

# Executive functions in preschool children - assessment and relation to ADHD symptoms

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## Abstract

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**Background:** The aim of this study was to examine the relationship between Executive Functions (EF) and Attention-Deficit/Hyperactivity Disorder (ADHD) in preschool-aged children. Deficits in EF are currently considered to represent an important weakness in this clinical group. To extend our knowledge about the relative contribution such functions have for the development of ADHD, it is essential to investigate whether this association is detectable during the preschool-years.

**Method:** 126 children ranging in age from 38 to 45 months ( $M = 40.78$ ;  $SD = 1.53$ ) were included. Children were identified as (1) meeting full ADHD-criteria (ADHD+), (2) obtaining criteria reaching below diagnostic threshold (ADHD÷), or (3) children with no ADHD symptoms (CC). These groups were compared on their performance on four different tasks developed to tap central EFs, (e.g., mental set-shifting, working memory (both verbal and nonverbal), and inhibition). Multivariate Analysis of Variance (MANOVA) was conducted, with group as independent variable and each of the four EF scores entered into the equation as dependent measures. Bivariate correlation analysis was also conducted in order to test the suitability of the theoretical model developed by Miyake et al., (2000) in preschool children.

**Results:** Inhibition, Verbal Working Memory and Nonverbal Working Memory significantly discriminated between the three groups. Both ADHD+ and ADHD÷ displayed significant difficulties on the inhibition-measure as compared to the control-children. The same relational pattern emerged for Verbal Working Memory. ADHD+ was significantly outperformed by control-children on this measure. The sub-threshold group did not differ from the two other, falling somewhere in between. In regard to the Nonverbal Working Memory, the ADHD÷ displayed significant impairments compared to both ADHD+ and CC. This indicates that this EF-deficit is not related to ADHD-symptoms as such. The

inter-relationship between the four EF-measures did imply that the theoretical vantage-point as stated by Miyake et al., (2000) might be applicable on the EF-structure in preschool.

**Conclusion:** The present study can only partly support the proposition that central EFs are causal in the development of ADHD. Deficient inhibition and Verbal Working Memory seems to be associated to ADHD. However, due to the lack of universality to the results, impaired EFs seem important but not deterministic in causing ADHD. The potential existence of several pathways is discussed.

## Table of content

Introduction.....	5
Executive Functions: An Empirical approach.....	6
Executive Functions: A theoretical approach .....	7
Executive Functions in an integrative theoretical framework.....	8
ADHD: development and diagnostic considerations .....	12
ADHD: A categorical versus a dimensional perspective .....	14
Extreme behavior in preschool.....	15
The benefit of knowing early precursors to ADHD.....	16
Executive dysfunction in children with ADHD .....	17
The influence of Intelligence on the ADHD/EF relation .....	23
Hypothesis.....	24
Method.....	25
The obtainment of data and the representativeness of the sample.....	25
Participants.....	25
Performance-based measures of Executive Functions.....	26
The NEPSY battery .....	27
Trucks Reversal Learning Task (Hughes & Ensor, 2002): .....	27

Stanford-Binet Intelligence Scales 5 <sup>th</sup> ed. (Roid, 2003) .....	28
General procedure and analysis .....	30
Screening procedure in the MoBa-study.....	30
The examination and diagnostic evaluation at the ADHD-study.....	30
Statistical procedure.....	31
RESULTS .....	33
Preliminary analysis.....	33
In what way is ADHD related to EF in preschool? .....	34
Correlation between EFs in preschool.....	38
Discussion .....	41
The relation between EF and ADHD in preschool .....	41
Inhibition and VWM Deficits in ADHD: How to interpret the findings .....	42
The possibility for multiple causal pathways in ADHD .....	44
ADHD: Continuum vs. category .....	45
The organization of EF in preschool: A theoretical overview .....	46
Strengths of the present study .....	48
Limitations of the present study .....	49
Future research .....	53
Concluding remarks.....	54
Acknowledgements .....	54
References.....	56
APPENDIX .....	70

## Introduction

*Attention-Deficit/Hyperactivity Disorder* (ADHD) is currently referred to as a neuropsychological disorder. The disorder is characterized by symptoms like extreme levels of activity, inattention, and/or impulsivity. Currently, it is thought to be one of the most prevalent developmental disorders. In Norway, it is estimated that this disorder affects as many as 2, 5% of children and adolescents before the age of eighteen (SINTEF Helse, 2004). The world- wide prevalence rate lies between 5-10 % (Faraone, Sergeant, Gillberg & Biederman, 2003). Individuals with ADHD are at an increased risk for experiencing several negative life outcomes. Children identified with the disorder are more likely than their typically developing peers to have impairments in social and emotional competence. Associated difficulties have been found to severely affect academic achievements (Faraone et al., 1993). Individuals with ADHD are also more prone to engage in substance abuse, and criminal behavior. Lastly, those with the disorder are at an increased risk for developing other psychiatric disorders (Friedman et al., 2003; DuPaul et al., 2001; Torgersen, Gjervan & Rasmussen, 2006).

Children suffering from ADHD are rated by their parents as being more difficult to manage and more demanding during preschool than children in general. Such findings indicate that the disorder may have important identifiable precursors early in childhood (Byrne, DeWolfe & Bawden, 1998; Harvey et al., 2009; Lahey et al., 2005; LeBlanc et al. 2008). Despite a wealth of research focus, there is still some uncertainty in regard to the whole picture of causal mechanisms underlying the disorder. One perspective that has gained research focus, proposes that the observable difficulties characteristic of ADHD are attributable to underlying deficits in higher order, cognitive functions (Barkley, 1997; Pennington & Ozonoff, 1996). These functions are commonly referred to as *Executive Functions* (EF). EF is as a set of effortful cognitive processes which aid in problem-solving and goal-directed behavior. This often implicates the need to override automatic and predominant responses (Goia & Isquith, 2004; Welsh & Pennington, 1988 ).

The present study aims to further investigate this association, and how it unfolds during the preschool years. In the first section a brief elaboration of empirical and theoretical research on the EF-concept will be presented. Next, the current understanding of ADHD in preschool, as well as empirical knowledge addressing how EF is related to ADHD in this age-group will be outlined.

## Executive Functions: An Empirical approach

In this article, the EF-concept is understood as constituting a supervisory cognitive construct which comprise several clearly differentiated, but moderately correlated processes. (Miyake et al, 2000). The definition implies that EFs controls and coordinates thoughts and behaviours (Welsh et al., 2005). The importance of the EFs is especially evident when the individual encounters novel and unfamiliar situations and obstacles where solutions are not readily at hand (Norman & Shallice, 1980). Specific regions in the prefrontal lobes, as well as descending networks, are identified as central in the healthy workings of EF (Dickstein, 2006; Miller & Cohen, 2001; Seidman, Valera & Makris, 2005). As such, the prefrontal lobes are considered to be actively engaged in effortful inhibition of more automatic or predominant behaviour inclinations, such as the ability to restrain behaviour, and/or choose to delay a given behaviour response, even when the immediate response is more potent. EFs are also at work when selectively allocating attention to what is necessary in a given situation. The ability to flexibly shift between task sets or mental sets also depends upon an intact EF-construct (Brocki et al., 2008; Senn, Espy, & Kaufmann, 2004; Singer & Bashir, 1999).

The impact of dysfunctions to EFs is detectable in several life domains during childhood. Academic achievements seem to rely heavily on the healthy workings of these neuropsychological skills (Espy & Wiebe, 2008; Gathercole & Pickering, 2000). EFs are further implied to be central in adaptive behavioral adjustments and in the development of social relations (Hughes, Dunn & White, 1998; Pennington & Ozonoff, 1996).

A great deal of research has focused on the development of neuropsychological tasks that are sufficiently sensitive to prefrontal lobe functioning in children (Carlson, 2005). Advancement in this field has for the most part relied on modifications to already existing tasks used to measure older children and adults. The application of such age-adequate tasks has revealed that rudimentary levels of EFs are markedly present already during preschool (Carlson, 2005). Further, EFs shows important developmental improvements during preschool, seen as children become more efficient and successful in their performance on neuropsychological tasks as they grow older. Older children will typically perform better on a given EF task than their younger counterparts. Such

developmental improvement has been thought to reflect an increasingly maturing and interconnected prefrontal lobe (Carlson, 2005; Huizinga, Dolan & Van Der Molen, 2006; Melinder, Endestad, & Magnussen, 2006). The need for a theoretical framework that could embrace and aid in the further understanding of the EFs emerged as empirical knowledge of the nature and workings of the different EF-components continued to expand. The next section will present the theoretical model upon which the present study is based, followed by a description of characteristics of ADHD. Finally, what is currently known about the relation between EFs and ADHD will be outlined.

