc. Thus, it is the cool system that overlaps with EF. Furthermore, in Rothbart’s conceptualization of temperament, individual differences in the dimension of “effortful control” can influence behavior in both affective and cognitive contexts (Rueda, Posner, & Rothbart, 2005). EF, in contrast, can primarily be delineated by its cognitive and volitional character and is used in situations to improve cognitive or behavioral performance (Blair & Razza, 2007). Because this specific characteristic is a main similarity to MC, EF in more cognitive sense is the primary focus of the present review.

Metacognition. Current conceptualizations of MC distinguish between declarative metacognitive knowledge (i.e., knowledge about cognition, learning processes, memory functioning, and factors influencing cognition, learning, and memory; Flavell, 1979), and procedural MC. Procedural MC comprises the processes of metacognitive monitoring (i.e., subjective assessments of ongoing cognitive activities: *"how much effort do I have to put into learning this material?*"; "*did I sufficiently learn this material to remember the details later on?*"; *"how sure am I that this answer is correct?"*), and metacognitive control (i.e., the regulation of current cognitive activities: selecting material for review while studying, differentially allocating study time to the learning material, withdrawing answers, or terminating memory search; Dunlosky & Metcalfe, 2009; Nelson & Narens, 1990). There is a constant flow of information between the different components of MC. In an iterative manner, metacognitive experiences made during learning and remembering (procedural metacognition) will lead back to changes in metacognitive knowledge (e.g., Dunlosky & Metcalfe, 2009; Efklides, 2011; Flavell, 1979).

This brief review of the theoretical literature thus uncovers many similarities between EF and MC: both are conceptualized as higher-order cognitive processes enabling an individual to operate flexibly and adapt efficiently to new and challenging tasks. Furthermore, as opposed to automatized responses, EF and MC are generally considered to be controlled processes initiated by the individual (Norman & Shallice, 1980). In both literatures, these higher-order controlled processes embrace various sets of sub-processes (shifting, updating, and inhibition for EF; monitoring and control for MC). These sub-processes are theoretically distinct, and successful information processing relies on an efficient and goal-directed orchestration of individual elements. In other words, the sub-processes are operating together and are constantly interacting with each other. Further, EF and MC similarly encompass dynamic and regulatory functions, which are utilized to optimize information processing of more elementary, first-order tasks.

Internal Structure of EF and MC

From a developmental perspective, the theoretically assumed subcomponents of EF and MC appear to manifest different changes over time. I describe these differing developmental timelines in the following paragraphs.

Executive function. A battery of commonly used tasks has been found to yield three distinguishable yet interrelated latent factors of EF in adults (Miyake et al., 2000): updating (i.e., short-term storage and manipulation of a limited amount of information), inhibition (i.e., the ability to interrupt or inhibit automated or prepotent responses or behavior), and shifting (also called cognitive flexibility, and refers to the ability to flexibly shift attention between task demands and flexibly apply changing rules or mindsets). Today, these factors are recognized as the classical subcomponents of EF. Importantly, however, they seem to be relatively undifferentiated early in development (Diamond, 2013; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al., 2011; Willoughby, Wirth, Blair, & Family Life Project Investigators, 2012). Over the course of development, EF components experience slow differentiation, with only two factors (inhibition and working memory) best representing the construct in preschool and early elementary school children (Brydges, Reid, Fox, & Anderson, 2012; Huizinga, Dolan, & van der Molen, 2006; Lee et al., 2012; van der Ven, Boom, Kroesbergen, & Leseman, 2012; Viterbori, Usai, Traverso, & De Franchis, 2015). Only in late childhood and adolescence (approx. 10–15 years of age) are the components of inhibition, working memory, and shifting empirically distinguishable (Lee et al., 2013; Lehto, Juujarvi, Kooistra, Pulkkinen, 2003; Monette, Bigras, & Lafrenière, 2015).

Metacognition. The theoretical assumptions and empirical evidence concerning the internal structure of MC point in a different direction. For procedural monitoring and control, the little empirical evidence available suggests relatively isolated and unconnected skills in elementary school children. The apparent fractionated nature of MC may be mainly methodological: studies on procedural MC typically include one measure each for monitoring and control, respectively. Additionally, there are almost no longitudinal studies on procedural metacognitive skills. Nevertheless, as one example, the ability to make accurate judgments of learning immediately after learning ("*How sure am I that I will remember this information in the upcoming test tomorrow?*") appears to be unrelated to adequate estimations of confidence given right after retrieving information ("*How sure am I that I answered this question correctly?*"; Destan, Hembacher, Ghetti, & Roebers, 2014; von der Linden & Roebers, 2006; von der Linden, Schneider, & Roebers, 2011). Through experience and feedback, these aspects of monitoring seem to merge into an overarching monitoring skill (van der Stel & Veenman, 2008). Empirical evidence in adults has also suggested only low correspondence of different monitoring indicators (Boduroglu, Tekcan, & Kapucu, 2014; Rhodes & Tauber, 2011). Little to nothing is known about whether and to what extent indicators of metacognitive control cohere with each other (e.g., differentially allocating study time to easy versus difficult learning material, making sensible re-study selections after a study period, selectively withdrawing previously given incorrect responses).

In sum, although the developmental courses towards the adult-like internal structure of EF and MC appear to differ, the final and theoretically assumed factorial structures are very similar. Furthermore, for both concepts, there is a set of sub-processes or components that interact with each other. Although it has proven useful to investigate the respective sub-processes separately, in real-life situations, neither the components of EF (updating, switching, and inhibition) nor those of MC (monitoring and control) can be easily separated.

MC and EF in Frameworks of Self-Regulation

From a broader perspective, MC and EF play a central role in models of self-regulation and self-regulated learning. These theoretical frameworks differ, however, with respect to the broadness of the contexts they are applicable to.

Executive Function. When taking into account cognitive/learning, social-interactive, and personality viewpoints, self-regulation frameworks consider EF as a means of enabling self-regulation in various situations. In that sense, self-regulation is defined as goal-directed behavior for a broad variety of contexts, including academic contexts, health-related behavior, and social interactions. In their review of the empirical literature, Hofmann, Schmeichel, and Baddeley (2012) describe the many ways in which EF, as a narrow set of higher order information processes (see above), are linked to self-regulation. First, EF, as an outcome, can be impaired when an individual is confronted with strong self-regulatory demands, such as intense desires and needs (e.g., a child strongly desires to go out and play with other children but must finish homework first; crossing a dangerous road to reach a long-waited-for family member). Second, individual differences in EF can also enable or constrain self-regulatory outcomes in that good EF allows efficient self-regulation in other domains. For example, well-developed inhibitory skills may help to override impulses (i.e., maintain the required behavior until a task is completed), and good working memory capacity can help to keep the overarching goal in mind. EF may also moderate, mediate, or modify the influence of situational characteristics on self-regulated learning activities. These different links are integrated in Blair and Raver's (2015) model of children's developing self-regulation. According to their developmental perspective, self-regulation is a multi-level allostatic system of feed-forward and feedback processes operating at the biological, social-emotional (including temperamental), behavioral, and cognitive levels. The system is assumed to be triggered when prepotent responses are no longer adequate or the individual faces new task demands. These multifaceted processes allow the child to adjust to the experiences and challenges in both informal social interactions and formal learning activities.

Metacognition. Models of self-regulation concerning MC are often positioned in the context of educational research, such as investigations in classroom settings with ecologically valid study material. In such research, self-regulated learning is not only considered *the* main goal of primary and secondary education, but also expected to be a life-long learning process. Typically, these models comprise long-term academic goals, personal characteristics, and micro-processes operating during learning and remembering. However, the models differ with respect to the positioning of metacognitive monitoring and control: while metacognitive monitoring and control play a key role and are considered as main sources of the individual differences in all phases of the self-regulated learning process (for a review see Greene & Azevedo, 2007; Winne, 1996, 2001), the models of Boekaerts (1997) and Zimmerman (1990, 2008) situate MC at the micro- and task-levels.

While the models of the of MC in self-regulated learning mentioned above do not explicitly include a developmental perspective, Efklides's model (2008, 2011) does. Her metacognitive and affective model of self-regulated learning (MASRL Model) proposes various mechanisms through which self-regulated learning improves over the course of development. With increasing metacognitive knowledge and through subjective metacognitive experiences within structured and unstructured learning situations (e.g., losing in a memory game because of distraction, not remembering the name of an age-mate, not being able to recall a poem), an individual becomes increasingly better at metacognitively monitoring and control. As long as feedback is intentionally provided (e.g., by the teacher) or occurs naturally (e.g., not finding a toy one has played with the previous day), the individual will, over time, improve his or her self-regulated information processing behavior.

