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Selective attention relates to the development of executive functions in 2,5- to 3-year-olds: A longitudinal study

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ABSTRACT

To study the central role of selective attention in the early development of executive functions (EFs), longitudinal relationships between selective attention, working memory, and simple response inhibition were explored. Selective attention, working memory, and simple response inhibition were assessed twice in our preschool sample ($N = 273$), which included a relatively large number of children from low SES families. The tasks were administered between age 2.5 (time 1) and 3 years (time 2). An analytical path model was tested to analyse the relationships simultaneously. The results indicate that selective attention at age 2.5 years predicts working memory and response inhibition at age 3 years. Controlling for gender, SES, home language, verbal ability, and age did not affect the strengths of these relationships.

1. Introduction

Executive Functions (EFs) refer to cognitive control processes aimed at regulating, organizing, and planning behaviour (Diamond & Lee, 2011) and have been found to be linked to good academic performance, good social skills, less criminal activity rates, and low substance abuse, or to overall success in life (Diamond, Barnett, Thomas, & Munro, 2007; Moffitt et al., 2011). Given the predictive validity of EF measures for such a wide range of developmental outcomes, EFs have increasingly become a focus point for early interventions. To target such interventions most optimally, it is essential that Executive Function (EF) development and its underlying factors are understood. However, although research on EF development at preschool age and beyond is flourishing, much less is known about EF development before the age of 3 years. Selective attention, or the ability to focus on a specific stimulus and to ignore other stimuli or distractors (Atkinson & Braddick, 2012; Mahone & Schneider, 2012; Plude, Enns, & Brodeur, 1994), has been hypothesized to constitute one of the core building blocks in infancy and toddlerhood on which (complex) EFs build as children grow older (Garon, Bryson, & Smith, 2008; Hendry, Jones, & Charman, 2016). Recent studies have indeed shown that measures of attention in infancy are predictive of EF in toddlerhood (Holmboe, Fearon, Csibra, Tucker, & Johnson, 2008; Johansson, Marciszko, Brocki, & Bohlin, 2015; Johansson, Marciszko, Gredebäck, Nyström, & Bohlin, 2015; Kochanska, Murray, & Harlan, 2000), providing initial evidence for the developmental model proposed by Garon et al. (2008) and Hendry, Jones, and Charman (2016). However, these previous studies were mostly small-sample laboratory studies with highly selective (i.e., high SES) groups of participants. As such, it is currently unknown whether results can be generalized to a wider population (including low SES children), and whether measures of selective attention remain of predictive value for EF development when assessed beyond infancy. This is particularly important, as intervention efforts aimed at boosting EF development, such as preschool remediation programmes, are likely to be targeted at low SES and/or immigrant children, and children often do not enroll into such programmes until some point during the 3rd year of life (for example, Department for Education, 2016; Government of the Netherlands, n.d.; U.S. Department of Health and Human Services, 2016). Therefore, the current study set out to investigate whether individual differences in selective attention at age 2.5 years, at a time when development of EF is particularly rapid (Gerardi-Caulton, 2000; Rueda, Posner, & Rothbart, 2005), predict EF at age 3 years in a large and heterogeneous sample. To this end, we used a previously validated battery of EF measures suitable for field-based assessment, focusing on core and relatively early emerging aspects of EF: inhibitory control and working memory (Mulder, Hoofs, Verhagen, Van der Veen, & Leseman, 2014). In the next sections, we first describe the general tenet of the hierarchical model of EF development, followed by

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a brief overview of current evidence regarding the relation between selective attention and early EF development.

1.1. Development of EFs

A number of researchers (e.g., Bull, Espy, & Wiebe, 2008; Davidson, Amso, Anderson, & Diamond, 2006; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) agree that EF comprises three basic interrelated cognitive processes, namely: updating of information in *working memory*, *inhibition* of responses, and *shifting* of attention sets or response sets. The hierarchical model of EF development postulates that there is a certain ordering in the development of these skills, with relatively simple and more basic EF skills providing the foundation on which more complex skills are built (Garon et al., 2008), as will be briefly reviewed below.

1.1.1. Working memory

A few days after birth, infants already demonstrate recognition memory, for example, the recognition of faces (Slater & Quinn, 2001). The ability to store and retrieve information over relatively short periods of time can be referred to as short-term memory (Astle & Scerif, 2011; Diamond, 2013). Memory span – the amount of visuospatial or phonological information that can be immediately recalled when it has been presented once – increases with age across childhood (Howard & Polich, 1985). ***Working memory*** involves both storing incoming visual or auditory information for brief periods of time, and actively performing cognitive operations on that information, such as updating or manipulation (Baddeley, 2003; Engel de Abreu, Conway, & Gathercole, 2010). As such, by definition, working memory relies on short-term memory. Working memory improves with age, from infancy through to adolescence and young adulthood (Diamond, Prevor, Callender, & Druin, 1997; Garon et al., 2008; Huizinga, Dolan, & Van der Molen, 2006).

1.1.2. Inhibition

Similarly, simple response inhibition, or the ability to refrain from acting on impulse, precedes development of more complex forms of inhibition (Garon et al., 2008). Simple response inhibition involves the suppression of a dominant response (Kochanska et al., 2000; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). One example is the ability to delay gratification, where the dominant response – giving in to the temptation – has to be suppressed. Simple response inhibition improves gradually with age (for example, from 22 to 33 months: Kochanska et al., 2000; and from 33 months to 66 months: Kochanska, Murray, & Coy, 1997). Carlson (2005) also showed that the percentage of children who passed a simple response inhibition task (such as *gift delay*) increased significantly with age (from the age of 3 years to the age of 5 years). Complex response inhibition implies that children not only suppress their primary response but also replace it by a subdominant behaviour (Karreman, Van Tuijl, Van Aken, & Deković, 2008). This requires children to remember and initiate the appropriate behaviour. Thus, in complex response inhibition, not only inhibition but also working memory is important. Like simple response inhibition, complex response inhibition improves with age. For example, Carlson (2005) showed that the percentage of children who passed a complex inhibition task (Stroop tasks such as "Grass/Snow" and "Bear/Dragon") increased significantly from the age of 3 years to the age of 5 years.