### Executive Functions: A theoretical approach

Two different theoretical perspectives have traditionally been embraced when seeking to understand the organization of EFs. The first perspective considers the EF-construct to be of unitary nature. The EF-construct is thought of as an attention system that operates through the regulation of belonging sub-processes (Norman & Shallice, 1986). Support for the unitary perspective comes from research pointing to the different EF-components as being highly inter-correlated. In addition, these components seem to be related to one mutual underlying attention mechanism (Carlson, Mandell & Williams, 2004; Engle, Tuhloski, Laughlin & Conway, 1999; Miyake et al, 2000). The other traditional approach emphasizes that the EF-construct comprises several, discrete processes that belongs to different functional domains (Carlson & Moses, 2001; Diamond, 1991; Welsh et al., 1999). Research findings that further support this view have pointed to findings of different components which develop at different rates during childhood. Different EF-components also seems to be following separate developmental trajectories (Huizinga, Dolan & Van Der Molen, 2006). Animal studies, investigating the brain in monkeys, have further revealed that different EFs seem to be differentially located in regions in the prefrontal cortex (Dias, Robbins & Roberts, 1996).

A third perspective on the EF-constructs organization has emerged in addition to the two outlined above. Research on adults and children up to date has yielded results pointing to EF as best conceptualized as an umbrella-like construct. The EF-construct is conceptualized as consisting of several clearly dissociable components which are moderately correlated to each other (Gioia & Isquith, 2004; Fugetta, 2006; Miyake et al.

2000). This perspective was embraced by Miyake et al. (2000), and used as foundation in their theoretical model on EF.

### **Executive Functions in an integrative theoretical framework**

The over arching aim of the study by Miyake and his co workers, was to develop a framework that could better account for the nature and workings of the EF-construct. Three EFs were investigated. These were chosen because of the central position held by each one in the research field. The three EFs were inhibition of prepotent responses, mental set-shifting and updating/working memory. Different measures were used to tap the same EF-component. In so doing, they were able to extract the latent variable for each EF of interest. The latent variable refers to the construct that a given task is designed to measure. The result of such an approach is a “purer” index for each EF component.

The application of a confirmatory factor analysis resulted in a comprehensive theoretical model that argued in favour of EFs as multidimensional in nature. More precisely, the three EFs came forward as distinct processes that were clearly separable from each other, but at the same time they were moderately inter- correlated. A visual representation of the theoretical model is depicted in Figure A.

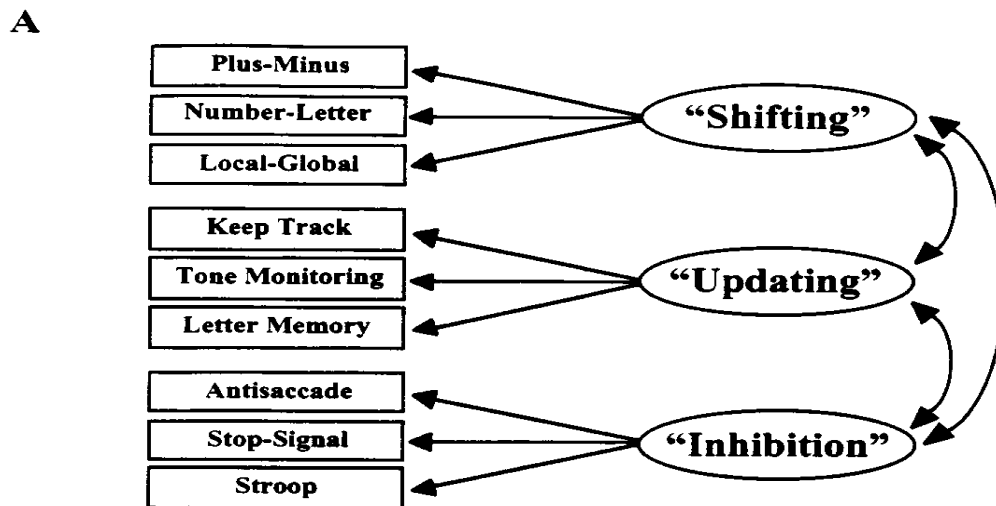


Figure A) Visual representation of the three-factor model from which the confirmatory analysis by Miyake and his colleagues is based upon. The ellipses represent the latent EFs. The rectangles represent the tasks used to measure the EFs. The double-headed arrows represent the correlations between the latent EF constructs (Miyake et al., 2000).



The theoretical model described above was initially developed by measuring an adult population consisting of college students. However, it has also been found to be suitable in a sample of children in the age-range from 8 to 13 years (Letho et al., 2003).

Huizinga, Dolan & Van Der Molan (2006) also found the model to fit on a sample of children and adolescents varying in age from 7 to 21 year-olds. By extracting the latent variable from 9 experimental EF-tasks designed to tap inhibition, working memory and mental set-shifting, the authors revealed an organization of the EFs which were similar to the one described by Miyake et al. (2001). In favour of the “diversity” criteria, Huizinga and his colleagues found the EFs to develop at different rates, independently from each other, through childhood and into young adulthood. Further, in support of the “moderately correlated” criteria, WM and mental set-shifting was found to be moderately correlated to each other.

Despite the fitting of the integrative model to older children and adults, there is still some uncertainty in regard to the application of this model to preschool-aged children. Some lines of evidence points to EFs as best conceptualized as unitary construct in preschool, rather than being moderately differential (Sonuga-Barke, Dalen & Remington, 2003). Wiebe, Espy & Charak (2008) investigated a sample of 243 children at 2, 3 and 6 years of age on a selection of what was regarded as age-appropriate EF-tasks. Included in the study were three tasks thought to tap WM and seven tasks thought to tap inhibitory processes. What came out of the analysis was interpreted to support EFs as best conceptualized as a unitary construct, at least in this age-group. The different tasks used to tap different EFs in this study seemed to measure the same, underlying construct rather than several differential components.

The theoretical model of the EF-construct, as it is outlined above, is adopted as a theoretical framework in the present study. Selections of EFs to measure, and the hypothesis which the analysis is based upon, is derived from the idea that several differential EFs coexist and can be measured independently of each other. As such, a measure of inhibition, WM and Mental set-shifting is included. A brief description of the three EF-components follows next in line, before what is known about the relationship between ADHD and these functions are reviewed.

*Inhibition of prepotent responses:* Inhibition is a multifaceted construct, referring to several related functions with a varying degree of complexity, which is essential for the deliberate control of behaviour (Friedman & Miyake, 2004). Inhibition includes the ability to withhold, restrain or suppress what is considered a prepotent, automatic or dominant response when required. In addition, the ability to partial out interfering stimuli in order to protect an ongoing behaviour sequence is thought to be an important functional domain (Barkley, 2006; Friedman & Miyake, 2004). The type of inhibition focused on in the present study concerns the ability to intentionally constrain automatic behaviour over a certain amount of time, and during this time be able to avoid reacting to intruding external stimuli.

Important brain structures are identified as involved when inhibiting behaviour. These include the inferior frontal gyrus, and fronto-striatal system as well as the basal ganglia (Aron & Poldrack, 2006; Sergeant et al., 2002; Roberts & Wallis, 2000).

Significant age-related improvements on tasks designed to measure inhibition are found all through the preschool-age (Carlson, 2005; Mischel et al., 1974). Simple forms for inhibition, like the ability to withhold an automatic dominant response, occur at elementary levels during infancy. The skill improves substantially in efficiency and complexity during preschool (Carlson, 2005; Diamond, 1990).

*Mental Set-Shifting (MSS):* MSS is defined as the ability to flexibly shift between different tasks, operations or mental sets (Monsett, 1996). In this article, this EF- construct will be interchangeable referred to as either MSS or *cognitive flexibility*. Several tasks have been developed to tap this ability in children. Examples of such tasks are the Day and Night card sorting task, the truck reversal learning task and the Dimensional Change Card Sorting task (Hughes & Ensor, 2002; Melinder, Endestad, & Magnussen, 2006, Zelazo; Perner & Lang, 2002). The complexity level differ somewhat, but a common feature is that successful accomplishment depends on the child's ability to disentangle itself from a well-learned response-set and further adapt to a new sorting rule which stands in conflict with the former.

MSS is thought to origin in medial frontal areas of the frontal cortex and depends upon regions in frontal-parietal networks (Collette & Van Der Linden, 2002; Crone,

Wendelken, Donohue & Bunge, 2005; Rushworth, Walton, Kennerley & Bannerman, 2004).