Taken together, the above research suggests that the framing of EF is broader in comparison to that of MC. Self-regulated learning models tend to limit the relevance of MC to learning and remembering and to educational or academic contexts, whereas the scope for EF appears to be unlimited. In fact, empirical evidence for EF in children suggests that the construct is relevant to domains such as food intake (Riggs, Spruijt-Metz, Sakuma, Chou, & Pentz, 2010), less-structured leisure time activities (Barker et al., 2014), social relations (Nigg, Quamma, Greenberg, & Kusche, 1999), emotion regulation (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009), and social competence (Razza & Blair, 2009), along with academic achievement, and intelligence (see below). However, despite having a narrower theoretical scope, MC in children has been empirically linked to a large variety of contexts, as well. Apart from academic performance and intelligence (see below), these include autobiographical memory (Ghetti, Papini, & Angelini, 2006), perception (Balcomb & Gerken, 2008; Lyons & Ghetti, 2013), decision making (Coughlin, Hembacher, Lyons, & Ghetti, 2014), eyewitness memory and suggestibility (Roebers, 2002), and social-cognitive development (Lockl & Schneider, 2007). Moreover, creative research paradigms have shown that young children demonstrate better metacognitive skills in social interactive settings compared to when the child is alone (Bernard, Proust, & Clément, 2015; Goupil, Romand-Monnier, & Kouider, 2016), suggesting that social interactions can facilitate the development of MC and play a noteworthy, but still often overlooked, role in many everyday life situations (see also Brinck & Liljenfors, 2013; Frith, 2012).

Neuropsychological Underpinnings of EF and MC

Executive Function. Besides the historical roots of EF concepts (see above) and the findings from varied disciplines already discussed, the neuropsychological underpinnings of EF are important and informative. Research has shown that the prefrontal cortex (PFC) is the brain region predominantly involved in EF. First, neuroimaging studies have consistently shown that in children and adults, the PFC is strongly activated when EF tasks are performed (Wendelken, Munakata, Baym, Souza, & Bunge, 2012). Second, patients with PFC brain lesions have shown relatively circumscribed deficits in executive domains, such as attention, working memory, planning, inhibition, interference control, and decision-making (Fuster, 2008). Third, the PFC and behavioral correlates of EF both show a protracted development into adolescence and even adulthood (Diamond, 2000; Gogtay et al., 2004; Wendelken, Baym, Gazzaley, & Bunge, 2011). Fourth, children with ADHD or children with acquired brain damage (traumatic brain injury, stroke) typically show specific deficiencies in the domain of EF, as well as specific structural and functional abnormalities in their PFC (Anderson, Jacobs, & Anderson, 2008).

Metacognition. Despite the intense research on MC in both cognitive and developmental psychology over recent decades, surprisingly few studies have addressed MC's neurophysiological and neuroanatomical basis. Moreover, the results of existing studies are difficult to interpret because of the confounds between first-order tasks (e.g., perception, memory, semantic knowledge) and second-order tasks (metacognitive task), thus making it difficult to attribute certain brain activation patterns solely to the metacognitive processes of interest (Metcalfe & Schwartz, 2016). In their review of studies on neurological patients (mainly patients with Alzheimer's disease and Korsakoff syndrome; see also Shimamura, 2000), Pannu and Kaszniak (2005) conclude that the PFC plays a central role in accurate monitoring and these processes can be distinguished from memory. This is in line with Bona and Silvanto's (2014) transcranial magnetic stimulation study, which showed that adults' confidence in memory, but not the memory itself, was specifically impaired. According to Metcalfe and Schwartz's (2016) review of the most recent neuroscientific evidence from healthy adults, complex neural circuits converging in the anterior cingulate cortex (ACC) and PFC contribute consistently to the processing of metacognitive information. In particular, the ventromedial PFC appears to be more closely linked to prospective judgments such as easeof-learning and feeling-of-knowing judgments. The anterior and dorsolateral PFC, by contrast, seem aligned to retrospective monitoring judgments, that is, to confidence judgments (Fleming & Dolan, 2012).

Although performance monitoring has been more strongly emphasized in frameworks of MC rather than of EF (see above), there is a small yet often overlooked body of neuroscientific evidence on "error monitoring" that seems highly relevant for both concepts. Indeed, this may serve as a bridge between the two lines of research (Shimamura, 2000). In these experimental approaches, classic EF tasks, such as the Flanker task, go/no-go task, or the Dimensional Change Card Sorting task (DCCS; see above) are completed while subjects undergo electroencephalographic (EEG) recording. For analyzing these data, researchers focus on the neural signs of error detection. In other words, they examine whether there are neural correlates unambiguously attributable to the detection of a committed error (i.e., N2 amplitude in older children and adults or N4 amplitude in younger children; that is, a negative EEG response 200 or 400 ms post error; Fernandez-Duque, Baird, & Posner, 2000; for a recent review, see Wessel, 2012). Results show that an error may trigger negative event-related potentials (ERPs) shortly after it has been committed, the so-called "error-related negativity" (ERN).

ERN (more in the dorsal regions) is functionally localized in the ACC (among other regions), which alerts the cognitive control system that adaptation is necessary (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Ridderinkhof, van den Wildenberg, Wery, Segalowitz, & Carter, 2004). In one such EEG study focusing on ERN, the brain activation of 7- to 18-year-old participants was assessed. Brain activation was measured 150 ms after an incorrect response in the Flanker task (Davies, Segalowitz, & Gavin, 2004a and b). Nicely matching the developmental literature regarding improvements in monitoring incorrect responses in the domain of MC (see below), the authors found pronounced age-related increases in the amplitude of ERN. From around the age of 10, significant, negative post-error responses in the ACC were found, which were similar to the patterns observed in adults. Furthermore, using the DCCS task, EEG recording and even younger participants, Espinet, Anderson, and Zelazo (2012) found that conflict monitoring quantified through N2 amplitudes (more negative amplitudes 200 to 400 ms after conflict stimulus onset) reliably differed between “passers” and “failers” and correlated with performance in the DCCS (see also Waxer & Morton, 2011). Together, these findings suggest that decreases in N2 amplitude coincide with improvements in EF tasks, suggesting that error monitoring is explicitly involved in EF (Lamm, Zelazo, & Lewis, 2006). This may indicate that monitoring plays a more important role in EF development than often assumed in behavioral approaches.

The Role of Monitoring in EF and MC

In my view, when discussing theoretical differences between EF and MC, monitoring deserves extra attention. While monitoring has been explicitly conceptualized as an integral part of MC (Nelson & Narens, 1994), for EF, monitoring is only implicitly assumed to take place, but often not studied directly (although the data would be available, for example, in terms of post error slowing down). Monitoring is certainly a part of theories of EF. However, within literature on MC, the monitoring concept is explicitly invoked. Lyons and Zelazo (2011) have theoretically integrated the different literatures and characterized monitoring as a reflective process. If such processes can range from momentary, fluctuating experiences of uncertainty to fully conscious and verbally reported monitoring judgments (Flavell, 2000), then the difference between EF and MC in terms of monitoring is mainly theoretical—EF monitoring is more momentary and less explicit compared to MC monitoring.

However, it is monitoring and the associated assumption of continuous bottom-up and top-down feedback loops during cognitive processing that critically distinguishes MC and EF on a theoretical level. Metacognitive monitoring offers explicit and theoretical explanations and—even more importantly—enables empirical predictions of why, when, and under what circumstances executive processes are initiated, changed, or terminated. If monitoring is relatively accurate, knowing the reason for an individual's uncertainty about his or her learning progress allows him or her to specifically predict which pieces of information will be selected for re-study. Regarding the few existing EF studies that have addressed individuals' error monitoring (e.g., in EEG studies, as described below; Lyons & Zelazo, 2011) as well as post-error slow-down during EF tasks (Jones, Rothbart, & Posner, 2003), the nature of ongoing monitoring might in fact be very similar to monitoring captured in MC paradigms. At the same time and as Yeung and Summerfield (2012) point out, EF monitoring appears to be an all-or-none process (error detected or not), while MC monitoring is more graded and confidence can be reported on a continuum ranging from certainty to uncertainty.

Unfortunately, in typical EF studies, researchers essentially focus on only the executive (control) processes (in terms of performance accuracy or reaction time to correct responses) but not the ongoing monitoring. Hence, further data, such as reaction time during and after incorrect trials (i.e., post-error slowing down), remain unexplored, despite being available. By hypothesis, directly addressing and quantifying monitoring processes within EF tasks would be an empirical means for bringing these fields closer together in future research. Furthermore, investigating the correspondence of brain activity patterns across a broader variety of EF and MC tasks, including classic MC contexts, would allow for integrating findings from different research domains into an overarching neuro-cognitive framework. Another fruitful neuroscientific direction for future research would be to use other psychophysiological methods in addition to EEG when investigating EF and MC. Two examples would be eye-tracking (Roderer & Roebers, 2010, 2014) and pupil dilatation (Johnson, Singley, Peckham, Johnson, & Bunge, 2014; Paulus, Proust, & Sodian, 2013).