1.1.3. Shifting

Shifting involves the ability to change flexibly between different tasks or between using different rules within the same task (Miyake et al., 2000). Shifting involves both working memory and inhibitory control processes (Blakey, Visser, & Caroll, 2016). Due to this relatively high level of complexity, children do not start to pass standard shifting tasks such as the Dimensional Card Sorting Task until after age 3 years (Zelazo, 2006). Although recent studies have started to include more basic shifting tasks for younger children too (for an overview, see Garon et al., 2008), these involve primarily lab-based measures which cannot easily be applied in field-based research. Similarly, at the time of the design of the current study, complex inhibition measures suitable for large-scale field-based research in toddlerhood were not available. As such, the current study is focused on the two core aspects of early EF: working memory and simple response inhibition.

1.2. Attention as foundation for EF development

The first 3 years of life are marked by rapid development of the ability to selectively attend to stimuli and ignore distracting information (Gerhardstein & Rovee-Collier, 2002; Scerif, Cornish, Wilding, Driver, & Karmiloff-Smith, 2004; Posner & Rothbart, 2007), and individual differences appear to be, at least partly, stable over time from the second half of the first year of life to 2.5 years of age (Kannass, Oakes, & Shaddy, 2006). In their developmental models, Garon et al. (2008) and Hendry et al. (2016) suggest that attention, and selective attention in particular, may provide one of the first 'building blocks' for, or precursors to, emerging EF, such as working memory and inhibitory control. Subsequently, across childhood and beyond, selective attention is assumed to continue to play a direct and important role in EF task performance (cf. Hendry et al., 2016), as regulating, organizing, and planning behaviour all involve attention.

A few longitudinal studies have shown that individual differences in infant selective attention predict EFs in toddlerhood. First, significant predictive relations from attention assessed in infancy to inhibitory control and working memory in toddlerhood have been observed (Holmboe et al., 2008; Johansson, Marciszko, Gredebäck et al., 2015). Moreover, Johansson, Marciszko, Brocki et al. (2015) found that infant attention predicted working memory at age 3 years. However, these studies all included small and mostly selected high SES samples with laboratory assessments. One exception is a study by Kochanska et al. (2000), which showed that observed attention in infancy predicted performance on a battery of inhibitory control measures at 22, but not 33 months in a sample of mixed SES backgrounds. Thus, there is converging evidence that infant attention serves as one of the core building blocks of emerging EF. However, replication in large heterogeneous samples is needed, and it is currently unclear whether selective attention remains a unique predictor of EF development when assessed beyond infancy. The present study aimed to address these issues, by studying if and how selective attention predicts EFs towards the beginning of the preschool period, including a large and diverse sample. Specifically, predictive relations from selective attention at age 2.5 years (time 1) to working memory and inhibitory control 6 months later, at age 3 years (time 2) were studied. Before turning to the goals of the present study, the theoretical rationale, including underlying mechanisms linking selective attention and EF, will be discussed. Furthermore, experimental work with older children and adults which provides evidence regarding the underlying mechanisms through which selective attention and EFs are linked, will be described.

1.3. Underlying mechanisms linking selective attention and EF

The central underlying mechanism linking selective attention and EFs is that an important function of selective attention is the ability to resolve conflicts among thoughts, feelings, and responses, whereas resolving conflicts is crucial for EF performance as well (Garon et al., 2008; Posner & Rothbart, 2007). Hence, orienting on relevant stimuli while ignoring other (possibly very attractive but,) irrelevant stimuli increases both working memory performance and inhibitory control. In addition, selective attentional orienting has been shown to aid in regulating and controlling emotions in young children (Harman, Rothbart, & Posner, 1997; Posner, Rothbart, Sheese, & Voelker, 2012; Rothbart, Sheese, Rueda, & Posner, 2011).

With regard to working memory, selective and focused attention is important in all stages: encoding relevant stimuli, holding the mental representation active in mind during the delay, retrieving relevant stimuli, making decisions, and responding. In the presence of several distracting stimuli, encoding relevant stimuli is particularly dependent of selective attention: the ability to focus attention and ignore distractors (Gazzaley & Nobre, 2012). With regard to inhibitory control, Mischel and colleagues propose that orienting attention on other stimuli or distractors (referred to as self-distraction) serves as a strategy to reduce the difficulty of inhibiting behaviour (Metcalfe & Mischel, 1999; Mischel, Cantor, & Feldman, 1996; Mischel, Shoda, & Rodriguez, 1989; Sethi, Mischel, Aber, Shoda, & Rodriguez, 2000). In accordance, different EF tasks may draw upon selective attention skills in a different way. In particular, a key distinction occurs between tasks which require focusing of attention on the task material, such as working memory tasks, and tasks which require moving the task material *out of focus* in order to reduce its emotional saliency, such as during delay of gratification tasks used to tap inhibitory control. Hence, focused attention is suggested to be essential for working memory task performance, whereas distracting attention is propounded to be important in order to succeed in delay of gratification tasks.

Finally, a distinction could be made between tasks relying on dorsolateral frontal cortex, involved in cognitive processes (cool EF), and tasks relying more on emotion and motivation and in which the orbitofrontal cortex is involved (hot EF), for example delay of gratification tasks (Alvarez & Emory, 2006; Zelazo & Müller, 2002). Likewise, the distinction between cool EF and hot EF has been demonstrated in studies in which EF tasks were administered to young children (Bassett, Denham, Wyatt, & Warren-Khot, 2012; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011).

Next, current evidence from experimental studies regarding the role of selective attention in working memory and inhibitory control, measured through delay tasks, will be discussed.