Dysfunctions to MSS are referred to as the *perseverative error*. This is the tendency to get stuck in certain response patterns when this no longer is appropriate (Norman & Shallice, 1986). Preschool-aged children will commonly be found to be robust perseverators when faced with such shifting-tasks. However, important improvements in cognitive flexibility are clearly evident during preschool. The application of a dimensional card-sorting task on preschool-aged children commonly find that three year-olds will be perfectly able to sort cards in accordance to the initial sorting rule. When required to shift to the conflicting sorting rule in the postshift-phase, they tend to apply the first selection rule, despite negative feedback. Four year olds, on the other hand, will have no difficulties adapting to the new, correct sorting rule (Bohlmann & Fenson, 2005; Deak, Ray & Pick, 2004; Melinder, Endestad & Magnussen, 2006). The application of a simple response-reversal task, which only requires the discriminating between two different looking stimuli, reveals that mental set-shifting is qualitatively present at the age of two (Hughes & Ensor, 2002).

*Updating and Monitoring of Working Memory Representations:* The third EF described in Miyakes model is called *Updating and monitoring of working memory representations* (Miyake et al., 2000). The processes conceptualized as involved in this particular EF component are considered by most researchers to be equal to those of *Working Memory* (WM) (Jonides & Smith, 1997; Lehto, 1996). WM is referred to as a collection of mental processes that are responsible for keeping a small amount of information active in mind over a limited period of time. During this retention period, the information will be available for active manipulation and monitoring, and thus aid in guiding ongoing behaviour (Fuster, 2000; Goldman-Rakic, 1995). Three components are proposed. The two storage components are the phonological loop which handles verbal information and the visuospatial sketchpad which handles visual and spatial information. The third is called the central executive (Baddeley, 2003). WM seem to be differentially localized in the brain, but the components seem to be highly dependent upon the intact workings of prefrontal brain regions (Bechara & Damasio, Tranel & Anderson, 1998).

A rapid maturation in Working Memory is evident for both the verbal and nonverbal domain from infancy and during childhood (Espy & Wiebe, 2008). This

capacity becomes increasingly more efficient during the preschool years and WM capacity keep on expanding beyond childhood (Gathercole, 1998; Luciana, 2003). This developmental change is observable by the child's ability to keep increasingly more information in mind over longer time periods (Pelphrey & Reznick, 2002). The ability to actively monitor, manipulate and update these representations emerges somewhat later in preschool, but also continues to show great maturational improvements through and beyond childhood (Gathercole, 1998).

## ADHD: development and diagnostic considerations

*Attention- Deficit/Hyperactivity Disorder* (ADHD) is defined as a neuropsychological disorder, with an onset in early childhood and is further conceptualized to be of chronic nature. The heritability estimate in ADHD lies between 70- 80 percent (Biederman et al. 2002). Brain structural abnormalities have been implicated in ADHD. The affected regions include those which are central for Dopamine regulation (Castellanos, 1994). Neural activity patterns have been found to differ between patients with ADHD and controls. This abnormal activity pattern is especially evident in frontal brain regions (Dickstein, 2006). Aman, Roberts and Pennington (1998) found that ADHD boys performed significantly better on neuropsychological tasks designed to tap prefrontal cortex functioning when using stimulant medication, compared to their performance when tested off medication, yielding further support for important disturbances in central neural networks.

*Gender differences in ADHD:* Girls are substantially outnumbered as compared to boys in clinically referred samples. As such, one might believe that boys are more vulnerable for developing ADHD than girls. However, by investigating a nonreferred sample, Biederman and his colleagues (2005) could not find any differences between boys and girls in regard to prevalence across sub-types, treatment history or psychiatric comorbidity. Rather than unequal prevalence rate, a difference in phenotypic expression has been suggested (Gaub & Carlson, 1997), and the observed prevalence rate has been attributed to referral bias.

*Diagnostic criteria in ADHD:* The diagnostic criteria used for identifying ADHD in children in the present study are those outlined in DSM-IV-TR (DSM) (Diagnostic and

Statistical Manual of Mental Disorders, text revision [DSM-IV-TR]: American Psychiatric Association [APA], 2000). However, the diagnostic manual used in Norway at present is the ICD-10 and the applied label for the disorder is *hyperkinetic disorder*. According to DSM, ADHD is associated with 18 different behaviour symptoms. Each symptom represents one diagnostic criterion. The diagnosis captures a multitude of different behaviour tendencies, and thus may comprise individuals with quite different symptom constellations. The behaviour criteria constituting ADHD can be divided into three different core- domains. These are outlined below, accompanied with the associated behaviour-criteria.

*ADHD-predominantly inattentive type*: Six or more of the symptoms for inattention outlined below is required. Further, these must have been present for at least 6 months to a point that is disruptive and inappropriate for daily functioning:

- *Inattention:*
  1. *Often does not give close attention to details or makes careless mistakes in schoolwork, work, or other activities.*
  2. *Often has trouble keeping attention on tasks or play activities.*
  3. *Often does not seem to listen when spoken to directly.*
  4. *Often does not fulfill instructions (not due to oppositional behavior or failure to understand instructions).*
  5. *Often have difficulties with the organization of activities.*
  6. *Seems to avoid, dislike activities that take a lot of mental effort for a long period of time (such as schoolwork or homework).*
  7. *Often loses things needed for tasks and activities*
  8. *Is often easily distracted.*
  9. *Often forgetful in daily activities.*

*ADHD- predominantly hyperactive/impulsive type*: Six or more of the following signs of hyperactivity-impulsivity is required. These must have been present for at least 6 months, also to such an extent that gives impairments in daily functioning:

- *Hyperactivity:*
  1. *Often fidgets with hands or feet or wriggle in seat.*
  2. *Difficulties with remaining seated when expected.*
  3. *Often runs about or climbs when and where it is not appropriate (restlessness).*
  4. *Often has trouble doing activities quietly.*
  5. *Often "on the go" or seemingly "driven by a motor".*
  6. *Often talks excessively compared to others.*
- *Impulsiveness:*
  1. *Often blurts out answers before questions have been finished.*
  2. *Often has trouble waiting one's turn, for example when waiting in line.*
  3. *Often interrupts or intrudes on others.*

*ADHD-combined type*: Six symptoms must be present from each ADHD-domain, and these must have been present for at least 6 months with following impairments in daily functioning.

Some additional requirements must be met in order to obtain the ADHD-diagnosis. These are outlined below.

1. *At least some of the symptoms must have been evident before the age of 7.*
2. *Behavior must be typical in at least two different settings, like at home and in kindergarten.*
3. *Symptoms must have been a typical trait for at least 6 months.*
4. *Symptoms must have caused some distress or impairments in daily functioning, such as in relationships, academic settings or the occupational domain.*
5. *The behavior is not explainable by other impairments (E.g. psychotic state, mood disorders, anxiety disorders or personality disorders. However, several disorders are not uncommonly coexisting with ADHD).*

### **ADHD: A categorical versus a dimensional perspective**

When referring to ADHD, two different approaches can be adopted. The first perspective view ADHD as a category in which encompasses those individuals that in some qualitatively manner is different from people without the disorder in question. The other view is the one of a continuum. Such an approach regards the behavior typical for ADHD as representing extreme points on behavior dimensions, or traits, that is present in everyone but to a lesser extent. The key question is whether ADHD is best considered as a discrete and qualitatively separate category or if the behavior in reality represents the dimensional behavior patterns. The required thresholds necessary for obtaining clinical status as a case, according to the DSM-IV-TR is an example of the categorical “all or none” perspective. The other perspective considers the behavior that is typical for ADHD children to represent extreme levels of behavior tendencies that are commonly found to a certain degree in all children (Sonuga-Barke, Dalen, Daley & Remington, 2003). This means that ADHD in reality is representing deviations from a normative referral point on a dimensional scale. The DSM-IV-TR operates with a categorical standpoint, depending on certain thresholds to be reached in order to obtain status as a “case”. Several authors have contrary to this claimed that the dimensional view might apply better to the disorder. Genetic analysis support the latter statement, referring to findings that ADHD seems to represent extremities of behavior that is genetically present in various degrees in the entire population (Levy et al., 1997). Others have found that the association between a specific

inhibition dysfunction and ADHD-symptoms in preschool-aged children is of linear nature, and hence gives support to the continuum view of the nature of the disorder as well (Sonuga-Barke et al., 2002). If the first perspective is true, then EF deficits will be qualitatively present or absent, depending on whether the child has ADHD or not. If the latter statement is true, then cognitive deficits will vary in a gradual manner, following symptomatic severity. Such findings can be evident when comparing children with escalating degree of symptomatic impact on their performance on EF tasks.

### **Extreme behavior in preschool**

Much more literature is published on children attending school compared to that of children of preschool age. However, there is a growing awareness of ADHD-typical behavior emerging already during preschool (Harvey et al. 2009).