II. Developmental Progression and Essential Empirical Links

Developmental Progression in EF and MC

Framed by the above discussion, in the following paragraphs I offer a summary of age-related improvements in EF and MC, with a specific focus on early developmental achievements. Table 1 captures some of this summary. There are a number of well-established measurement tools for EF. For MC, the summary will focus on examples of both very recent creative approaches and long-forgotten paradigms, with the aim of providing insights that could improve our developmental understanding of this concept (for a recent review see Roebers, 2014). I do not contend that the present review or Table 1 are exhaustive. Rather, I focus selectively on some clear and prototypical examples along with their main findings to illustrate parallels of EF and MC development in the age range of 2–6 years and to direct the reader to this literature. Because the information provided in the papers varies widely, an entirely consistent way of presenting the data is not possible. This is why the review outlines either the earliest point in development for these tasks to produce meaningful, reliable, and valid results or estimations of expected mean performance in typically developing children.

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Executive function. Diamond (2006) argued that the ability to pass the A-Not-B task, which emerges at the end of children`s first year of life, indicates the emergence of EF components of inhibition and working memory. In an early study using this task, 16-month-olds were found to be correct in 80% of the first conflict trials (not-A trial) when given a two-choice trial; by contrast, 2.5-year-olds were correct in about 90% of the trials when given a three-choice trial, which is a much more difficult (in terms of working memory demands) version of the task (Sophian & Wellman, 1983). This suggests that strong improvements in EF appear in this early age range. Continuous task improvements in inhibition can also be measured in children’s second year of life, with either the “Baby Stroop” task (small objects belong to the baby, big objects to the mother; the rule is then reversed) or the “Shape Stroop” task. Updating can also be quantified early on, such as with the so-called "Spin the pots task" (also the "Six Boxes" task where stickers are hidden in pots and the colors of the pots must be memorized). Such simple tasks reliably capture early individual differences in updating, differences that have been found to explain substantial variance in different social and cognitive outcomes (Carlson, 2005; Hughes & Ensor, 2007). By about the age of 3, children can also reliably complete a spatial conflict task (one object "goes" right, one "goes" left; the appearance of the object can then be congruent or incongruent) or the Day/Night task (i.e., saying "night" when a sun is presented, or "day" when a moon is presented). For these tasks, the number of errors or the reaction time reflects children's ability to engage in top-down control or inhibition. There are various updating or working memory tasks available (e.g., the Beads task or the self-ordered pointing task), and research employing such tasks has made it apparent that 3-year-olds' capacity is, on average, about 3 to 5 items, depending on the task (Hughes & Ensor, 2007; Hongwanishkul et al., 2005).

Concerning shifting, the widely used DCCS task poses serious problems for 3-year-olds, while 60–80% of 4-year-old children pass the task (Zelazo, Müller, Frye, & Marcovitch, 2003); hence, a remarkable improvement in EF development appears to take place in children's third year of life, which is attributed to their growing ability to abstractly represent current and previous task rules. Similarly pronounced developmental achievements have been reported for inhibition tasks, such as "Simon says" (do not do what Simon says) or the "Bear and Dragon" (follow the nice bear's commands, but do <u>not</u> follow the bad dragon's commands). More precisely, children younger than 4 years of age have considerable difficulty in correctly responding to incongruent trials (Carlson & Moses, 2001; Jones, Rothbart, & Posner, 2003). However, a year later, these same children might have already reached the performance ceiling (this makes it further clear that such tasks might not be optimal for capturing a wider age range).

Some EF tasks commonly used with adults have been adapted for use with children aged 5 years and older. Examples include the Stroop tasks, Backward Digit Recall, Simon task, and Flanker tasks (see Table 1). While for the age range of 2–4 years, qualitative changes (pass or fail; percent accurate responses) have been documented, speed-based dependent measures (reaction times) seem best for depicting individual differences in inhibition and shifting in 5-year-olds and older. Later on, that is, in elementary school children, a trade-off between accuracy and speed has repeatedly been documented (Best, Miller, & Jones, 2009), mirroring children's growing awareness that improvement in one aspect of performance (responding too quickly) might come at cost of another (errors).

Updating, in contrast, is typically quantified in terms of the number of correct trials, with the length of the to-be-remembered sequence being continuously increased. While recalling 2 units of information is possible for most preschool children, recalling 3 or 4 units in reversed order poses difficulties, even to 6- to 7-year-olds (Pickering & Gathercole, 2001). Thus, in comparison to speed or interference measures of inhibition and shifting, for updating it appears that developmental progression is less continuous. Furthermore, developmental improvements in updating appear to slow down around the age of 12–13 years, suggesting that an individual might have reached its capacity limit around that age (Jarvis & Gathercole, 2003). Taken together, one major developmental milestone in EF development in terms of inhibition and shifting takes place between the ages of 3 and 4, which is attributed to improvements in ability to form abstract rule representations. A second major milestone can be observed between the ages of 6 and 8, when speed measures of EF performance are considered.

In middle childhood and adolescence—while not the primary focus of this review—continuous developmental changes in EF can still be observed. In particular, in classic EF tasks, improvements in reaction times are observed over this age range (Best, Miller, &

Naglieri, 2011), along with substantial increases in the ability to manipulate multiple items simultaneously in mind, future planning, decision making, and relational reasoning (e.g., Blakemore & Mills, 2014; Dumontheil, Houlton, Christoff, & Blakemore, 2010; Paulus, Tsalas, Proust, & Sodian, 2014).

Metacognition. Traditionally, it was assumed that the most pronounced developmental improvements in MC are observed once children enter formal schooling (Roebers, 2014; Schneider, 2015), mainly employing structured learning tasks. Recently, however, some innovative paradigms that include natural indicators of metacognitive control, such as help seeking (Coughlin et al., 2014), information seeking (e.g., Call & Carpenter, 2001), or opting-out (Balcomb & Gerken, 2008; Bernard et al., 2015), have successfully explored metacognitive skills in younger children. As mentioned above, the focus in this section will especially concern recent studies, as well as some classic ones, that address *early* MC development. The aim is to draw a more differentiated picture of measurement of this concept, especially for emerging metacognitive monitoring and control skills. Table 1 provides some examples indicative of early, but still rudimentary metacognitive skills.

The goal-directed behaviors of toddlers (24–26 months of age) in a hide-and-seek task are among the earliest indications of emerging metacognitive skills. More precisely, in an early study by DeLoache and colleagues (DeLoache et al., 1985) toddlers showed on average of 2–3 different behaviors indicating an awareness of forgetting and the prevention thereof, such as peeking, verbalizing, and pointing. Furthermore, within the context of a tower building task as well as in direct interaction with an experimenter giving ambiguous commands (e.g., “get the red one!”), monitoring (checking back and forth; asking for specification) and control (change of strategy, corrections) can be observed in the second year of life, and is even more pronounced in the third (Bullock & Lütkenhaus, 1988; Revelle et al., 1985).

However, these indicators of MC skills are typically only nominal data and thus are psychometrically sub-optimal. In the last years, Simona Ghetti's research group has successfully developed paradigms, mostly in the context of object perception and identification, suitable for detecting early MC. They found that, without an additional memory (cognitive) load, young children's emerging MC skills seem to be reliably quantifiable by using a 2-point scale ("unsure" – "very sure"; Lyons & Ghetti, 2013) or a 3-point scale ("unsure" – "neither sure nor unsure" – "very sure"; Coughlin et al., 2015; Hembacher & Ghetti, 2014). With these scales the majority of children of that age give more frequently low confidence judgments after providing incorrect responses compared to correct responses, indicating the emergence of the ability to metacognitively differentiate between correct and incorrect performance. However, from these studies it also appears that children`s concept of "certainty" is most likely dichotomous: that is, children at this young age are either "very sure" or "very unsure" about the accuracy of their answers (and they have a strong tendency to be very sure whenever partial knowledge or any sense of familiarity is present; Rohwer, Kloo, & Perner, 2012; see also Kim, Paulus, Sodian, & Proust, 2016).

A relatively serious disadvantage of these studies (when aiming to integrate these MC components with EF) is the explicit nature of the monitoring and control measures used. To overcome this, Kim and colleagues (Kim et al., 2016) captured 3- and 4-year-old children's gestures of uncertainty, including the frequency of children's head tilting or shaking, shrugging, and looking away through video recording, in addition to their control decisions (verbally informing a third person or not, depending on their state of knowledge). While there were no age differences in the explicit indicators of MC (informing or not informing a third person), 4-year-olds showed significantly more non-verbal signs of uncertainty than did the 3-year-olds, with these uncertainty gestures becoming more frequent the less knowledge the children had. These findings might indicate a gradual developmental trajectory in early monitoring skills, one that may not be possible to capture using explicit measures.

By the age of 5, children begin showing increasingly differentiated monitoring judgments and more efficient control skills, according to studies charting MC development through memory recognition paradigms. Except for Balcomb and Gerken (2008) and Bernard et al. (2015) --who documented first signs of monitoring-based control in 3.5- and 3-year-olds respectively--the majority of studies have included 5-year-olds. Against the background of existing findings, one can expect kindergarteners to give reliably more positive monitoring judgments (judgments of learning: "*how likely is it that you'll remember this name later on?*", confidence judgments: "*how confident are you that you got that answer correct?*") to correct responses than to incorrect ones. Although their monitoring judgments are still strongly and positively biased (i.e., "overconfidence"; Lipowski, Merriman, & Dunlosky, 2013), children of that age are clearly beginning to build their control behavior and improve their selection of task strategies through monitoring (Coughlin et al., 2015; Destan et al., 2014; Destan & Roebers, 2015; Hembacher & Ghetti, 2014).