1.3.1. Selective attention and working memory

Selective attention has been consistently linked to short-term memory capacity in adults (Poole & Kane, 2009; Vogel, McCollough, & Machizawa, 2005; Zanto & Gazzaley, 2009). Moreover, several neurophysiological studies into the association between selective attention and working memory have shown that the same brain regions are involved in both selective attention and working memory in adulthood (Awh, Anllo-Vento, & Hillyard, 2000; Awh, Smith, & Jonides, 1995; Kiyonaga & Egner, 2013; Mayer et al., 2007; Rutman, Clapp, Chadick, & Gazzaley, 2010; Sreenivasan & Jha, 2007; Zanto, Rubens, Thangavel, & Gazzaley, 2011). A recent series of experimental studies with infants suggests that the close ties between selective attention and memory are already present during the first year of life (Markant, Ackerman, Nussenbaum, & Amso, 2016; Markant & Amso, 2013, 2016; Ross-Sheehy, Oakes, & Luck, 2011). For example, Markant and Amso (2013) showed that selective attentional suppression of a previously visited location facilitated memory encoding of a target appearing at a new location in 9-month-old infants. Moreover, work with older children, aged 7 and 10 years, and adults shows evidence that cueing of selective attentional orienting towards the location of a target which needs to be retained in short-term memory facilitates memory performance. Most importantly, individual differences in sensitivity to attentional cueing predicted performance on a standard measure of working memory (Astle, Nobre, & Scerif, 2012). Thus, these experimental studies combined provide evidence that selective attention and working memory are closely tied from infancy through to childhood and beyond. In particular, the strength of encoding of information in working memory appears to be strongly reliant on both selective attentional orienting to the relevant stimulus and the ability to ignore irrelevant distracting information at the same time.

1.3.2. Selective attention and inhibitory control

Associations between selective attention and inhibitory control, as assessed with delay of gratification tasks, have been consistently found in young children (Peake, Mischel, & Hebl, 2002; Rodriquez, Mischel, & Shoda, 1989; Sethi et al., 2000; Vaughn, Kopp, Krakow, Johnson, & Schwartz, 1986). Importantly, Mischel and colleagues have shown a direct effect of effective attention deployment on children's ability to delay gratification, both in low-risk 4- to-5-year olds (Peake et al., 2002), and in maladjusted 6- to 12-year-old boys (Rodriquez et al., 1989), such that active selective attentional distraction strategies – that is, persistent distraction of attention away from the reward – facilitate performance. There is some evidence that relations between selective attentional distraction strategies and inhibitory control on delay of gratification tasks are relatively stable over developmental time. For example Sethi et al. (2000), used a prospective longitudinal study on attentional precursors of delay abilities in preschoolers from primarily upper- to middle-class families. They found that 18-months-old toddlers who were able to use distraction as a coping strategy during a separation from their mother in a structured laboratory situation were better able to wait in the standard delay paradigm at age 5 than toddlers who were unable to direct their attention away during mother's absence. Thus, previous studies have shown that direction of attentional focus during delay of gratification tasks aids inhibitory control in children.

1.4. The present study

The aim of the present study was to examine the role selective attention plays in the development of EFs in a heterogeneous sample of 2–3-year-old children, using a longitudinal design. Based on the perspective that EF is at least partly componential (Miyake et al., 2000) and the fact that the developmental timing of various EF abilities varies (Carlson, 2005; Garon et al., 2008; Klenberg, Korman, & Lahti-Nuuttila, 2001), the interrelations among selective attention and two distinct EFs (simple response inhibition and working memory) are examined in 2–3-year-old children. By doing so, this study is, to our knowledge, the first to evaluate the relation between selective attention in toddlerhood and developing EFs in a mixed sample involving a large number of disadvantaged children, focusing on two key aspects of early EF – working memory and simple response inhibition – which are both hypothesized to recruit selective attention, albeit through different underlying mechanisms (i.e., focusing and distracting). Given previous experimental and longitudinal findings, we hypothesize that selective attention at age 2.5 years uniquely predicts working memory and simple response inhibition at age 3 years (see Fig. 1). To establish independent predictive relations between selective attention at time 1 and EF at time 2, we included the autocorrelations between time 1 and time 2 working memory and time 1 and time 2 response inhibition in the model. Moreover, we controlled for time 1 short-term memory in the prediction of time 2 working memory, given the importance of short-term

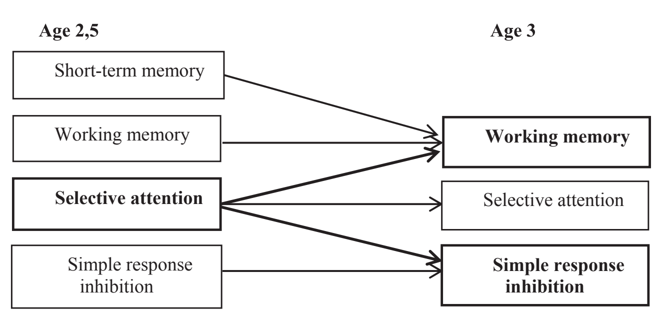

Fig. 1. Hypothesized model for the relationships (bolded font) between selective attention (at age 2.5, time 1), working memory, and simple response inhibition (at age 3, time 2). These relationships are controlled for prior levels of working memory, simple response inhibition and short-term memory (at age 2.5, time 1).

memory development for working memory in the hierarchical model (Garon et al., 2008). In addition, we explored the developmental stability of individual differences in selective attention across this period. Based on previous work that individual differences in attention already show some stability from infancy onwards (Kannass et al., 2006), we hypothesized that selective attention would show significant stability over time.

2. Method

2.1. Design

A longitudinal design was used in this study, with measurements at two occasions (time 1 and time 2). One group of participants was recruited in the fall of 2012 for the first measurement, and their second measurement occasion was in the spring of 2013. A second group of participants was recruited in the fall of 2013, and their second measurement occasion was in the spring of 2014. We chose to limit the time span between the two measurement occasions to approximately 6 months (but always after the participant's 3rd birthday). This time span was expected to be long enough to exclude the measurement of training effects and short enough to measure the same constructs over time using the same tasks.

In contrast to investigations with adults using complex, multi-componential tasks, investigations with children demand simplified (or purer) tasks. Tasks that do not require, e.g. both response inhibition and working memory (such as the Stroop task). These tasks are easier to interpret than the multi-componential adult tasks. Moreover, children's relatively limited processing capacity makes them more sensitive to effects of increased demands for particular functions. Therefore, ideally young children with developing EFs are included when examining the role of selective attention in the development of EFs (Hughes, 2002). Accordingly, this study focuses on preschoolers between 2 and 3 years of age, and we used simpler tasks to measure distinct EFs. Selective attention, working memory, and simple response inhibition were measured at both measurement occasions. Short-term memory was measured once (time 1) because a pilot revealed that the measure was not suitable for 3-year-olds (for more information about the pilot, please contact Mulder et al. (2014) and for a more detailed task description, see the "measures" section below). As mentioned above, complex EF tasks where integrated EF is required are rather difficult for preschoolers at that age to perform (Hughes, 2002). As a consequence, we did not include measures of other EFs (shifting attention, complex response inhibition).