In an unstructured play setting, differences between children of preschool age with ADHD and their normally developing peers was impossible to detect. All children, regardless of presence or absence of ADHD, were rated similarly in relative activity level. However, ADHD-children differed significantly from control children as they were seemingly unable to resist the temptation to play with a set of “off-limits”-toys. ADHD-children were also significantly more inclined to grab test-materials during a test-session. The authors could also document that the ADHD children needed more directives from the examiner during such structured tasks (Byrne, DeWolfe & Bawden 1998). Such findings imply that the aim to discriminate between children at risk for developing ADHD from children following a normal developmental trajectory is highly challenging. However, the introduction of restrictions to the context may reveal substantial differences between the clinical group and what is within the normal behavioural variation for the age group.

Some uncertainty remains in regard to the validity of the ADHD-diagnosis in preschool. The debate centres on whether ADHD is identifiable in preschool, and whether the diagnostic cut-offs, as outlined in diagnostic manuals, shall be the same for preschoolers as it is for older children (Blackman, 1999). As mentioned elsewhere, the DSM states that some of the problem behaviour must be present before the age of seven. Clever research has derived at results in favour for the early identification of ADHD already in preschool. However, many children identified with hyperactive, impulsive or inattentive trait, tend to outgrow these elevated behaviour inclinations during childhood (Lahey et al, 2006).

In regard to the diagnostic threshold-issue, predictions made about the presence of later behavioural problems has been found to be correct in as many as three out of four 3-year old children identified as reaching the diagnostic threshold for ADHD (Harvey et al. 2009). Those with the actual disorder will usually continue to be affected through adolescence and adulthood (Moffitt, 1990). It is estimated that as many as twenty to thirty percent of those diagnosed with ADHD as children will continue to suffer from the disorder until adulthood (Muglia et al. 2000). However, only four percent of those diagnosed with ADHD as a child will reach the full clinical criteria as adults (Mannuzza et al, 1998). This latter estimate is based upon self-reports, and might not be reflecting an actual remission rate for the diagnosis. The exact phenotypic expression of the disorder seems to be changing with age (Lahey et al., 2005). In preschool, ADHD predominantly hyperactive/impulsive-type seems to be most frequent. The combined type is not as common, but ADHD-predominantly inattentive-type is very rare in preschool. The latter two emerges at a greater scale in older samples (Applegate et al., 1997; Nolan, Gadow & Sprafkin, 2001). Although studies have been able to identify ADHD in preschool, and diagnostic predictions based upon preschool behaviour have been found to stand correct (Byrne, DeWolfe & Bawden, 1998; Harvey et al., 2009; Lahey et al., 2005) much work still remains in regard to validity issues.

### **The benefit of knowing early precursors to ADHD**

ADHD is accompanied by an increased risk for experiencing several negative life outcomes, (e.g., learning difficulties, social problems, and later comorbidity with depression and anxiety), and it is an important clinical challenge to identify those children at risk for developing ADHD as early as possible (SINTEF-Helse, 2004). In the search for early precursors for ADHD, a relatively new wave of research emphasizes the potential role of the prefrontal lobes in moulding the difficulties known to accompany the disorder. Findings of abnormal activity patterns in the prefrontal lobe and associated networks, which emerge when ADHD-children actively engage in solving neuropsychological tasks are revealed. Such findings fuel the prefrontal lobe hypothesis in ADHD (Dickstein, 2006). In addition, ADHD-patients usually have great difficulties when performing on such neuropsychological tasks (Castellanos & Tannock, 2002; Pennington & Ozonoff, 1996; Sonuga-Barke, 2003; Willcutt et al. 2005).



Most of the available literature investigating impairments in EFs in ADHD has primarily focused on children attending school, adolescents and adults, and a relation between the two is readily established (Barkley, 1997; Berlin et al. 2004; Fugetta, 2006; Pennington & Ozonoff, 1996; Quai, 1997). However, children in preschool have been greatly overlooked as a group. This is unfortunate given the importance of this period for the current neuropsychological understanding of ADHD (Barkley, 1997; 2006). Preschool is recognized as a period in life characterized by important development. The foundation for important abilities, such as school readiness, social adjustment and self-regulation has been found to emerge during preschool (Kochanska, Murray & Harlan, 2000). The lack of focus on this preschool-aged group has more recently been addressed in a much greater scale. Now, several attempts have been made in order to reveal the potentially early precursors for the EF/ADHD relationship that seem to coincide in older samples (Espy, 2004; Espy, Kaufmann, Glisky, & McDiarmid, 2001; Welsh & Pennington, 1988; Welsh, Pennington, & Groisser, 1991).

## Executive dysfunction in children with ADHD

*Executive dysfunctions in childhood:* Compared to normal controls, children with ADHD have been found to exhibit significant impairments to inhibition (e.g., interference control and response inhibition), working memory, emotion regulation, planning, cognitive flexibility and phonetic fluency (Berlin et al., 2004; Harris et al., 1995; Marzocchi et al., 2008; Oosterlaan, Scheres & Sergeant, 2005; Pennington & Ozonoff, 1996).

Research findings regarding WM are somewhat inconsistent across studies but much research has successfully revealed this EF to be significantly impaired in children with ADHD (Brocki et al. 2008; Mariani & Barkley, 1997; Martinussen et al, 2005; Wilcutt et al., 2005). In these studies, the impairment has been found to remain associated to ADHD even after non-executive processes, such as language disorders and general intellectual ability, has been accounted for (Martinussen et al., 2005). One proposed explanation is that the impairment in question is due to an inability to actively manipulate verbal material (McInnes et al., 2003). Others have failed to find differences between

children with and without ADHD, and thus questioned the position of this EF as being a precursor for the disorder (Sonuga-Barke et al., 2002).

A more consistent finding pertains to that of a malfunctioning inhibition mechanism in children with ADHD. This might come forward as difficulties in withholding a dominant behaviour response or as an inability to resist the temptation to take hold of immediate rewards, even when resisting would give a greater, long term gain. In addition, children with ADHD will often display a tendency to be easily distracted by interference in the environment when compared to typically developing children. Barkley (1997) made this the core deficit in ADHD. He believed that inhibition was implicated in the healthy workings of all other EFs and that a deficit in this underlying mechanism would lead to secondary deficits in EFs commonly associated with ADHD.

As for MSS in children with ADHD, research findings are usually inconsistent. There are some authors which claim to find this EF to be impaired in children with ADHD (Shue & Douglas, 1992), but much variability in test results leave this area quite unresolved (Ozonoff & Jensen, 1999). A commonly applied task is the Wisconsin Card Sorting Task. Children and adolescents in a clinical referred sample with ADHD has been found to perform significantly worse than controls on this particular task (Seidman et al., 1997; Martel, Nikolas & Nigg, 2007) However, Ozonoff and Jensen (1999) could not reveal any significant impairment on this task in ADHD-children.

*Comorbidity in ADHD in childhood:* ADHD often coexist with other disorders (APA, 2004). As a result, caution should be made before deriving at a conclusion. Findings, such as those presented here, might be due to comorbid disorders, not to ADHD as such. However, taking this fact into account, several research papers has found EF dysfunctions to remain related to ADHD even after controlling for often coexisting disorders, such as oppositional defiance disorder, conduct disorder (Klorman et al., 1999; Oosterlaan et al., 2005), Tourettes (Harris et al, 1995), language disorders (Martinussen et al., 2005) and reading disability (Klorman et al., 1999; Marzocchi et al., 2008; Oosterlaan et al, 2008). Such findings support the specificity of the EF dysfunction to ADHD.

*Meta-Analysis: Making the field comprehensible:* Pennington & Ozonoffs (1996) published an often cited meta-analytic review, trying to find the central leanings in the multitude of research on the subject of EF and its relation to ADHD. Eighteen studies was included, resulting in a compilation of sixty EF-measures, tapping EFs in six different domains: Mental set-shifting, Planning, Working Memory, Contextual memory, Inhibition

and Fluency (Pennington & Ozonoff, 1996). Fifteen of the eighteen studies included in the meta-analysis could document a significant association between ADHD and EF. Forty of the EF-measures discriminated between ADHD-children and controls. As such, the authors could support the hypothesis that dysfunctions to EFs are associated to ADHD.

Another, more comprehensive meta-analysis was later conducted by Wilcutt et al (2005). The aim was to test the assumption previously made by Pennington and Ozonoff back in 1996. In all, thirty-eight research papers on ADHD in childhood and adolescence were identified as suitable, and included in this meta-analysis. Overall, the results were in the same direction as the previous analysis. ADHD-children were found to be impaired in several EFs as compared to children without ADHD. However, due to small to moderate Effect Sizes, the authors stated that the detected association should be regarded as one of several important weaknesses found in ADHD, not the one single causal factor. (Wilcutt et al, 2005).