Through daily experiences, including success and failure of their memory and learning efforts in school, children may slowly calibrate their monitoring skills (e.g., by becoming less overconfident, making more precise performance predictions, and being increasingly able to differentiate between correct and incorrect responses as well as between sufficient and insufficient learning). While monitoring skills are found to be relatively accurate by the age of 8, control skills (e.g., study time allocation, withdrawal of errors) are repeatedly found to lag behind, as children seem to have difficulties transferring their monitoring into adequate control actions. Indeed, the following actions still pose difficulties to older elementary school children: allocating study time in line with their judgments of learning (Lockl & Schneider, 2002), monitoring text comprehension and selecting text passages for re-reading (de Bruin, Thiede, Camp, & Redford, 2011), making performance predictions and selecting the most meaningful passages for re-studying (van Loon, de Bruin, van Gog, & van Merriënboer, 2013a), or withdrawing answers when unsure about their correctness (Krebs & Roebers, 2010).

It is therefore not surprising that even in adolescence, metacognitive monitoring and control continue to improve. For example, in the context of decision-making tasks, individuals' relative confidence in different options and their strategy of seeking out additional information substantially improves between 11 and 18 years (Weil et al., 2013). In the context of reading comprehension, significant age differences have been documented in relation to monitoring discrepancies and correcting spelling errors in texts between the ages of 12 and 16 years (e.g., Hacker, 1997). Generally, as Roebers (2014) noted, metacognitive development in later childhood and adolescence can best be described as the fine-tuning of earlier developed monitoring and control skills, including the adaptive and increasingly flexible use of control actions and the efficient use of information stemming from progressively more accurate monitoring.

In sum, the current literature provides considerable evidence for rudimentary EF and MC skills in children as young as 3 years of age. For both domains, children at around the age of 4 years start to increasingly differentiate between rules or mental sets (EF) as well as between different degrees of certainty (MC). A further parallel in terms of development takes place at around school entry. For EF, children show rather accurate performance in simple EF tasks, with the developmental progression concerning mostly the trade-off between speed and accuracy. For MC, the development involves fine-tuning monitoring in able to better act upon it during learning. Finally, there is evidence for a continuous and protracted development into adolescence within both domains, especially in the context of planning and problem solving (for overviews, see, for example, Blakemore & Mills, 2014; Schneider, 2015).

Environmental Factors Influencing Developmental Progressions

The relatively similar developmental timetables in EF and MC just outlined lead to a question: "*What are the underlying mechanisms of these developmental changes?*" The literature on both concepts suggests that developmental progression is driven by a constant interaction with the child's environment (Bunge & Crone, 2009). For example, when solving a new task, a child faces numerous challenges, experiences troubles moving on, or detects errors. Consequently, the child may try different ways of mastering the task, either through trial-and-error or guidance by a more skilled individual. Strategies that turn out to be successful have a higher likelihood of being applied in later, similar situations than do unsuccessful strategies. Thus, I hypothesize that children continuously improve and fine-tune their EF and MC skills and adapt them according to the problem that needs solving. In the following paragraphs, I identify some prominent factors that I propose foster this developmental progression in EF and MC.

Effects of Parenting on EF and MC. Research on factors that drive improvements in children's EF has consistently suggested that the quality of parent–child interactions can only explain not only individual differences in EF performance but can also substantially predict EF growth over time (Blair, Raver, Berry & Family Life Project Investigators, 2014). Most of this research has focused on very young children (infants and toddlers), and involves having parents and their children solve a difficult task, such as jigsaw puzzle, together. The parental behavior during this task is observed and categorized. For this particular age range, individual differences in the mother's and father's "autonomy support" and "caregiver's sensitivity" (i.e., praising, encouraging pursuit of a task, elaborations, positive feedback), as well as the synchrony of parent and child behavior, are significantly associated with individual differences in EF performance and growth, potentially because these factors allow the child to develop a sense of mastery without too much control (Bernier, Carlson, & Whipple, 2010; Blair et al., 2014; Hughes & Ensor, 2009; Meuwissen & Carlson, 2015). Typically, these predictive links hold true even after controlling for socioeconomic status (family income or parental education) and language development (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Meuwissen & Carlson, 2015). Furthermore, enduring environmental effects might have an even stronger impact on EF development (Matte-Gagné, Bernier, & Lalonde, 2014). Thus, parents' thoughtful and intentional efforts to support a child's goal-directed actions and problem-solving behaviors are a means of fostering the child's independence from external guidance or control; these, in turn, yield a positive impact on EF development (Carlson, 2009; Hughes, 2011).

Concerning parental factors fostering early MC development, research has revealed similar findings regarding the importance of parents. Namely, parental language during social interactions might influence children`s metacognitive development. Specifically, parents' utterances relating to planning, self-monitoring, and control such as *"what do you think we should do next?" "are you sure that this is right?"* or *"did you want it to go that way?"* are considered important for MC development. In this context, an observational study showed that 39% of parents' task-related utterances were of metacognitive character; however, of those, only 8% were categorized as being related to monitoring (Thompson & Foster, 2013). Further evidence suggests that parents' metacognitive language is linked to their children's use of mental verbs (e.g., guess, think, know, forget, believe, remember, wonder), which in turn positively influences children's metacognitive knowledge (Lockl & Schneider, 2006). Additionally, parents differ in how they instruct children to use certain strategies, how they check or help children self-check their schoolwork, and how often they play certain games with their children (in particular games that require monitoring, control, or strategic thinking; Moore, Mullis, & Mullis, 1986). These differences among parents are substantially linked to children`s metacognitive development (Carr, Kurtz, Schneider, Turner, & Borkowski, 1989). Consequently, MC development—similar to EF development—is supported by parents' explicit and implicit input, which allows the child to have metacognitive experiences and benefit from feedback and supervision. In the course of development, this seems to lead to improved MC skills.

Effects of schooling on EF and MC. Schooling on its own, as well as direct instructions provided by teachers, are two further factors that influence EF and MC development, both in kindergarten and school-aged children alike. A cut-off design including children of similar age but who differ in terms of school enrolment (because they were born shortly before or shortly after the school's district cutoff date) helps address schooling effects. Concerning EF development, Burrage and colleagues' (Burrage et al., 2008) cut-off design study revealed a disproportionate EF improvement for the component of updating. Additionally, they reported a trend for an advantage in inhibition in children enrolled in kindergarten in comparison to age-mates who remained in pre-kindergarten. In a similar vein, when comparing children that either attended or could not attend school (because they live in countries where not all children can go to school), school-attending children typically outperform their non-attending age mates in terms of metacognitive skills (Rogoff, 1994). Going to school or kindergarten and thereby being confronted with the teachers` requests and assignments thus seems to foster a child's self-regulatory skills in both EF and MC.

Despite the revealing findings of these studies, investigating the direct effects of instructions on EF and MC development would additionally illuminate the underlying mechanisms possibly responsible for progressive improvements. In an effort to link the memory-related quality of teachers' instructions to children`s development of strategic memory behavior (which is an aspect of MC), Coffman, Ornstein, McCall, and Curran (2008) conducted a classroom observation study. Similar to what was found for parents' influence (see above), only 5–9% of teachers' requests or explanations were categorized as being metacognitively oriented. Furthermore, considerable variance between different teachers was found. Those teachers who were classified as giving strategy suggestions and asking metacognitive questions more often improved their first graders' metacognitive memory behavior in the long run. Specifically, first graders instructed by teachers with a strong mnemonic orientation underwent a stronger, more positive change in MC skills over the two-year study period. These effects were later confirmed in an experimental approach (Grammer, Coffman, & Ornstein, 2013).

Curriculum-based studies have also shown that the quality of teacher–student interactions and types of classroom activities initiated and supervised by the teacher play a crucial role for EF development. For instance, Tools of the Mind (Bodrova & Leong, 1996), an educational approach based on Vytgotskian theory that strongly focuses on socio-dramatic play and teachers' scaffolding, yielded positive (albeit relatively small) effects on EF when implemented in kindergarten (e.g., Blair & Raver, 2014; Diamond, Barnett, Thomas, & Munro, 2007; but see Barnett et al., 2008). Similarly, Lillard and Else-Quest (2006) compared two different kinds of educational programs, with one being Montessori education. Montessori programs are characterized by age-mixed classes, provision of special materials, long time blocks of self-selected project work, no tests or grades, and mainly small group or individualized instructions. Five-year-old children randomly assigned to a Montessori educational kindergarten program were found to outperform children from a conventional kindergarten in terms of EF (Lillard & Else-Quest, 2006). Specifically, kindergarten children attending the Montessori education outperformed children in the "normal" kindergarten in terms of card sorting, a classical measure of task switching, while there were no differences in terms of vocabulary (known to be strongly influenced by family background characteristics). In this context, it is interesting to note that specific instructional effects on EF development tend to be stronger when children grow up in adverse environments (e.g., in poverty; Blair & Raver, 2014), which is of great practical importance.