We included five background variables at the child level. First, we included gender, because gender differences have been found in performance on (selective) attention tasks (Klenberg et al., 2001; Merrit et al., 2007) and working memory tasks (Duff & Hampson, 2001), as well as in simple response inhibition tasks (Klenberg et al., 2001). Secondly, we included socio-economic status, indicated by level of maternal education, since empirical evidence suggest that this indicator of SES is related to selective attention task performance (Klenberg et al., 2001), short-term memory, and working memory scores (Noble, McCandliss, & Farah, 2007). As researchers have found enhanced selective attention and inhibitory skills in bilingual children, in comparison with monolingual children (Bialystok, 2001; Bialystok, Craik, Green, & Gollan, 2009; Carlson & Meltzoff, 2008), we also included home language as one of the background variables. Fourth, we included age, because EFs develop rapidly in early childhood (Diamond et al., 1997; Garon et al., 2008) and, therefore, even small age differences (a few months) can explain differences in the development of EFs. Finally, verbal ability was included, because research has shown a strong relation between EFs and verbal ability (Carlson, 2005).

Gender, maternal education, home language, and birth date (to calculate age at time 1 and time 2) were measured once (time 1). Verbal ability was measured at both measurement occasions.

2.2. Participants

As part of a national study in the Netherlands, 318 two-year-old children were selected from 30 preschools in rural, semi-urban, and urban locations spread across the Netherlands. Parental consent was obtained for 313 preschoolers (98%). A total of 306 respondents were available for the first measurement occasion, because seven children left preschool before the first test was administered. On the second measurement occasion (on average 6.4 months later), 283 preschoolers who had not moved or switched to another preschool participated. For the present study, children who completed at least one task at both time 1 and time 2 ($N = 273$) were included (age time 1: $M = 32.7$ months, $SD = 2.1$ months, range 27.7–36.0 months; age time 2: $M = 39.1$ months, $SD = 2.0$ months, range 36.0–44.6 months). To check for differences between included and excluded participants (in the group of 306 participants that were available for the first measurement occasion), an independent samples *t*-test was performed. The results showed that there were no significant differences ($p < .05$) between the groups with regard to gender, maternal education, home language, age, and verbal ability at time 1.

Girls (54%) were slightly overrepresented in the sample. Fewer than half of the children (45%) were from monolingual Dutch families, 23% were from bilingual families (Dutch and another language), and 33% came from families where the home language was not Dutch.

SES was indicated for 97% of the sample, using the International Standard Classification of Education (UNESCO, Institute for Statistics, 2007, see Appendix A). A large proportion (45%) of the children were from low SES families, 34% were from middle SES families, and 22% were from high SES families (LIS Cross-national Data Center, 2016). For 263 mothers (96%), country of birth was available. Of the 44% mothers born in a non-Western country, most were born in Turkey (10%) or Morocco (11%). Most of the mothers born in a Western country (56%) were born in the Netherlands (51%). According to the European poverty line, approximately one-third of the families who reported their income (82% of the total sample) could be considered to be poor because these families earned less than €1764 a month (Phelps & Crabtree, 2013).

2.3. Procedure

In the period from September 2012 until July 2014, the first author (experimenter) visited all preschools multiple times to test all of the children who participated. Only the children who dropped out of the study (e.g., due to moving) or who were not willing or able to participate were not tested. When children were absent, the experimenter always came back on another day. In all preschools, the tasks were administered in a quiet room. The test battery consisted of tasks, lasting approximately 45 min, which were presented in a fixed order. In order to administer the tasks in a valid and reliable way, the first author was trained by the designers of the standardized task protocol (H. Mulder and J. Verhagen). For a description of the training phase and evaluation process, see Mulder et al. (2014).

Along with the battery of tests, parents were asked to complete parent questionnaires (see the "measures" section below). If necessary, a translator was available to assist parents.

2.4. Measures

2.4.1. Selective attention

To measure selective attention, a computerized visual search task was administered, which was developed by Mulder et al. (2014). The task was based on the work of Gerhardstein and Rovee-Collier (2002), and Scerif et al. (2004) and administered on a computer using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002). The goal of the task was to identify the targets (elephants) as quickly as possible by pointing to them, and to ignore the distractors (horses and bears), which were relatively similar to the targets with respect to size and colour. After the child had identified a target, a blue line appeared through it. The experimenter encouraged the children to search for elephants as quickly as possible throughout the task. Children were presented with a number of practice items and three test items at each measurement occasion. One test item constituted of a screen with targets and distractors shown for a set time of 40 s. At the first measurement occasion (time 1), three different items (screens) with the same level of difficulty were presented successively (8 targets and 40 distractors, hence target: distractor ratio 1:5). At time 2, the first and second items were identical to the first two items at time 1, and item three was more challenging (8 targets and 64 distractors, hence target: distractor ratio 1:8). The mean score was calculated for the number of correctly identified targets for the three items (range 0.33–8.00). Following Mulder et al. (2014), scores of children with a mean score of 0 – that is, children who did not find a single target across all three test items – were set to missing, because we cannot be entirely sure that they had understood what was required of them during the task. Their scores might thus reflect verbal comprehension instead of selective attention. This concerned five children (< 2% of the sample) at time 1, and no children at time 2. (Findings from analyses including the five participants who scored 0 on the selective attention measure at age 2 showed that including these five participants did not alter the results substantially: some path coefficients were marginally affected and the fit of the model decreased slightly. See model 5 in Appendix B). We calculated reliability over the three items at time 1 and time 2. Cronbach's alpha's for the task at both time 1 (.88) and time 2 (.84) were good.