*ADHD and its relation to EF in Preschool:* Findings of important dysfunctions to EFs in children and adults with ADHD have sparked research interest into how this relation unfolds in preschool. If a causal relationship exists, supporting the idea that ADHD grows out of deficits to EFs, it should be possible to use EF-tasks in order to discriminate between preschool aged children with and without ADHD-symptoms, provided the tasks are sufficiently sensitive. A deficit or developmental delay to EF will thus reveal itself as an inability for ADHD-children to complete tasks designed to tap prefrontal lobe functioning, while same age peers under normal development commonly succeed upon such tasks (Barkley, 1997; Carlson, 2005). The development of tasks specifically designed to tap EFs during preschool has demonstrated what best can be understood as significant cognitive maturation during the first years of life. The question pertaining to whether preschool-aged children with ADHD differ in their respective EF-profiles during this developmental spurt has gained an increasingly amount of scientific interest. At present, findings remain inconclusive.

One example of such divergent results is found in studies on Working Memory. Several authors claim to find a deficient WM component in ADHD, present already in preschool (Mariani & Barkley, 1997; Sonuga-Barke et al., 2003; Thorell & Wahlstedt, 2006). Other research projects fail to find such deficits in their samples (Brocki et al, 2008;

Sonuga-Barke et al, 2002). Research on older children identified with ADHD commonly finds this EF to be impaired (Martinussen et al., 2005; Willcutt et al., 2005).

In regard to MSS, the last EF that is to be investigated in this article, the published work is limited, and the results are mixed (Barkley, 1997).

A deficient inhibition-mechanism is perhaps the most well-established finding when examining EFs in ADHD at this age (Barkley, 1997; Sonuga-Barke et al., 2002). This has come forward as a rather robust finding which not seems to be affected by other processes, such as gender, intelligence and other non-executive processes.

Sonuga-Barke, Dalen and Remington (2003) confirmed the hypothesis that dysfunctions to EFs are an associated problem in the ADHD-population in preschool by conducting a study using a collection of age-adequate neuropsychological tasks on a community-based sample of preschool-aged children. Children in this study displayed impairment to EFs, such as working memory, planning, delay of gratification, and preference for delayed rewards, compared to typically developing children. The respective associations remained even after controlling for gender and intelligence. However, the contribution made by EFs was too limited in order to account for all the psychologically heterogeneity evident in the disorder during preschool. The authors proposed a dual-pathway model for the disorder. Dysfunctions to EFs and a construct named delay-aversion contribute independently in predicting ADHD. The dual-pathway model states that ADHD is characterized by a certain motivational style. Affected individuals will tend to escape or avoid what is perceived as potential delays. A delay is thought to cause conflict in certain brain-structures which are sensitive for rewarding stimulus (Sonuga-Barke, 2003). Caution should be made when interpreting the findings from the study by Sonuga-Barke and his colleagues. Children with ADHD were identified using only maternal reports. This might lead to single-source bias. An additional point concerning this study is due to the sampling method. As mentioned above, the included children were drawn from a community-based sample, using a dimensional approach to ADHD. The result is a sample of children with a broad range of symptom severity, possibly also beyond diagnostic cut-off values.

Hughes and Ensor (2007) went out to investigate what they called problem behaviour (ADHD and CD) and its relation to EF in preschool. A longitudinal design was applied, measuring children at the age of three and the age of four years. First of all, they found that early EF dysfunction, controlled for behaviour problems, could predict later, aggregated problem behaviour, but not the other way around. Problem behaviour did not

predict later emergence of EF dysfunctions. Such findings indicate that EFs is important for behaviour regulation, an association that is evident already in preschool. Another finding of interest is that there seemed to be an age-related increase in the specificity of the relationship between problem behaviour and specific EFs. This implies that EF is going through a modularization process in preschool. This strong association between EFs and problem behaviour were found to remain even after controlling for verbal skills and Theory of Mind. This study did not discriminate between the two disorders and thus cannot state from which the dysfunctions are associated.

Wåhlstedt et al., (2001) was interested in the predictive qualities to different measures of ADHD and EF-impairments during preschool, and how they relate to expressions of problem behaviour that is specifically associated with ADHD years later. Using a non-clinical sampling strategy, they went out to compare three different groups (One pure EF-dysfunction group, one ADHD+EF-dysfunction group and one pure ADHD-group). As a result, they revealed that both ADHD and deficits to EFs predicted later impairments within their respective domains. That is, early deficits to EFs would predict later deficits to EFs, when reassessed. The same was true for ADHD. Early ADHD-symptoms predicted later expression of ADHD. In addition, some important cross—domain effects were noticed. Impairments to EFs during preschool were found to predict later inattentive impairments. Group-comparisons also revealed that children with EF dysfunctions in preschool demonstrated significantly elevated hyperactivity and inattentive traits later on. Lastly, ADHD by itself were independently associated with later, more wide-ranging impairments in socio-emotional functioning (Wåhlstedt et al, 2001).

Thorell & Wåhlstedt (2006) lent further support to the specificity of the relations between EF and ADHD. A community-based sample consisting of 101 boys and 100 girls was included, ranging in age from 4 to 6 years. Inhibition, working memory, both verbal and spatial, as well as verbal fluency was measured using age-adequate tasks designed to specifically tap each EF independently. The children rated as high on ADHD-symptoms were markedly outperformed on all EF-tasks compared to children with low levels of ADHD-symptoms. The exception was the verbal fluency task. The pattern remained even after controlling for ODD-symptoms and gender. An important aspect of this study is the use of only teacher- reports in identifying children with high levels of ADHD-symptoms. “Caseness” was defined as children scoring in the upper twenty percent at the ADHD symptom-scale. Thus, the ADHD group might encompass children who belong in the

upper range of what is within normal behaviour variation, as well as children with behaviour according to diagnostic thresholds for ADHD.

Overall, all of the research projects described above extends the findings of dysfunctional EFs associated with ADHD into the preschool years. Taken together, such results point toward the hypothesis that important features in ADHD in fact might be due to discrepancies in prefrontal lobe activity. Despite promising results, some research projects fail to support the prefrontal lobe hypothesis in ADHD. The strength of a relationship between EF and ADHD has also been found to diminish as third variables are included as covariates.

One study which failed to find a significant relationship between EFs and ADHD applied a *paired-control condition* to each EF-task. The paired-control condition is constructed in order to be similar to the EF-task, except for minimal EF-loading. As such, the isolation of the EF under investigation is accomplished. What came out of the analysis suggest a neurocognitive deficit in the ADHD group, demonstrated by weaker performance on tasks when compared to typically developing children. However, this weaker performance was also evident in the control-condition, indicating that such weakness is not attributable to deficient EF per se, but rather reflects impairments to lower, non-executive processes (Marks et al., 2005).

Another study which revealed the moderating effect of third factors was conducted by Sonuga-Barke et al (2002). Preschoolers with and without ADHD-symptoms were examined using tasks designed to measure inhibition, working memory and planning. The relations between ADHD and WM and planning disappeared when controlling for age and intelligence. However, the relationship between ADHD and inhibition remained significant, fuelling the hypothesis about the primacy of a compromised inhibition mechanism as leading to later emerging, and more global dysfunctions to EFs in ADHD.

Hughes, Dunn and White (1998) also could present results indicating that preschool-aged children described as hard-to-manage, performed significantly worse than control children on four of six EF tasks designed to tap inhibitory control, working memory, and cognitive flexibility. Despite these promising results, not one relation remained significant after controlling for verbal ability and socioeconomic status. Concealed third variables and comorbide conditions to ADHD are evidently present and potentially influential, and should be taken into account when doing research on EFs and ADHD.

Despite the empirical findings pointing to central deficits to important EFs in ADHD children, there are researchers who doubt the causal role thought to be hosted by such impairments (Zelazo, 2003). Children identified with other known developmental neuropathological disturbances also reveal important impairments in components of the EF-structure (Ozonoff & Jensen, 1999). However, these groups of children (e.g., autism, tourettes) display symptom constellations which are clearly different from the symptoms characteristic of ADHD. If children with ADHD have difficulties with inhibition *because* of EF-impairments, it is difficult to explain how come they are exceedingly different from children with autism and tourettes. According to Zelazo (2003), it is more likely that the causal pattern is the opposite. The impairments seen in children with ADHD and children with autism are, according to him, resulting from different mechanisms. In regard to these two groups, it might be that children with autism have difficulties with EF as a result of rigidity, a central symptom to this group. The impaired EFs evident in children with ADHD, might rather stem from disturbances in their ability to inhibit thought and action, as stated by Barkley (1997) or it might be due to impairments in what is referred to as ‘*Energetics*’ (e. g, effort, arousal, activation), as stated by the Cognitive Effort Model (Sergeant, 2005).