Overall, the literature shows that, to a certain degree, EF and MC are higher-order cognitive processes that develop through children's continuous and active interaction with their natural environment. More sophisticated skills, however, develop only if an individual receives direct instructions, close supervision in critical situations or challenging tasks, and feedback from skilled partners. Such factors allow the child to experience the benefits and possible use of EF or MC. In other words, cognitive instructions and social learning mechanisms appear to be major developmental forces in the ontogeny of EF and MC.

Relevance of EF and MC for Academic Performance

Executive Function. Cross-sectional and longitudinal studies on EF have consistently revealed that EF is closely linked to different areas of school performance. Research does not evenly cover the different school subjects—it has generally focused more on mathematics than on literacy or science (Bull & Lee, 2014; Latzman, Elkovitch, Young, & Clark, 2010; Rhodes et al., 2016). In general, individual differences in EF typically explain 20–60% of the variance in children's school achievement. This holds true for young elementary school children through to high school students (Best et al., 2011; Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, & Jäger, 2014), and for early word reading and spelling to 10-year-olds' reading comprehension (Kieffer, Vukovic, & Berry, 2013). It also appears to apply to achievements in science and social studies (Latzman et al., 2010). As for mathematics, the impact of EF has been shown for different sub-domains, such as simple arithmetic or applied problems (Fuhs, Nesbitt, Farran, & Dong, 2014), and updating appears to have a larger impact compared to inhibition and shifting (Lee et al., 2012; Monette, Bigras, & Guay, 2011; Roebers, Röthlisberger, Cimeli, Michel, & Neuenschwander, 2011). Of course, this does not imply that the other EF components are negligible. In a meta-analysis in which only the effects of switching on school achievement were examined, reliable effects of isolated measures of switching for mathematics and literacy performance were reported (Yeniad, Malda, Mesman, van Ijzendoorn, & Pieper, 2013).

The impact of EF is long lasting: the predictive power of EF as a unified construct (latent variable) has appeared in a number of longitudinal studies. Typically, individual differences in EF for preschoolers and kindergarteners can explain between 5 and 36% of the variance in early academic attainment (e.g., Blair, Ursache, Greenberg, Vernon-Feagans, & Family Life Project Investigators, 2015; Clark, Sheffield, Wiebe, & Espy, 2013; Roebers, Röthlisberger, et al., 2014; Viterbori et al., 2015). As is the case in cross-sectional studies, longitudinal links between EF and academic achievement tend to be stronger for mathematics (explaining 25% of the variance) than for literacy (explaining 16% of the variance; Monette et al., 2011; see also Blair et al., 2015; Clark, Pritchard, & Woodward, 2009). Among the EF components, updating seems to be the most important predictor for later mathematical achievements and for a variety of mathematical skills (Viterbori et al., 2015).

The effect of EF for school achievement is both direct (see above) and indirect. EF appears to facilitate learning-related behavior (β =.60, in Neuenschwander, Röthlisberger, Cimeli, & Roebers, 2012), and behavioral classroom adjustment, which in turn appears to positively influence later academic achievement (e.g., Clark et al., 2013; Fuhs, et al. 2014; Monette et al., 2011). Importantly, the effects of EF on academic achievement remain substantial when controlling for important predictors of academic achievement, such as socioeconomic background, home environment, and general cognitive abilities. Several studies have indicated the opposite—namely, that mathematics influence later EF performance (e.g., Blair et al., 2015; Clark et al., 2009, 2013). At the same time, note that these links are suggestive, because they cannot definitively test causal relations (Clements, Sarama, & Germeroth, 2016).

Metacognition. Reviewing the literature on the relevance of MC for academic performance is a challenge. This is because, for one, developmental psychologists have focused on the developmental progression of various aspects of MC by conducting experiments with different age groups and often neglecting individual differences within age groups. Furthermore, procedural MC is always assessed within the context of certain tasks, which are often school-related ones themselves. Nonetheless, existing studies suggest a substantial and direct link between MC and performance in adults and children (e.g., Dunlosky & Rawson, 2012; Geurten, Catale, & Meulemans, 2015; for overviews see Dunlosky & Metcalfe, 2009; Schneider, 2015). In Krebs and Roebers's (2010) study, 9- to 12-year-old children achieved between 25% and 50% gains in test performance (i.e., accuracy) through adequate metacognitive control. Similarly, students who severely overestimate their performance (i.e., poor monitoring or poor calibration), either before or after completing a task, typically perform the poorest (e.g., Dunlosky & Metcalfe, 2009; Dunning, Johnson, Ehrlinger, & Kruger, 2003; Kruger & Dunnig, 1999). In a short-term longitudinal study, fifth graders were asked to predict their test results in every test taken throughout of the school year (Roderer & Roebers, 2014). The weak students overestimated their test result as much as 20%, while the high-performing students were mostly accurate in predicting their achievement (only 5% overestimation); this pattern held true over the entire school year. This "unskilled but unaware" effect is even more pronounced in younger compared to older children or adults (Destan & Roebers, 2015; Lipko, Dunlosky, & Merriman, 2009; Lipowski, Merriman, & Dunlosky, 2013). Overall, MC seems critical for students' effective regulation of learning and remembering, with the effects of procedural MC on achievement being direct and long-lasting (Vo, Li, Kornell, Pouget, & Cantlon, 2014).

The substantial impact of procedural MC on academic achievement holds true for reading (meta-comprehension skills; De Bruin et al., 2011; Markman, 1979; Pressley & Afflerbach, 1995), writing (Hacker, Keener, & Kircher, 2009), mathematics (Desoete, Roeyers, & De Clercq, 2003; Dunlosky & Metcalfe, 2009), science (Roderer & Roebers, 2014; van Loon, de Bruin, van Gog, van Merriënboer, & Dunlosky, 2014), and general knowledge tests (Roebers, Krebs, & Roderer, 2014). When comparing the patterns of results across different age groups, it appears all children require a certain degree of monitoring and control skills; otherwise, no significant and positive effect on performance is observed. In younger elementary school children, high confidence is typically linked with better performance (explaining up to 50% of the variance in performance; Roebers, Krebs, et al., 2014; note that this effect has been attributed partly to motivation and persistence, see Shin, Bjorklund, & Beck, 2007). In older elementary school children, however, metacognitive monitoring is substantially linked to efficient MC control behavior ($\beta = .30$) that, in turn, positively influences academic performance ($\beta = .28$; Roebers, Krebs, et al., 2014; see also Schneider et al., 1987).

In their longitudinal study, Rinne and Mazzocco (2014) did not only test whether metacognitive monitoring skills were cross-sectionally related to mathematical achievement in students in grades 5–8, but also whether accurate monitoring contributes to *improvements* in mathematics over time. Their regression models revealed that good monitoring skills predicted *increases* in arithmetic ($\beta = .27$). The authors interpreted their findings as an indication that good monitoring skills directly enable a student to more effectively control mathematical information processing (e.g., more flexible problem solving strategies, more sensible error detection). This, in turn, leads to a more efficient allocation of effort, more attention on harder compared to easier problems, a better use of feedback, and, overall, to benefits in mathematical achievement.

For younger children, the link between MC and academic performance might be in the opposite direction: More precisely, increasing skills in first-order tasks might support the development of metacognitive skills. A recent study with second graders showed that spelling skills in the beginning of the school year predict spelling skills at the end of the second grade; at the same time, positive longitudinal links from earlier spelling to later metacognitive monitoring (discriminating between correctly and incorrectly spelled words: $\beta = .33$) and later control (correction of errors: $\beta = .40$; Roebers & Spiess, 2017) have been documented, suggesting that academic performance might also facilitate accurate MC. Together, the evidence has indicated bi-directional links between MC and achievement, with these relations possibly undergoing changes over time as competencies in both the first order tasks and MC improve.

Relative Importance of EF and MC for Academic Performance. Undoubtedly, both EF and MC are directly related to children's academic achievement, both cross-sectionally and longitudinally. Thus, the question arises which, if either, of these two constructs is more important? Obviously, this issue can only be tackled when measurements of both are included in one study. One investigation did so by simultaneously estimating the predictive power of EF and MC for 8-year-olds' academic achievement in mathematics and literacy (Roebers, Cimeli, Röthlisberger, & Neuenschwander, 2012). While EF was assessed with the classic tasks of the EF components, MC was quantified only in the context of a spelling task. Both EF and MC were strongly linked to curriculum-valid, independent tests of school performance. While the impact of EF was valid for both mathematics and literacy ($\beta = .66$ and .48, respectively), the effects of MC were only marginally significant for mathematics but very strong for literacy ($\beta = .24$ and .56, respectively). These findings, together with those of Rinne and Mazzocco (2014; who showed that monitoring accuracy contributes to improvements in mathematics), suggest that the predictive power of EF for academic attainment is more general, whereas the effect of MC is more circumscribed but possibly even stronger, because it is also task-bound (see also Bryce, Whitebread, & Szucs, 2014, for a cross-sectional study on this topic including younger children).