2.4.2. Short-term memory

To measure short-term memory (span), the memory for location task, developed by Mulder et al. (2014), was administered. This task was based on work of Oudgenoeg-Paz, Boom, Volman, and Leseman (2016), Pelphrey et al. (2004), Rose, Feldman, and Jankowski (2009), and Vicari, Caravale, Carlesimo, Casadei, and Allemand (2004). The goal of this task was to identify the box(es) under which one or more objects (wooden pictures) were hidden. In this task, six boxes were placed upside down in two rows. The experimenter hid one or more objects (wooden pictures) under one or more boxes and distracted the child for one second by raising a hand and calling the name of the child. Subsequently, the child was asked to lift up the box(es) under which the object(s) was/were hidden.

An adaptive procedure was used based on task performance: that is, the number of items (with varying degrees of difficulty) and the number of attempts administered depended on task performance. In the first item, only one object was hidden under one box. If the child did not locate the object in the first attempt, a second attempt was given, with the object being hidden in a new location. If the child did not locate the object on the second attempt, a third attempt was administered. If the child did not locate the object on the third attempt, the task ended (score: 0). If the child located the object in the first item (either the first, second, or third attempt), the assessor moved on to the second item in which two objects were hidden under two boxes, and so on. From item two onwards, children were given a maximum of two attempts at each difficulty level. Whenever children failed to find the object(s) in all attempts at an item, the task was ended at that item and a score was assigned. Children who passed all items in one or more attempts received a score of 4. The possible score ranged from 0 to 4. This task was only administered at time 1.

2.4.3. Working memory

To measure working memory, the six boxes task (where boxes remain stationary) was administered (Diamond et al., 1997; Mulder et al., 2014). The goal of the task was to find six toys (located in six identical boxes closed with lids) in six items (trials), which meant keeping track of which boxes had already been chosen. In each item, children were requested to locate a toy by selecting one of the six boxes, removing the lid from this box, removing the toy (if this box still held a toy), and closing the box with the lid again. After each item, they were distracted by the assessor (who encouraged the child to look away from the boxes by raising their hand and counting to six out loud) for 6 s. The score indicated the number of toys collected in six items, range: 1–6. The task was nearly identical at time 1 and time 2, with the exception that at time 2 a screen was placed between the child and the boxes during the distraction phase.

2.4.4. Simple response inhibition

A gift delay (of gratification) task, developed by Mulder et al. (2014) based on the gift delay task designed by Kochanska et al. (2000), was administered. The goal of this task was to inhibit the tendency to touch and unwrap an attractive gift (wrapped in multi-coloured paper with a ribbon). The children were instructed in a friendly way that the game involved trying to wait to touch and unwrap the gift until the experimenter had finished writing. After giving this instruction, the experimenter sat behind the child, pretending to write and not interacting with the child for one minute. The task was identical at time 1 and time 2. Possible scores were 0 (both touching the gift and tearing its paper/ribbon), 1 (touching the gift but not tearing its paper/ribbon), and 2 (not touching the gift and not tearing its paper/ribbon). Mulder et al. (2014) video-taped gift delay tasks in a separate study, and reported Kappa's coefficients of .89 for the behaviour of "touching the gift" and .74 for the behaviour of "tearing the gift". Agreement between video codes and live codes was 94%.

2.4.5. Gender, home language, age

Preschool teachers from all 30 preschools were asked to send an overview of *gender*, *language(s)* spoken at *home*, and birth date of all participating children (to calculate *age* at time 1 and time 2). For home language, three categories were used: another language than Dutch (1, bilingualism: primarily not Dutch), Dutch and a second language (2, bilingualism: primarily Dutch), and only Dutch (3, monolingual children).

2.4.6. Socio-economic status (SES)

In line with Ensminger and Fothergill (2003), and Noble et al. (2007), we used maternal education as an indicator of SES. A parent questionnaire was handed out to the parents of all children to measure the highest level of maternal education (Veen et al., 2012), using the ISCED levels of education (levels 0–5, see Appendix A).

2.4.7. Verbal ability

Receptive vocabulary (as an indicator of verbal ability) was measured with a shortened version of the Peabody Picture Vocabulary Task (PPVT-III-NL, Dunn & Dunn, 2005; Verhagen, De Bree, Mulder, & Leseman, 2016; Verhagen, Mulder, & Leseman, 2015). The task was administered on a computer screen using E-Prime 2.0 (Schneider et al., 2002).

At the first measurement occasion, 24 selected items from the original PPVT-III-NL version (sets 1–3) were administered (Verhagen et al., 2016). At time 2, a revised version with eight of the same items (of set 3) and 16 new items (sets 4 and 5) was administered (Verhagen et al., 2015). The experimenter pronounced a word and the child had to point to the picture (one out of four) he or she believed represented the word. Non-responses (not pointing to any of the pictures) were identified as incorrect. Following Verhagen et al. (2015), scores were calculated only for children who responded to at least 12 of 24 items. At time 1, data from four children were excluded due to this criterion (< 2% of the sample) and at time 2, data from one child was excluded (< 1% of the sample). The percentage of correct items was calculated for each measurement occasion. Reliability was good: Cronbach's alpha's were .88 (time 1) and .79 (time 2).

Table 1
Descriptive statistics for measures of selective attention, EFs, and control variables.

	M (SD)	*Range*	*N*	Percentage missing values
Selective attention, age 2.5	4.72 (1.56)	0.33–7.67	265	2.9
Selective attention, age 3	5.66 (1.28)	1–8	273	0.0
Short-term memory	2.33 (0.90)	0–4	270	1.1
Working memory, age 2.5	4.31 (0.92)	2–6	264	3.3
Working memory, age 3	4.80 (0.87)	1–6	271	0.7
Simple response inhibition, age 2.5	1.61 (0.62)	0–2	270	1.1
Simple response inhibition, age 3	1.85 (0.38)	0–2	271	0.7
Gender (1 = female)	0.54 (0.50)	0–1	273	0.0
SES (maternal education)	7.83 (3.41)	1–12	259	5.1
Home language	2.12 (0.87)	1–3	273	0.0
Verbal ability, age 2.5 (% correct)	54.30 (22.65)	8–100	269	1.5
Verbal ability, age 3 (% correct)	45.97 (20.30)	0–96	272	0.4
Age, time point 1 (months)	32.69 (2.11)	27.68–36.00	273	0.0
Age, time point 2 (months)	39.10 (2.00)	36.03–44.65	273	0.0

2.5. Analytical strategy

The relations between the variables in our hypothesis were investigated through a path analysis, using Mplus version 7 (Muthén & Muthén, 1998–2012). Missing data on the variables ranged from 0.0% on selective attention age 3, gender, home language and age, to 5.1% on maternal education (see Table 1). The default function in Mplus (listwise = off) was used in order to include all available information.