### **The influence of Intelligence on the ADHD/EF relation**

A highly debated issue when doing research on EF’s in ADHD-populations pertains to the issue of whether or not to control for the influence of intelligence (IQ) on neuropsychological test performance. Assessment of full scale IQ reveals that individuals with ADHD display significant decrements in regard to overall intelligence level compared to individuals without ADHD (Faraone et al., 1993; Fraizer, Demaree & Youngstrom, 2004). Further research on the topic has found that a revealed relationship between EFs and ADHD tend to diminish, when the effect of IQ is included in the analyses as a covariate (Sonuga-Barke et al, 2003). Such findings indicate that much of the variability in EF-performance seen in ADHD populations might be due to variations in IQ, not solely to the effect of ADHD-symptoms. Such findings argue in favour for careful consideration and control for variations in IQ between clinical and control groups when conducting research. Another perspective has argued against this proposition. Low IQ has been proclaimed to be a feature to the actual disorder in question (Fraizer, Demaree & Youngstrom, 2004; Mariani & Barkley, 1997). When controlling for intellectual ability, some of the variance

that in reality is due to ADHD will be eliminated (Barkley, 1997). Following this line of arguments, controlling for IQ is unfortunate in that some of the true variance between groups will be lost.

## Hypothesis

The present study seeks to answer several related research questions in regard to the relationship between EF and ADHD-symptoms in preschool.

The first set of research questions pertains to whether or not three groups of preschool children, categorized in accordance to degree of symptom severity due to ADHD, will differ in their performance on tasks that are designed to tap four different EFs: 1) inhibition, 2) verbal working memory (VWM), 3) nonverbal working memory (NVWM) and 4) mental set-shifting (MSS). The first group is a “pure” ADHD-group (ADHD+) which includes those children which reach the diagnostic criteria for ADHD according to DSM-IV-TR. The second group (ADHD÷) contain children with symptoms for ADHD which reach just below diagnostic threshold. The last group includes control children (CC). The prediction states that the ADHD+ group will demonstrate more impairment on all measures, in comparison to the other two groups. The difference is predicted to be most pronounced between the ADHD+ and the CC. The CC group is thought to obtain the best scores, which represents a more mature EF-construct. The ADHD÷ group is predicted to obtain scores somewhere in the middle range between the ADHD+ and CC group. The relational pattern is hypothesised to be of linear nature, with ADHD÷ performing better than ADHD+ but demonstrate more difficulties as compared to the CC.

The last prediction in the present study pertains to a more theoretical aspect of EF. Research on EF in general has commonly supported a differentiable but moderately intercorrelated cognitive control system. When examining preschool aged children, several researchers have found the postulated EF's to be rather undifferentiated at this point in development. The research question that follows is: Will EFs best fit into a unitary model or a multifaceted, integrative model in preschool?



## Method

Before moving on to the details of the present study, the origin and ownership of the data materials that are utilized will be outlined. A description of the participants comes next in line, followed by a description of the tests of interest and the general procedure employed.

### **The obtainment of data and the representativeness of the sample**

All data used in the present study is obtained through the research project called the ADHD-study. Access to the data was made possible as the author of the article has been an employee at the research project during the last years.<sup>1</sup> The ADHD-study is made possible due to collaboration between the Norwegian Institute of Public Health (FHI) and Oslo University Hospital (OUH). The ADHD-study is a sub-study launched through a pioneering ongoing research project known as *The Norwegian Mother and child- study* (MoBa). MoBa is a national cohort study that is currently taking place in Norway. Utilizing a longitudinal design, it intends to follow Norwegian children and their parents through pregnancy and during childhood. As for today, 100 000 mothers has given their consent to share biological and environmental/social information to the MoBa project, contributing to a valuable source of data. The ADHD-study aims to collect data from a total of 1600 children. These children will further be retested in a planned follow-up study (Magnus et al., 2006).

### **Participants**

*Inclusion criteria:* A total of 121 children participated in the present study. Due to missing data, only 96 children (53 boys and 43 girls) were available for further analysis. Missing data is a result of failure to obtain the necessary information from the child during the neuropsychological testing to make a valid score. Children's age range from 38 to 45 months ( $M = 40.78$  months,  $SD = 1.53$ ). Both boys and girls are included and present in each group. Three groups are identified. Children are classified as ADHD+, ADHD÷ or CC. The ADHD+ contains those individuals who reach the full diagnostic criteria for an ADHD-diagnosis according to DSM-IV-TR ( $n = 32$ ; 16 boys and 16 girls, age;  $M = 40.62$ ;  $SD = 1.47$ ). The second group is labelled ADHD÷ (Total  $n = 17$ ; 14 boys and 9 girls, age;

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<sup>1</sup> The author of this article is hired as a research assistant at the ADHD-project. Primary obligations are the administration of the PAPA-interview. Other central responsibilities are to control video-recordings of the test-administrations and to register test-data electronically.

M = 40.78; SD = 1.57) and consists of those children who is identified as having several symptoms for ADHD, but does not reach the necessary cut-off requirements for obtaining the diagnosis. They are either 1) present with enough symptoms, but these does not contribute to functional impairment in daily functioning, or 2) they have some of the symptoms, but these are reported to have a substantial negative impact on daily functioning. The behaviour problems are described in both teacher and parental reports. The third subgroup is labelled CC (n=79, 38 boys and 33 girls, age; M = 40. 86, SD= 1. 55). This group contains typically developing control children. Children in this group will interchangeable are referred to as CC, typically developing children, or control children.

All children in the MoBa have been drawn from mixed social backgrounds. Norwegian is the primary language. It is no reason to assume that the sample in this particular study should be biased in any way on these characteristics.

*Exclusion criteria:* All individuals identified with ADHD- predominantly inattentive-type were excluded. This decision is due to the very limited number of children reaching the criteria necessary for this sub-type of ADHD in the original sample derived from the ADHD-study. In addition, the children identified with a situational ADHD were also excluded. This was due to few subjects in this particular category. In addition, the inclusion of one group below diagnostic thresholds for ADHD seems sufficient in order to test the hypothesis in the present study. The ADHD-study, which the data-materials are derived from, also has excluded children with pervasive developmental disorder. These subjects were not invited to participate in the one day-long examination. The stated rationale for this exclusion was due to the fact that this group of children would probably not be testable. This initial exclusion means that the sample included in this particular study will be free for this group of individuals as well.

### **Performance-based measures of Executive Functions**

The tasks of interest in this study are designed to measure four different EFs. These are 1) inhibition, 2) verbal working memory, 3) nonverbal working memory and 4) mental set-shifting/ cognitive flexibility. The tasks utilized in the present study are derived from two comprehensive, well validated test-batteries as well as one additional experimental task. All tasks are of short duration (approximately 5 minutes), considered attractive for the age-group examined and has a game-like appearance.

### **The NEPSY battery**

*NEPSY* (Korkman, Kirk, & Kemp, 2000) is a comprehensive test battery which consists of several, different sub-tasks that are developed in order to measure neurocognitive performance. Of interest in this particular study is the statue task, designed to measure the inhibition mechanism.

*Statue task*; Here, the child is instructed to hold a completely motionless pose, similar to that of a statue, during a limited time period. Further on, the child is told to keep his/her eyes closed, keeping one arm out from the body while holding on to a pencil. They are also asked not to make any verbal sounds until given permission. This pose is to be held for a total of 75 seconds. Several distracters are introduced during this session at certain predefined time intervals. The final score on this task depends on how well the child is to inhibit behaviour. Error evaluation is based upon how many eye blinks, limb movements (beyond 45 degrees), head movements and verbal noises the child has made during the test. A maximum of 30 points is possible, and represents perfect performance. Earlier research using this task has found preschool children with ADHD to perform worse than normal controls (Mahone et al, 2005).

### **Trucks Reversal Learning Task (Hughes & Ensor, 2002):**

*The Truck reversal Learning Task* (Trucks-task) is a card-sorting task which consists of two phases, one pre-shift phase and one post-shift phase. The basic intention is to reveal whether or not the preschool-aged children are able to flexibly switch from one well established rule (mental-set) to another rule, when the old, already learned rule turns out to no longer be correct. Four yellow and four green cards are used. Yellow cards belong to the pre-shift phase and green cards are used in the post-shift phase. Two different sets of picture cards, each depicting two different looking trucks, are used in each phase. The two cards depicting the same-looking trucks present the trucks in opposite succession. These four cards are presented in succession, one at a time, for maximum 12 trials. The child is to recognize individual trucks and choose the one out of the two depicted trucks on each card which correspond to the selection rule. Each choice is followed by feedback. Correct response leads to a “reward”. This could be a raisin or a small piece of biscuit. Corrections are given if the child picks the wrong truck. Next, the child is urged to make another try. If the child is able to select the correct truck corresponding to the rule, four times in a row *after* the five first trials (which are thought of as rule-learning trials), he or she is invited to participate in the post-shift phase. The same Trucks are depicted, but this

time on the green cards. The child is told that this time, the other truck is the winner-truck. A total of eight trials are administered, and the child must choose the correct truck four times during the last five trials in order to reach the criterion for success.