At the same time, when explaining academic performance with EF or MC, we might in fact be looking at and addressing the same underlying mechanisms. An individual's awareness that one has not yet achieved the desired goal (e.g., working too slow, using an inappropriate strategy), or that one has to only pay attention to certain task features, in combination with the general ability to act on this introspection, might be a common (monitoring) ground for EF and MC. This is especially true when predicting academic performance. Even if labeled and studied differently, the exchange of bottom-up, first-order task performance information (error/performance monitoring) with top-down regulation of ongoing cognitive processes (executive control) constitutes, at least in my view, an important shared feature of EF and MC. Similar to what has been termed "psychological distancing" in addressing commonalities between EF and theory of mind (e.g., Carlson, Claxton, & Moses, 2015; Carlson, Davis, & Leach, 2005; Devine & Hughes, 2014), an individual's ability to take a meta-view on one's ongoing information processing and to act on this meta-view might be shared between EF and MC. In other words, the ability "to step back" from ongoing processing (triggered through some fast and early monitoring processes and made possible through inhibition) and to observe oneself as an agent with the intention to improve one's performance is a central aspect to both EF and MC, which calls for an integration into one framework.

Relations of EF and MC to Intelligence

As just noted, EF and MC are strongly related to school achievement. Examining intelligence should also be helpful, because traditionally that has been considered the prototypic predictor of academic attainment. All three constructs—MC, EF, IQ-- are higher-order cognitive processes, triggered and utilized in complex tasks and problem-solving contexts. According to Sternberg`s theoretical perspective on intelligence, EF and MC may be considered integral parts of intelligence and show massive overlap between each other

(Sternberg, 1985; 1999). Consequently, once intelligence is controlled for, one would assume that no further variance in school achievement would be explained through EF or MC, respectively.

Executive Function. Empirical studies addressing overlap between intelligence, EF, and MC have not found evidence for strong overlap. When linking EF and intelligence at the task level, moderate associations in the range of r = .25 to .40 have been reported (Cornoldi, Orsini, Cianci, Giofrè, & Pezzuti, 2013; Friedman et al., 2006; Lee, Pe, Ang, & Stankov, 2009), and this pattern generalizes across a wide age range, from 7-year-olds to adolescents, and for both fluid and crystallized intelligence (Brydges et al., 2012; Friedman et al., 2006; Lee et al., 2009). Studies considering the different EF subcomponents have suggested that shifting and updating each make a unique contribution to intelligence (Lee et al., 2009; Yeniad et al., 2013). Together, the overlap between EF and intelligence is substantial, but not total; significant amounts of variance in intelligence remain unexplained, leaving room for other information processes.

Metacognition. There are only a few studies directly linking MC to intelligence. However, learning-disabled children are consistently found to have poor declarative and procedural metacognitive skills (e.g., Desoete, Roeyers, & Huylebroeck, 2006; Job & Klassen, 2012). Likewise, gifted compared to non-gifted children typically have a more elaborate metacognitive knowledge base, are able to more accurately monitor their learning progress, and can more efficiently control their learning and academic performance (Alexander & Schwanenflugel, 1996; Krebs & Roebers, 2012; Snyder, Nietfeld, & Linnenbrink-Garcia, 2011). Using the term "metacognitive skillfulness," which covers declarative metacognitive knowledge and qualitative as well as quantitative data from "thinking aloud" protocols, Veenman and colleagues have documented parallel developmental improvements and substantial overlaps between MC and intelligence, with the correlations between them ranging from $r = .16$ to .39 (Panaoura & Philippou, 2007; van der Stel & Veenman, 2008, 2010, 2014; van der Stel, Veenman, Deelen, & Haenen, 2010).

Obviously, both EF and MC share a significant amount of variance with concurrent measures of intelligence, although the overlap seems to be larger for EF than for MC. An interesting follow-up question then concerns the predictive power of EF and MC versus intelligence for academic achievement. Given the lack of studies that have simultaneously included EF, MC, and intelligence in predicting academic achievement, the current review focuses separately on the predictive powers of EF or MC *versus* intelligence. Rather few studies have simultaneously compared the longitudinal links of EF or intelligence with academic outcome measures. Those that exist suggest that intelligence is more closely related to objective measures of school performance than is EF (for a meta-analysis, see Yeniad et al., 2013), whereas EF has greater potential to contribute to the prediction of school performance over and above intelligence. In other words, even after controlling for individual differences in intelligence, EF has been reported to explain a further 6–10% of the variance in school performance). Interestingly, this pattern holds true for young (preschool) children when predicting early academic outcomes (Clark et al., 2009) as well as for older (middle to high school) students, and generalizes to different school domains (literacy, mathematics, social studies, science; Latzman et al., 2010).

In comparing the impacts of MC and intelligence on children's academic performance, a similar picture emerges as for EF. Individual differences in MC have an additional and direct effect on students' learning outcomes, after controlling for the influence of intelligence (for example, 26% additional unique metacognitive variance explains history achievement, over and above intelligence; van der Stel & Veenman, 2014). Further, it appears that in younger students (late elementary school children), the impact of MC on academic attainment over and above that of intelligence is smaller compared to in older students, for whom MC has been reported to be more important than intelligence in the domains of mathematics and history (van der Stel & Veenman, 2010; van der Stel et al., 2010).

Empirical links between EF and MC

In this last section, *direct* links between the two constructs of EF and MC will be considered. Against the background of similarities reviewed so far, one would expect strong evidence for a close link between these two higher-order information processes. Surprisingly, very few studies have directly addressed the shared processes and variances. Moreover, the results do not confirm the assumption of closely linked domains. With respect to *declarative* MC, one recent study documented substantial links between verbal fluency (an often-used index of switching), and working memory and an overall measure of declarative metamemory in 6- and 9-year-olds (Geurten, Catale, & Meulemans, 2016). This pattern, however, was found neither for 4- nor for 11-year-olds. Furthermore, it did not generalize to inhibition.

Regarding *procedural* MC, researchers have mostly used individual EF subcomponents to explain variance in MC (and not *vice versa*), particularly *updating*. This is because it is commonly assumed that the iterative flow of information in both a bottom-up (monitoring) and top-down (control) direction requires sufficient cognitive capacity, which is best captured with updating measures. Studies by Dunlosky and Thiede (2004, Experiment 3) and Rhodes and Kelley (2005) have documented this link for adults. Rather few studies have also addressed the link in elementary school children—that is, in children aged 5–10 years. Interestingly, these studies have consistently found a significant, albeit small, association between working memory (or updating) and MC, explaining between 5 and 10% of the variance (with correlations consistently being in the r = .20–.35 range). The included MC measures range from strategic behavior in a memory task (DeMarie & Ferron, 2003) to metacognitive control in the context of a school achievement test (Spiess, Meier, & Roebers, 2015, 2016). When both monitoring and control measures are available, the results point to a closer link between updating and control than between updating and monitoring (Bryce et al., 2014; Roebers et al., 2012). It thus seems safe to conclude that individual differences in updating are related to metacognitive skills, both in children and adults.

In the context of children's flexible strategy use, Kuhn and Pease (2010) have reported that *inhibition* might be a necessary but insufficient prerequisite of effective use of metacognition. Successful problem solving or efficient memory operations might rely on the production of a new strategy as well as the inhibition of a previously used strategy. When using more classical indicators of inhibition (Stroop tasks) and MC, Bryce and colleagues (2014) reported a correlation of $r = .35$ between inhibition and monitoring (i.e., looking back and checking in a train-track building task) among 5- and 7-year-olds. However, in Roebers et al.'s (2012) study, monitoring discrimination was not found to be associated with inhibitory skills, whereas 8-year-olds' metacognitive control in a spelling task was (with *r*s = .25–.29; see also Spiess et al., 2016, for similar findings).

Finally, one would theoretically expect that *shifting* one's attention back and forth between the task at hand (an EF component) and ongoing metacognitive processes (MC) could be a crucial link between the two. However, results from the few existing studies (embodying a variety of approaches) have mainly reported insubstantial links between *switching* (or shifting, or cognitive flexibility) and metacognitive monitoring and control in elementary school children (Roebers et al., 2012; Spiess et al., 2016). Moreover, it is important to note here that in some other studies trying to link EF components with MC, only non-significant links between MC and EF in children were found (e.g., Destan & Roebers, 2015; Geurten, Catale, et al., 2015), suggesting that the links reported above are far from firmly established.

Although these approaches are interesting, they have some serious methodological disadvantages. For one, EF tasks, and even more so MC tasks, trigger non-executive or nonmetacognitive processes, such as domain-specific knowledge, momentary motivation, and familiarity with the task. For another, no single EF component or MC aspect can be quantified in isolation, because the different sub-processes within one concept are strongly intertwined and mutually dependent. Miyake and Friedman (2012) labeled this issue as the "task-impurity" problem in the context of EF, but it also seems to apply to MC. For instance, working memory strongly relies on an individual's ability to inhibit interference and shift between the storage and processing of to-be-remembered information. Or, a learner's re-study selections might be based on her or his—more or less accurate—monitoring of learning progress (monitoring-based control). As a result, the true amounts of shared variances between "pure" EF and MC are likely underestimated (Roebers & Feurer, 2016). Structural equation modeling techniques (SEM) offer a unique solution to these methodological concerns. With such an approach, the individual EF or MC tasks can be loaded onto a latent EF or MC factor, respectively, which then captures only the shared variances of the individual indicators. These variances can then be used on the construct-level to estimate the relations between EF and MC.