We started with a model (model 1) including the following variables: selective attention measured at age 2.5 years, and working memory and simple response inhibition, both measured at age 3 years. To control for prior levels of EFs, we included short-term memory, working memory, and simple response inhibition, all measured at age 2.5 years. Further, to investigate the stability of selective attention as a construct over time, we included selective attention measured at age 3 years in the model.

Given the nested structure of our sample (children nested within preschools), we calculated intraclass correlations (ICC's). In our study, an ICC is an estimate of the proportion of variation among preschools (Hox, 2002). Three of the variables had ICC's of .00, the other ICC's were .01, .03, .05, and .06. These ICC's are all below .10, which is considered as a medium ICC (Hox, 2002; Scherbaum & Ferreter, 2009) However, we decided to take the nesting structure of the data into account by applying the complex sampling option in Mplus (model 1a). To compare the results with nesting with the unnested results, we conducted analyses without taking the nested structure into account (model 1b). Based on the findings of these analyses, we controlled for background variables by successively including gender, SES, and home language (model 2), verbal ability (model 3), and age (model 4) in additional models. With regard to the time-invariant covariates (model 2: gender, SES and home language) paths were specified from the covariates to the test variables at time 1 and at time 2 (e.g., relationship between gender and working memory at time 1, relationship between gender and working memory at time 2, SES and working memory at time 1, SES and working memory at time 2, etc.). With regard to the covariates that vary over time (model 3: verbal ability; model 4: age) paths were specified from the covariates at a specific time to the covariates at the same time (e.g., relationship between verbal ability at time 1 and selective attention at time 1, relationship between verbal ability at time 2 and selective attention at time 2, etc.).

We will report the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA) and the Standardized Root Mean square Residual (SRMR) (Hu & Bentler, 1999). The fit of the model is considered acceptable when CFI and TLI are .95 or higher, RMSEA is less than or equal to .06 and SRMR is less than or equal to .08 (Hu & Bentler, 1999; Schreiber, Stage, King, Nora, & Barlow, 2006). Acceptable fit on these four fit indices supports the absence of type 1 errors: false, positive results, and type 2 errors: false, negative results (Hu & Bentler, 1999).

All models will be compared on similarity of path coefficients. Substantial differences of path coefficients (> 0.10) between model 1 and the alternative models (models 2–4: background variables included) indicate a substantial impact of background variables. To ground the impact of adding background variables in additional models, we also compare the goodness of fit indices among all models. Finally, we compare the models, using the Akaike Information Criterion (AIC) values for non-nested models (models containing structurally different parameters). The model with the lowest AIC value demonstrates the best fit and will be accepted.

For an overview of the descriptives (means, standard deviations) and the correlations of all variables we refer to Tables 1 and 2.

3. Results

The nested model with the hypothesized relations between selective attention and EFs (model 1a) provided acceptable fit for the data: CFI = .977, TLI = .942, RMSEA = .056, SRMR = .032, and a $X^2(6)$ of 11.091 (p = .0856). The unnested model with the hypothesized relations between selective attention and EFs (model 1b) provided a better fit for the data: CFI = .980, TLI = .951, RMSEA = .054, SRMR = .032, and a $X^2(6)$ of 10.722 (p = .0973). Including the background variables successively in additional models (models 2–4) showed that the differences between the path coefficients in these models and the path coefficients in the unnested model (model 1b) were not substantial (maximum difference .08). Moreover, all the goodness of fit indices of the additional models (models 2–4) were inacceptable (see Appendix B). These findings indicate that the background variables did not affect the interrelations among the variables, demonstrating the robustness of the unnested model without background variables (model 1b). Correspondingly, the AIC value of model 1b was lower than the AIC values of the alternative models (see Appendix B). Hence, the findings showed that model 1b provided the best fit for the data. The path coefficients and correlations among the variables of model 1b are presented in Fig. 2.

The final model shows that, in line with our expectation, selective attention at age 2.5 years was significantly ($p < .01$) related to working memory and simple response inhibition at age 3 years. This indicates that children who scored higher on selective attention at age 2.5 years also scored higher on working memory and simple response inhibition at age 3 years. The associations between selective attention at age 2.5 years and working memory (.28) and simple response inhibition (.17) at age 3 years were moderate.

Concerning the autocorrelations, the results also show that selective attention, working memory, and simple response inhibition at age 2.5 years were significantly ($p < .01$) related to selective attention,

Table 2
Pearson's bivariate correlation coefficients (r) between selective attention, EFs and background variables.

	01	02	03	04	05	06	07	08	09	10	11	12	13
01. SA T1	–												
02. SA T2	.55**	–											
03. STM	.36**	.29**	–										
04. WM T1	.24**	.24**	.15*	–									
05. WM T2	.37**	.31**	.28**	.35**	–								
06. SRI T1	.19**	.20**	.07	.14*	.16**	–							
07. SRI T2	.23**	.21**	.12	.18**	.26**	.41**	–						
08. GEN	.15*	.14*	.20**	.13*	.24**	.13*	.12	–					
09. SES	.16*	.18**	.14*	.03	.16**	.15*	.10	−.00	–				
10. HL	.23**	.18**	.08	−.05	.01	.16**	.15*	.08	.31**	–			
11. VA T1	.48**	.33**	.22**	.06	.22**	.24**	.25**	.15*	.30**	.61**	–		
12. VA T2	.42**	.40**	.17**	.10	.20**	.18**	.26**	.12	.25**	.52**	.72**	–	
13. AG T1	.27**	.21**	.16**	.20**	.13*	.15*	.07	.04	−.04	.02	.23**	.15*	–
14. AG T2	.12	.18**	.09	.10	.21**	.11	.09	.14*	.02	.03	.05	.21**	.45**

Note: T1 = time 1, T2 = time 2, SA = selective attention, STM = short-term memory, WM = working memory. SRI = simple response inhibition, GEN = gender (female), SES = socio-economic status (maternal education), HL = home language, VA = verbal ability, AG = age.
* $p < .05$.
** $p < .01$.

working memory, and simple response inhibition at age 3 years. Hence, children with higher scores for selective attention at age 2.5 years also scored higher on selective attention at age 3 years. The same applied to working memory and simple response inhibition. The autocorrelations of selective attention (.59) and simple response inhibition (.39) appeared to be larger than the autocorrelation of working memory (.28).