The scoring procedure used in this task is referred to as a “total success”-score. A score of 2 is set if the child is able to shift to the post-shift rule during the eight trials. A score of 1 is set if the child learns the initial, pre-shift rule, but is unable to adapt to the post-shift rule. 0 is given if the child is unable to learn the initial rule. This indicates that the child was unable to understand the instructions (Hughes & Ensor, 2005). The Trucks-task has earlier been successfully administered to a group of 140 2-year olds. Only 2 of the 140 children tested were unable to carry out the task. The different trucks that are depicted on the test cards are displayed in Figure 1.



**Figure 1: The pair of trucks from the Trucks-task**

**Stanford-Binet Intelligence Scales 5<sup>th</sup> ed. (Roid, 2003).**

*The Stanford-Binet Intelligence Scales 5<sup>th</sup> ed.* (SB5) was used in order to obtain an index for Verbal Working Memory, Nonverbal Working Memory, Verbal intelligence and Nonverbal Intelligence. All of these four scales use a mean score at 10, and standard deviation at 3. The battery is tested for validity and reliability and is based upon norms from a total of 4800 individuals with age ranging from 2 to 85 years (Roid, 2003). Below follows a short description of each of the tasks used to index the four abilities.

*Verbal Memory for Sentences (VMS)* requires the child to hold a limited sequence of verbal material in mind over a minimal time period. The repetition of the information

follows immediately after the first representation. The VWM test consists of six sentences of increasing complexity and length. Each sentence is orally given to the child, one at a time. After each sentence, the child is asked to repeat the exact same sentence. The final score depends upon number of errors. 2 points are given for each correctly repeated sentence. 1 point is subtracted if one error is committed during repetition. 0 points are given with more errors. A total of 12 points is possible to obtain, but requires perfect performance on all sentences. The SB5 allows for using scaled scores on all sub-tests, with  $M=10$  and a  $SD$  at 3. The use of scaled scores makes the results more easily interpretable as it becomes possible to compare each individual result to a norm and to compare groups to each other.

*Delayed Response task/Block Span Task (DR/BS):* The first task contributing to the NVWM score is a delayed response task for objects location, which aim to measure fundamental short-term memory for objects (Roid, 2003). Here, the child is presented to an object. After presentation, the object is hidden beneath one out of two cups. In order to increase complexity level, the cups are rearranged while the child is watching. A plate is further placed in between the cup and the child for a few seconds. When removed, the child is prompted to pick the one cup which the object is placed beneath. This sequence is repeated for 6 trials. Correct pick gives a score and the incorrect choice does not. All trials are fulfilled no matter if the child succeeds on successive trials or not. The Block Span Task (SB5) represents the rest of the NVWM-score. Here, the child is to immediate recall a sequence of block taps demonstrated by the test-administrator. More complexity is added to the task with increased number of cubes and cubes to be tapped. As such, this task is thought to be taxing for the child's nonverbal working memory in that the child is required to construe and use a visual sketch-pad in order to manage the sequence of taps over the arrangement of cubes. One point is given for each trial correctly managed. The task is terminated with four failed trials in a row.

*Object series, Pattern analysis/Matrices (OS/PAM):* The Nonverbal intelligence routing score is derived through the use of tasks for nonverbal fluid reasoning (Object series/Matrices). The child is first required to match one cube to the corresponding one when aligned next to several other cubes with different shapes and colours. The following task is also one of pattern analysis. The child is to correctly place a given piece into a sequence of cubes arranged in a certain manner by the administrator. Following this task, a series of 4x4 matrices is presented. Three of the four rubrics depict figures of different

shapes, colours or size, but one is left empty. Here the child is to point to the one shape which is missing in the one empty square.

*Comprehension/Vocabulary (CM)*: The routing score for the verbal intelligence domain is obtained through a subtask tapping knowledge about bodily parts, followed by understanding of process, such as behaviour processes. The first test trials require a pointing gesture. The child must point at the corresponding item. The latter test trials require the child to produce a verbal response. In the following Vocabulary task, the child is presented to a series of pictures. The child is asked to name the object depicted in each one. In the more advanced trials, the examinee is asked to orally explain the meaning of a word.

## General procedure and analysis

### **Screening procedure in the MoBa-study**

An initial identification process is made in the MoBa. Several research questionnaires are distributed to parents. The one of particular interest to the ADHD-study is sent out when the participating children reach 36 months of age. Embedded in this particular questionnaire, there are 11 screening questions thought to be sensitive to ADHD-symptoms that are based upon DSM-IV criterion for ADHD. Children that are positively screened for ADHD on these questions (those in which obtain a score above the 90<sup>th</sup> percentile) will further be invited to participate in the ADHD study along with a randomly drawn control group. A written informed consent is given by all participating individuals in the MoBa. In the ADHD-study, a new informed consent is obtained.

### **The examination and diagnostic evaluation at the ADHD-study**

All children that participate in this study has previously been individually examined and tested on several medical and neuropsychological tasks. In addition, both parental and teacher-reports are collected. The child and the parent are invited to the lab at Ullevål University Hospital. All neuropsychological testing is executed by an experienced clinical psychologist. Clinicians hired in the ADHD-study are blind to the results of the initial screening procedure in the MoBa. This is done in order to reduce the risk for bias against children screened positive for ADHD. One parent is allowed in the test room, initially placed in a chair in a corner behind the child. All activities are videotaped or recorded. The neuropsychological tests are administered in a quasi-randomized order. The tasks are

initially supposed to be presented in a prearranged sequence. However, the clinicians are allowed to make judgements in regard to which tasks should be presented in what order, depending on such factors as characteristics to the child. The individual tasks are of short duration, but the total time used to administrate the whole set of tasks varies depending upon the child. Full administration can last up to 2 hours. Intra-session brakes are inserted in order to counter fatigue.

The diagnostic evaluation of each child is made at the end of the day in a consensus meeting between the clinicians who are involved in the testing of the given child. Reports have earlier been collected from both parents and teachers. In addition, the comprehensive diagnostic interview named *The Preschool Age Psychiatric Assessment* (PAPA) (Egger & Angold, 2004) is central for the diagnostic decision. The child's behaviour during the test-setting is also taken into account. The group distribution in the present study is based upon the final conclusion made in the consensus.

## Statistical procedure

The main focus of this study is to compare three different groups on their performance on four measures tapping associated EFs. Due to the interest in several dependent variables, a Multivariate Analysis of Variance (MANOVA) was performed. This statistical approach is offered in the statistical program SPSS for data analysis. This approach will investigate whether there are significant differences between the groups in question on the dependent variables. Effect sizes will be calculated in order to get an index of explained variance. Authors highlight Effect Size as the preferred statistics for presenting the strength of the relationships rather than referring solely to significance estimates. It is quite possible to execute multiple ANOVA'S on the data. Such an approach will allow for the analysis of one variable at a time. However, the MANOVA allow for the inclusion of multiple variables into the same analysis. When executing several separate analyses, the risk for making the Type1 error, that is finding a significant result where there in fact is none, increases. To counter this, the Bonferroni correction is applied to the Alpha-level.

The alpha-level is usually put to .05. A p-value less than  $p < .05$ , means that the probability for the 0-hypothesis is less than 5 %. To make sure not to commit the type I error, which is a potential risk in a MANOVA, the Bonferroni correction to the alpha-level

was applied, making this level more stringent. The Bonferroni correction will divide the default alpha level ( $p < .05$ ) with the number of dependent variables in the follow-up analysis. The inclusion of four dependent variables in the present study reduces the alpha-level to  $p = .125$ .

Four dependent variables were used. These were included in order to index 1) Inhibition 2) mental set-shifting, 3) Verbal Working memory and 4) Nonverbal Working Memory. The independent variable was group inclusion into one out of three possible groups: 1) Clinical ADHD group, 2) ADHD-sub threshold and 3) control group. A further description of the three groups is outlined below.

Search for potential significant differences between the groups due to age, IQ and gender was executed. The rationale for this was due to previous findings indicating that boys and girls differ in prevalence, symptom-constellations and associated vulnerabilities due to ADHD (Baving et al, 1999; Gaub & Carlson, 1997; Overman, Bachevalier, Schuhmann & Ryan, 1996). Age has previously been found to exert significant contribution to the relative performance on EF-tasks (Carlson, 2005). Intelligence has also previously been found to be related to both ADHD and EF (Mariani & Barkley, 1997; Sonuga-Barke et al, 2002). A full scale IQ index was calculated by adding verbal and nonverbal IQ measures and divides the result in two. This index will follow the same normative qualities, mean and SD values as the VIQ and NVIQ.