To date, only two studies have addressed direct links between EF and MC at the latent-variable level, using SEM techniques. One of them, a cross-sectional approach including second graders, reported a link as high as $\beta = .51$ between metacognitive control and EF (with indicators of inhibition, updating, and shifting (verbal fluency) being used to load onto the latent EF variable; Roebers et al., 2012). The link between metacognitive monitoring and EF, however, was not significant. Since monitoring and control were found to be strongly related ($\beta = .46$), it seems that there is no direct effect of monitoring on EF. In a follow-up study targeting direct links between EF and metacognitive control only, Spiess and colleagues (2016) confirmed a concurrent relation between the two constructs. Individual differences in second graders' EF and MC were substantially related at the beginning of the school year, accounting for as much as 34% of the shared variance. Apart from this link and because of the very high stability of both constructs in that short-term longitudinal study, *earlier* EF or MC did not predict *subsequent* EF or MC (i.e., at the end of the second school year). These findings suggest that the developmental progression in the two constructs are not entirely dependent on each other, but rather follow distinct pathways, at least in this age.

One possible reason that the empirical links between EF and MC are lower than one might expect is children's ability to form meta-representations—that is, some kind of self-awareness of one's performance is necessary to switch from automated to controlled processes or to change a selected strategy. Consequently, age-related and individual differences in the ability to hold a representation of one's performance should be related to both EF and MC. In this context, one cross-sectional and one longitudinal study reported substantial links between kindergarteners' and second graders' self-perceptions of competence (i.e., self-concept) and EF or MC (Hughes & Ensor, 2010; Roebers et al., 2012).

Following this argument, a child's ability to hold in mind two divergent representations (actual and desired performance) might even constitute a link between EF and MC, at least in young children. In the domain of theory-of-mind development, understanding that one entity can be represented in two different ways (for example, by two different individuals, as is investigated in so-called false-belief tasks) is an important achievement in cognitive and social-emotional development. From this perspective, theory-of-mind skills might moderate the link between EF and MC. This assumption has been supported by a handful of studies revealing empirical associations of EF and MC with theory-of-mind skills. Specifically, while Carlson and colleagues found significant links between preschoolers' EF and their theory-of-mind skills (Carlson et al., 2015; Carlson, White, & Davis-Unger, 2014), other researchers report links between theory-of-mind skills and either declarative (Lecce, Caputi, & Pagnin, 2015; Lecce, Demichelli, Zocchi, & Palladino, 2015; Lockl & Schneider, 2006, 2007) or procedural monitoring skills (Feurer, Sassu, Cimeli, & Roebers, 2015).

Besides these theoretical accounts, there are also methodological reasons for the empirically poor links between EF and MC. For one, EF is typically quantified in a decontextualized manner using electronic devices that present simple stimuli. MC, in contrast, is almost always measured in a circumscribed, explicit, and task-specific context, such as by reading a text, learning paired associates, or solving a certain problem. Consequently, it is quite likely that MC measurements include greater variance attributable to domain- or task-specific knowledge or familiarity than do EF tasks (e.g., responding to the stimuli's orientation). For another, the focus of the measurements entails a further methodological difference between the two domains. For EF tasks, the focus is either on accuracy (e.g., DCCS task or updating tasks), speed of information processing (e.g., the Simon task or Flanker task), or both (which is because most tasks have a speed-accuracy trade-off: if you respond too fast, you are risking errors). Primary measures of MC, in contrast, focus on the timing of processes (MC during encoding, storage, or retrieval) and the qualitative nature of measurement. If one would use, for example, reaction-time-based measures of MC (see, for example, Koriat & Ackerman, 2010; van Loon, de Bruin, van Gog, & van Merriënboer, 2013b) and relate them to reaction-time-based measures of EF (e.g., Flanker performance in terms of reaction times), the obtained correspondence might be more substantial. The same might be true for more qualitative measures of EF (e.g., complex versions of the DCCS task) in relation to classical MC measures (e.g., flexible strategy use). Future research should broaden the methodological approaches for quantifying EF and MC, and thereby provide a more comprehensive picture of the assumed links.

One might assume that the direct empirical links between EF and MC documented so far are due to their overlapping effects with intelligence. In other words, it is possible that the relation between EF and MC is best explained with individual differences in intelligence. Unfortunately, no study has yet included intelligence when linking EF and MC. This constitutes an important issue for future studies. Drawing on the literature linking EF to theory-of-mind skills, I expect that the link between metacognitive control (but not necessarily monitoring) and EF still holds true after controlling for intelligence. Several studies have shown that the EF–theory-of-mind link remains substantial even after controlling for language abilities (Carlson & Moses, 2001; Devine & Hughes, 2014; Lockl & Schneider, 2007), which points to unique shared processes. Thus, even though intelligence, EF, and MC are higher-order cognitive processes (see above), I assume that an EF–MC link remains significant even when controlling for psychometric intelligence. This is because EF and MC involve information processes that are more proximal and similar to each other than to intelligence. In particular, the control aspect of EF and MC, which is triggered to improve current task performance, is not made explicit in intelligence.

Towards a Unifying Framework of Cognitive Self-Regulation

Because EF and MC have different research traditions and are embedded in different theoretical frameworks, the connection between the two has not received sufficient attention. In the present review, key aspects relevant to cognitive functioning in general as well as for self-regulatory skills in particular have been discussed separately for EF and MC, with a focus on the similarities between these two domains. With respect to controlled (versus automated) processing, neuropsychological correlates, relevance to self-regulated behavior (especially learning, intelligence, and academic performance), developmental timetables, and the driving forces for developmental progression, it appears that there are more commonalities than differences between the two constructs.

Against this theoretical and empirical background, and with the aim of theoretically integrating EF and MC, I propose that a core feature for an overarching framework of these two concepts concerns an individual's ability to form and use meta-representations of cognitive and learning processes. This includes the ability to look at one's actions at a remove, ideally objectively, and to act on the information that stems from this meta-perspective. [Although not the primary focus here, from this perspective, theory of mind skills may also be incorporated as meta-representations of one's own and others' thoughts, motivations, and goals, or, more generally, cognitive processing (Frith, 2012; Kuhn, 2000; Perner, Lang, & Kloo, 2002)]. According to such a view, the integration of these two concepts would provide a domain-general, second-order cognitive processing account, with EF and MC being expressions of the same underlying system of self-regulative processing (Best & Miller, 2010; Kuhn, 2000).

Within this integrative view, monitoring processes would be another shared, and central feature. The neuroscientific evidence suggests that one can assume a network of brain areas, predominantly located in the PFC and ACC, which alerts the system if ongoing information processing should be slowed down or adjusted. The activity of such a monitoring system would be a prerequisite for both EF and metacognitive control (see Espinet, Anderson, & Zelazo, 2013, for a training approach). Although not studied simultaneously, monitoring appears to be very similar in its neuro-anatomical and neuro-physiological function and structure in both the EF and MC contexts, differentially recruiting interacting neural circuits. As such, EF and MC monitoring can range from very fast monitoring that alerts the system of a potential error in an all-or-none reaction (detectable as N2 and N4 in EEG studies or as post-error slowing at the behavioral level) to the more explicit and verbalized forms of fine-grained monitoring (Dumontheil et al., 2010; Fleming & Dolan, 2012; Metcalfe & Schwartz, 2016; Weil et al., 2013; Wessel, 2012; Yeung & Summerfield, 2012). Such a wider range of monitoring processes might constitute an avenue for better understanding the development of cognitive self-regulation: momentary all-or-none error detections may also serve as a developmental precursor for more fine-grained monitoring skills.

Concerning how EF and MC are related under the umbrella concept of cognitive self-regulation, empirical data have predominantly pointed to an "expression account" (Carlson et al., 2015; Devine & Hughes, 2014), by which EF facilitates or is necessary for MC. In other words, EF deficits would be responsible for MC failures (e.g., experiencing comprehension problems while reading, but nevertheless continuing reading; mixing up the names of playmates, but not asking for clarification; realizing that one is using an inefficient strategy, but still sticking to that strategy). From this perspective, EF are necessary for metacognitive control at the basic level of any self-regulated cognitive task. For example, inhibition enables hesitation and interruption (Bryce et al., 2014); working memory is involved in the exchange of information between first- and second-order processing (the task at hand and the corresponding metacognitive monitoring and control processes; Dunlosky & Thiede, 2004; Spiess et al., 2015); and shifting is triggered whenever information from monitoring must be translated into control actions. Thus, one may consider EF and EF error monitoring as rapid micro-processes that operate at the very basic level of information processing and can integrate with the slower metacognitive control processes. Consequently, EF would be necessary, but still not sufficient, for efficient metacognitive control.