Finally, the correlation between short-term memory at age 2.5 years and working memory at age 3 years was small (.13) but significant ($p < .05$).

4. Discussion

In the current study, a heterogeneous sample of children was recruited and followed from age 2.5 to 3 years to explore the central role of selective attention in the development of EFs. The relations between selective attention, working memory, and simple response inhibition were examined using path analysis. The findings clearly showed that selective attention at age 2.5 years is uniquely related to the development of the two EFs over time. Controlling for gender, home language, SES, age, and verbal ability did not affect the strength of the relationships. Hence, we found evidence for the theory suggested by Garon et al. (2008) that selective attention plays an important role in the development of EFs.

Furthermore, Gazzaley and Nobre (2012) proposed attention focusing as an underlying mechanism of working memory performance, and. Mischel et al. (1989, 1996, 1999, 2000) propounded that distracting attention served as an effective approach to inhibit responses. Although the findings of this study suggest that focusing and distracting serve as underlying mechanisms of EF performance, more research is needed to validate our findings and draw definite conclusions. Therefore, we advocate further research into attentional mechanisms underlying EF performance.

Moreover, the results of this study provide evidence for the hierarchical model proposed by Garon et al. (2008) in which basic skills provide the foundation on which more complex skills are built. The results show that short-term memory at age 2.5 years is exclusively related to working memory half a year later, even after controlling for prior working memory.

In addition, we found that selective attention showed significant stability across the 6-month period under study. These findings concur with results from a previous study showing significant stability of individual differences in attention already in the first years of life, from infancy through to 2.5 years of age (Kannass et al., 2006).

In line with findings from other studies (Bialystok, 2001; Bialystok et al., 2009; Carlson, 2005; Carlson & Meltzoff, 2008; Diamond et al., 1997; Garon et al., 2008; Klenberg et al., 2001; Merrit et al., 2007; Mulder et al., 2014; Noble et al., 2007), gender, SES, home language, verbal ability, and age were significantly related to performance on the selective attention and EF tasks (see Table 2). However, our findings clearly show that these variables did not affect the interrelations between selective attention and EFs over time. That is, the strength of the relationships between selective attention, working memory, and simple

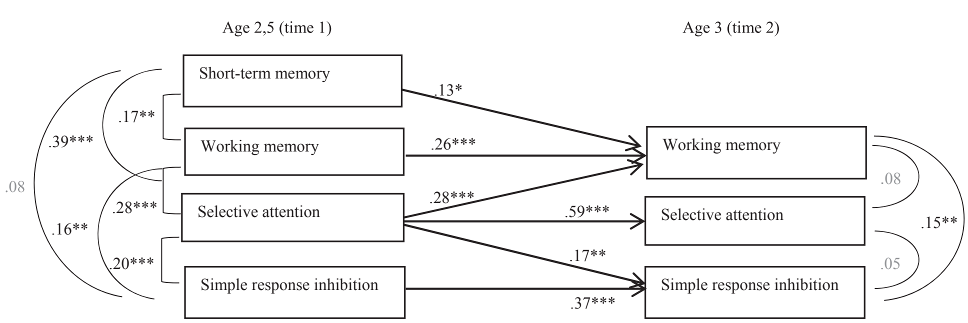

Fig. 2. Standardized solution of the path model for the effects of selective attention (at age 2.5, time 1) on working memory and simple response inhibition (at age 3, time 2), controlled for prior levels of working memory, simple response inhibition and short-term memory (at age 2.5, time 1).

* $p < .05$.
** $p < .01$.
*** $p < .001$.
† $p < .10$.

response inhibition did not change substantially by including different background variables, and only the model without the background variables fit the data well.

The findings from this longitudinal study indicate that selective attention is a key factor underlying EF development towards the end of the 3rd year of life—an important age for studying such relations, as it is the typical enrollment age for preschool education in many countries. Most of the previous studies showing longitudinal links between selective attention and EFs were small-scale laboratory investigations with generally high SES samples (Holmboe et al., 2008; Johansson, Marciszko, Brocki et al., 2015; Johansson, Marciszko, Gredebäck et al., 2015). Using a mixed sample, including low SES children (45%) and children from non-monolingual Dutch homes (55%), the findings of our study add to this literature by showing that these associations between selective attention and EF can be generalized to a wider population and remain present towards the end of the 3rd year of life. To the best of our knowledge, only one previous study included a larger and more mixed sample, and showed that infants' attention predicted EF at age 22 months, but not 33 months (Kochanska et al., 2000). One explanation for the differences between Kochanka's findings (at age 33 months) and our own may be the different methods used to assess selective attention. Whereas Kochanska et al. (2000) used a measure of observed attention during free play, a specific test of selective attention was used in the present study. As a broad range of different measurement instruments for assessing attention in young children are available and used (see Mahone & Schneider, 2012), it remains unclear to what extent these different instruments capture the same underlying processes. Further work is needed to investigate whether specific measures of selective attention – capturing both selective attentional focusing and the ability to ignore distractors, which appears to be key to EFs such as working memory (Markant et al., 2016) – can assess attention of infants in the first year of life in a valid way, and are predictive of EF beyond toddlerhood.

Although we found significant predictive relations from selective attention at age 2.5 years to working memory and simple response inhibition at age 3 years, the underlying mechanism through which these relations may occur may be different for the different constructs under study. In particular, previous studies have shown that whereas working memory requires selective attentional focusing, the delay of gratification task used to study simple response inhibition requires active attentional distraction from the reward (an attractively wrapped gift with a ribbon in the current study) (Peake et al., 2002; Rodriquez et al., 1989; Sethi et al., 2000; Vaughn et al., 1986). The current study findings add to this literature as they confirm that selective attentional orienting appears not only to be important for focusing and learning, but also for regulation and control of emotional responses (Harman et al., 1997; Posner et al., 2012; Rothbart et al., 2011). Further work is needed to test these proposed relations more directly: that is, by investigating whether direct observations of attentional focusing and distracting behaviours during EF tasks such as the ones used in the current study mediate the relation between selective attention and EF task performance.