Within this integrated framework, metacognitive monitoring and control processes are thought to be slower, longer-lasting, more fine-tuned, and therefore possibly farther-reaching. One reason for this assumption is that MC is always very closely connected to, and even dependent on, the first-order task. In other words, metacognitive processes loop (or make a "detour" and are thereby slowed down) via the domain-specific knowledge or prior experiences an individual has for the task at hand (e.g., the better a child gets in spelling, the better she or he can monitor her or his spelling and act on this). There is a bulk of evidence showing that domain-specific knowledge is strongly related to efficient MC. Furthermore, longitudinal data also suggest that domain-specific knowledge for the task to which MC is applied predicts developmental improvements in MC (Roebers & Spiess, 2017), which links

MC more strongly to the domain-specific knowledge or task experiences than EF. This is not, of course, to say that EF is not influenced by a person's domain-specific knowledge (see, for example, working memory performance for chess positions recalled by chess experts and novices; Chi, 1978). However, the prior knowledge effect is likely to be substantially stronger in MC than in EF.

At the same time, I posit that EF and MC have a dynamic relation in the course of development. In other words, the relationship between EF and MC within a broader conceptualization of cognitive self-regulation is likely to change over time, as EF and MC undergo substantial improvements in childhood and this is likely to affect their interplay. In very young children, EF and MC may be mutually dependent on the ability to form, experience, and use meta-perspectives on behaviors, outcomes, actions, and cognition. Once this ability is established, which occurs around the age of 4–6 years, EF may be a prerequisite of MC (Roebers et al., 2012). More specifically, EF skills might then be needed to master metacognitive demands in a task (self-initiated stopping and double checking: error monitoring and inhibition; shifting strategies: switching; using monitoring for control: updating). By the time an individual has acquired basic MC skills (typically in the early elementary school years), further improvements in MC might then be facilitated by, but no longer fully depend on, EF because domain-specific knowledge increasingly comes into play (Roebers & Spiess, 2017). Based on these assumptions, one would consider EF to have a causally primary role in the development of MC, but only early on. Later in development, EF and MC may follow distinguishable (although similar) developmental timetables. This would explain why some individuals may be good in EF but may nevertheless perform poorly in MC (or vice versa).

Going forward, I have not only suggested encouraging avenues for a theoretical integration of EF and MC but also better empirical approaches for examining these two concepts. To improve our understanding of the commonalities and differences of EF and MC, and of the development of cognitive self-regulation in the course of development, multilevel, multi-methodological lines of research are needed. Behaviorally and neuro-scientifically investigating the early and perhaps common ontogenetic roots of EF and MC within a cognitive developmental framework (e.g., integrating EF error monitoring with MC monitoring) may be a promising way to achieve a conceptual integration and a developmental framework for the ontogeny of cognitive self-regulation.

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Table 1

Examples of Early Developmental Achievements in Executive Function and Metacognition (2 to 6 years)

	Executive Functions	**Metacognition**
2 years	• *A-Not-B task (inhibition; Sophian & Wellman, 1983): 2 year* olds reach out correctly on the first conflict trial (3 hiding locations) in 75-92%; 2 ½ yr olds perform already at ceiling; • *Spin the pots task/Six Boxes (updating; Hughes & Ensor, 2007; Wiebe, Espy, & Charak, 2008): on average* about 75% correct trials; • *Baby Stroop/ Shape Stroop (inhibition; Carlson, 2005; Hughes & Ensor, 2007): on average* about 60-70% accuracy.	• *Hide and Seek game (DeLoache, Cassidy & Brown, 1985)*: children show on average 2 - 3 different and specific behaviors indicating preventing forgetting (e.g., peeking, pointing, approaching, verbalizing etc.); • *Tower Building task (Bullock & Lütkenhaus, 1988)*: with 26-32 months of age, 85-100% of the children compare own construction with targeted state (=monitoring); 48-58% of the 26-32 months olds made corrections during building (=control).
3 years	• *Spatial conflict task (modified Simon task/inhibition; Geradi-Caulton, 2000):* about 90% accuracy on spatially incompatible trials; • *Day/night task (Go/NoGo inhibition task; Carlson & Moses, 2001; Gerstadt, Hong, & Diamond, 1994): about 60% accuracy;* • *Beads task (updating; Hughes & Ensor, 2007):* about 50% of the trials correct; • *Self-ordered pointing (updating; Hongwanishkul, Happaney, Lee, & Zelazo, 2005):* on average 4-5 items correctly remembered.	• *Interaction with experimenter (Revelle, Wellman, & Karabenick, 1985):* when asked to bring an ambiguously described item, 3 yr olds asked in about 50% of the requests for specification (=monitoring); • *Perceptual Identification task (Coughlin, Hembacher, Lyons, & Ghetti, 2015): on average* "40% confident" (3-point scale) for incorrect and "50% confident" for correct responses (=monitoring); selective help-seeking when less than on average "40% sure" (=control) leading to higher accuracy; • *Picture naming task with opting out (Bernard, Proust, & Clément, 2015):* of all items 3 yr olds opted out, only 7% were later accurately solved indicating good uncertainty monitoring; • *Paired-associate learning task (Balcomb & Gerken, 2008):* after 3 yr olds have declined a recognition trial (=monitoring), accuracy of their later response on that trial is systematically poorer (approx. 50%) compared to the accepted trials (approx. 80% accuracy).
	• *Dimensional Change Card Sorting task (shifting; Zelazo, Müller, Frye, & Marcovitch, 2003)*: 50-80% of 4-yr olds pass;	• *Informing or not informing a third person about the content of a box (Kim et al., 2016):* 4 yr olds produce gestures indicative of uncertainty in 35-45% of the trials when they are ignorant;

4 years	• *Simon Says/Bear-Dragon task (Inhibition tasks; Carlson & Moses, 2011; Jones, Rothbart, & Posner, 2003*): approx. 80-90% accuracy on inhibition trials;	• *Feeling-of-knowing judgments (FoKs; Cultice, Somerville, & Wellman, 1983): correct recognition in 51% of "yes"* - FoKs (=monitoring) for somewhat familiar children/photo-items; • *Picture-pairs Learning and Recognition task (Geurten, Willems, & Meulemans, 2015):* judgments-of-learning (JoLs) reveal use of the "easily-learned-easily-remembered"-heuristic by giving lower JoLs to hard picture pairs (on average "50% sure") compared to easy ones (on average "70% sure").
5 years	• *Backward Digit Span / Backward Color Recall (updating; Gathercole, Pickering, Ambridge, & Wearing, 2004; Roebers & Kauer, 2009):* average span length of 2-3 items; • *Fruit Stroop task (inhibition; Archibald & Kerns, 1999; Monette, Bigras, & Lafrenière, 2015; Roebers, Röthlisberger, Neuenschwander, Cimeli, Michel, & Jäger, 2014):* on average 30-50 sec slowing down in the incongruent trial (interference); 33% increase in errors in the incongruent trial; • *Flanker task (inhibition; Roebers & Kauer, 2009; Rueda, Checa & Rothbart, 2010):* accuracy of 80-90% in the incongruent trials; • *Mixed Flanker task (shifting; Röthlisberger, Neuenschwander, Cimeli, Michel, & Roebers, 2012)*: about 80% accuracy overall (switch and non-switch trials).	• *Old-New Recognition Paradigm (Hembacher & Ghetti, 2014)*: on average "50% sure" for incorrect and "86% sure" for correct recognition (=monitoring); 54% correct "withdraw" decisions when recognition failed; 93% correct maintain decisions when recognition was accurate (=control); • *Object Perception* task *(Lyons & Ghetti, 2013)*: 55% of "unsure" confidence judgments (2-point scale) for incorrect responses (=monitoring); selective use of the "escape" response in 53% of the trials (=control) leading to improvements in overall accuracy; • *Train Track Building task (Bryce & Whitebread, 2012)*: on average 4.8/min comparisons between own and targeted train track (=monitoring); 2.2/min control actions (changes of strategy, clearing, and block seeking); • *Paired-associates learning and recognition task (Destan, Hembacher, Ghetti, & Roebers, 2014):* confidence judgments (CJ; =monitoring) differentiate between correct (on average "56% sure") and incorrect recognition (on average "68% sure"); 59% correct control decisions (withdrawal after incorrect recognition).
6 years	• *Advanced Dimensional Change Card Sorting* task (shifting; Chevalier & Blaye, 2009): about 60-80% of 6 yr olds pass the task; • *Go/No-Go task (inhibition; Cragg & Nation, 2008)*: on average 77% correct trials with an average speed of 450 ms reaction time; • *Listening Recall (updating, Gathercole et al., 2004):* recall after max. 2 sentences correct.	• *Paired-associates learning and recognition task (Destan, Hembacher, Ghetti, & Roebers, 2014):* on average 0.5 sec more study time for hard than for easy items (=monitoring-based control); • *Paired-associates learning and recognition task (Destan & Roebers, 2015):* 58% correct control decisions (withdrawal of incorrect and maintenance of correct recognition).