4.1. Limitations

The strengths of the current study include the longitudinal design and relatively large and heterogeneous sample. However, along with its several strengths, a number of limitations were present in our study as well. A first limitation relates to the selection of measures in the present study as the results can be impacted by the choice of tasks (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012). For example, the number of items and range of possible scores was higher in the selective attention task than in the other tasks. Presumably, this may have affected task reliability: indeed, in an absolute sense, the stability of the selective attention construct was larger than the stability of the working memory and simple response inhibition constructs (.55, .35, and .41, respectively, see Table 2). To strengthen the reliability of task scores, multiple items (and measures) for every component of EF should ideally be used in future research. A further limitation was that we only included measures of working memory and simple response inhibition to assess EF, and as such, did not cover the multi-dimensional nature of the construct EF discussed in the literature. Specifically, we did not include measures of attention shifting and complex response inhibition, as no such measures suitable for field-based research were available for 2-year-olds at the time of the design of the study. However, measures to assess shifting and complex inhibition for children as young as 18 months of age for use outside the laboratory have been developed recently and so are now available for field-based research (Garon, Smith, & Bryson, 2013). As such, further work is needed to investigate whether selective attention predicts EF in 2- and 3-year-olds beyond measures of working memory and simple response inhibition. Another limitation concerns the fixed order in which tasks were administered. Therefore, the impact of fatigue effects differed between tasks and may have affected the relations between selective attention and EFs in our study. A final limitation relates to the strong ceiling effects in the simple response inhibition scores (see Table 1). It might be that the delay time (one minute), in which children had to wait with touching or opening the gift, was too short to differentiate between children's abilities. In addition, inhibiting responses might be easier for some children in a setting in which the experimenter is in the same room (behind the child) compared with, for example, testing children in a lab setting, using a one-way-screen. Advantages of the task battery used in the current study are that measurement invariance was demonstrated such that the measures were appropriate for use with a socio-economically diverse sample of children, and measures were suitable for 2-year-olds, which tend to have limited attention spans and low verbal ability (Mulder et al., 2014).

4.2. Implications

The finding that selective attention underlies EF development in a heterogeneous sample during the second half of the 4th year of life has important theoretical and practical implications. In particular, results from the current study support the idea that selective attention is key to early EF around the time many (disadvantaged) children enroll in preschool programmes. As several studies have shown that EF is linked to academic performance (Blair & Razza, 2007; Brock et al., 2009; Bull et al., 2008; Clark, Pritchard, & Woodward, 2010; Von Suchodoletz et al., 2013), it may be important to design programmes that optimally promote young children's selective attention, in order to foster subsequent EF development and, in turn, learning. Two recent studies have already shown that boosting selective attention may be a fruitful way to enhance young children's learning, especially for those from low SES backgrounds. First, facilitating distractor suppression has been shown to diminish SES-related differences in memory and learning already in infancy (Markant & Amso, 2016). Second, the family-based 'Parents and Children Making Connections—Highlighting Attention' intervention programme, which is aimed at training selective attention in 3–5-year-olds, has shown significant far transfer effects in a low SES sample, for example to language development, social skills and problem behaviour (Neville et al., 2013). Based on the findings from these recent studies and our own study, it may be hypothesized that the effects of boosting selective attention on learning are mediated by EF—both working memory and inhibitory control. Future longitudinal and (quasi) experimental studies are needed to test this hypothesis. Findings from these studies can provide more insight into the role selective attention may play as a building block for fostering EF and improved learning of disadvantaged children and relates this to the design of effective preschools programmes.

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Appendix A

See Table A1.

Table A1
Maternal level of education.

ISCED level	Educational level	Percentage
ISCED level 0	No education, pre-primary education	10.0
ISCED level 1	Primary education	5.4
ISCED level 2	Vocational education training to assistant level pre-vocational secondary education, class 1 to 3 of general secondary education	27.4
ISCED level 3	Senior general secondary education	1.9
ISCED level 4	Vocational education specialist training	33.6
ISCED level 5	Higher professional education, university	21.6

Appendix B

See Table B1.

Table B1
Standardized path coefficients, goodness of fit indices, and Akaike Information Criterium values.

Path coefficients		Model 1a (nested model)	Model 1b (unnested model)	Model 2 (gender, SES, home language)	Model 3 (verbal ability)	Model 4 (age)	Model 5 (SA scores changed[a])
Age 2.5	Age 3						
STM	WM	.13[†]	.13[*]	.10[†]	.14[*]	.13[*]	.14[*]
WM	WM	.26[***]	.26[***]	.22[***]	.25[***]	.24[***]	.26[***]
SA	WM	.28[***]	.28[***]	.28[***]	.27[***]	.27[***]	.27[***]
SA	SA	.59[***]	.59[***]	.55[***]	.51[***]	.56[***]	.59[***]
SA	SRI	.17[**]	.17[**]	.15[*]	.10	.16[**]	.15[**]
SRI	SRI	.37[***]	.37[***]	.36[***]	.36[***]	.37[***]	.37[***]
Goodness of fit indices							
	X^2 (df)	11.091 (6)	10.722 (6)	101.525 (14)	75.237 (19)	76.350 (19)	13.649 (6)
	CFI	.977	.980	.747	.905	.852	.969
	TLI	.942	.951	.241	.820	.720	.923
	RMSEA	.056	.054	.151	.104	.105	.068
	SRMR	.032	.032	.098	.088	.098	.036
	AIC	10413.662	10413.662	11813.467	15031.210	11543.269	10493.856

Note: STM = short-term memory, WM = working memory, SA = selective attention, SRI = simple response inhibition.
[a] Model 5 includes the 0 scores on selective attention of five children at age 2,5 instead of missing values as in Model 1b.
[†] $p < .10$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

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