The *p-values* are presented in order to refer to the statistical significance to a relationship. This estimate is interesting as far as that they can say something about whether the obtained result could be due to chance or not. Small *p-values* indicate that the probability for the results to be due to chance is highly unlikely.

Several authors have warned against giving too much reliance on *p-values* (Cohen, 1988). A problem that might arise when only referring to *p-values* is that this index is susceptible to qualities with the sample size. A more suitable and interesting value, the Effect Size ( $\eta^2$ ), will be referred to in this study. The Effect Size inform about the strength of a relationship. It gives an estimate of how much percent of the observed variance that is due to variance in the independent variable. The use of such estimates is also essential because it makes it possible to compare the experimental effects of the independent variables on the dependent variables in one study to those obtained in other studies. An increasingly amount of published papers now take advantage of the Cohen's interpretation when referring to Effect Sizes (Cohen, 1988). The Cohen's *d* is mathematically speaking



the difference between the means in the groups, divided on the standard deviations. The values can range from 0 to 1. SPSS does not calculate Effect Size estimates. Instead, the Effect Sizes must be calculated manually. The formula is as follows;  $\eta^2 = \text{sum of squares for the given effect} / \text{sums of squares for corrected total}$  (Levine & Hullett, 2002). When referring to Effect Sizes, it is an assistance to clarify the cut-off values for what is a small, medium and strong effect size. According to conventional criterions, a small Effect Size is .01. A medium effect size lies around .06 and a large effect size in which indicates a strong relationship, is .14 and above (Cohen, 1988).

Bivariate correlation analysis was used to explore the relationships between the four different EFs. The rationale for this was to investigate the fit of the theoretical model proposed by Miyake and colleagues. Pearson Product-Moment Correlation Coefficient is an indicator for the linear relation between two variables. The correlation coefficient ranges from 0 to +/- 1. Scores of 0 denotes no inter-relation and scores of 1 equals a perfect linear relationship. This was firstly done for the groups together and followed by analysing the three groups separately.

## RESULTS

### Preliminary analysis

Preliminary analysis was performed, investigating mean and standard deviations for the dependent variables for each group. These are depicted in Table 1. The potential effect of gender, nonverbal intelligence, verbal intelligence, and age on the dependent variables was also investigated prior to the implementation of the MANOVA.

**Table 1: Descriptive Statistics**

Groups	ADHD+		ADHD÷		CC	
	N = 32 16/16		N = 23 14/9		N = 71 38/33	
Boy/Girl	Mean	Std.D	Mean	Std.D	Mean	Std.D
Age	40,62	1,47	40,78	1,57	40,86	1,55
NVWM	9,06	2,79	8,52	2,71	10,96	2,77
VWM	9,26	3,27	11,30	2,40	11,39	2,93
Inhibition	9,30	9,68	9,53	8,40	17,05	8,38
MSS	.90	.79	.82	.88	1,08	.88
full scale IQ	9,35	1,68	10,30	1,48	10,40	1,58

*Descriptive Statistics, here presented as Means and Standard Deviations, for ADHD+, ADHD- and CC.*

*Age is presented in months. NVWM = Nonverbal Working Memory; VWM = Verbal Working Memory; MSS = Mental Set-Shift.*

Age did not make a contribution to the relation between the other variables,  $F(4, 89) = .65$ ;  $p = .63$ ;  $\eta^2 = .028$ . Preliminary analysis of the effect due to gender revealed no significant gender effect in regard to any of the dependent variables  $F(4, 89) = .47$ ;  $p = .76$ ;  $\eta^2 = .021$ . Nonverbal intelligence did not contribute to any of the observed variance as well,  $F(4, 89) = .17$ ;  $p = .95$ ;  $\eta^2 = .008$ . The following analyses will therefore not include gender, nonverbal intelligence or age as covariates in the MANOVAs. However, when investigating verbal intelligence in the preliminary analysis, it became clear that this variable had a significant effect on the EF measures;  $F(4, 89) = 3.811$ ;  $p = .007$ ;  $\eta^2 = .146$ . When looking at the four variables, it became clear that VIQ did have a significant effect on VWM;  $F(1, 92) = 9.34$ ;  $p = .003$ ,  $\eta^2 = .092$ , and on the measure of NVWM;  $F(1, 92) = 8.41$ ;  $p = .005$ ;  $\eta^2 = .084$ . However, VIQ did not exert influence on measure of inhibition  $F(1, 92) = .74$ ;  $p = .39$ ,  $\eta^2 = .008$ , or on the measure of mental set-shifting;  $F(1, 92) = .31$ ;  $p = .58$ ,  $\eta^2 = .003$ . In addition, the relationship between ADHD-symptom severity and performance on the two WM measures were influenced by the inclusion of VIQ. Because of the significant effect VIQ has on the Working Memory measures makes it somewhat problematic to include the variable as a covariate. It is possible that by controlling for this, much of the effect due to VWM will be eliminated while not removing proportional amount of general IQ-effect in NVWM. Rather, the full scale IQ measure was investigated. Full Scale IQ, which is a combination of verbal and nonverbal IQ, did not contribute to group differences;  $F(4, 89) = 1.82$ ;  $p = .132$ ;  $\eta^2 = .076$ .

Preliminary analysis of the Trucks-task shows that forty-six children (thirty-eight percent) did not succeed the pre-shift phase. Thirty-five children (twenty-nine percent) learnt the initial rule but did not successfully shift to the new rule in the post-shift phase. Forty children (33 percent) were successful in accomplishing the task.

### **In what way is ADHD related to EF in preschool?**

The first research question pertains to whether the symptom-groups will differ in their performance on tasks designed to tap a selection of EF's. To address this, the four EF measures were entered as dependent measures into a MANOVA with group membership as the independent factor.

For the full model, a statistical significant difference was found between the groups,  $F(8, 182) = 4.625$ ,  $p < .000$ ;  $\eta^2 = .17$ . This initial finding implies that there are significant differences between the included groups on the independent variables and the model is

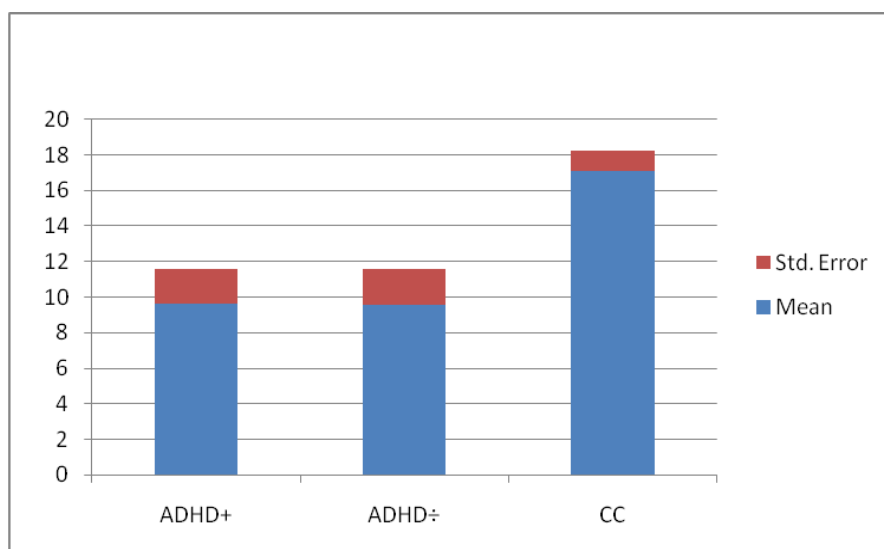
supported. According to Cohen's  $d$ , this is to be interpreted as a strong relation. However, in order to know which groups differ from each other, Post-Hoc analysis using Bonferroni corrections were executed.

For the measure of inhibition, a statistic significant differences was found between the groups,  $F(2, 93) = 8.73$ ;  $p < .000$ ;  $\eta^2 = .16$ . The Effect Size indicates a strong relationship. Post Hoc analysis using the Scheffe option, with Bonferroni correction to the alpha-level, revealed that the detected significant group differences was due to discrepancies in performance between ADHD+ and CC;  $p = .005$ , and between CC and ADHD-;  $p = .008$ . There was no group difference between ADHD- and ADHD+;  $p = .999$ . The means and SE are depicted in Figure. 2.1.

In regard to the VWM variable, a significant effect of group emerged:  $F(2, 93) = 4.65$ ;  $p = .012$ ;  $\eta^2 = .09$ . The strength of the relation lies between moderate to strong according to Connor's suggestions. Post Hoc analysis revealed that this was due to the difference between CC and ADHD+;  $p = .014$ . No difference of significance emerged between the ADHD- and CC group;  $p = .994$ , or between the ADHD+ and ADHD- group;  $p = .085$ . Means and SE is visually represented in table 2.2 for each group separately.

Figure 2. 1

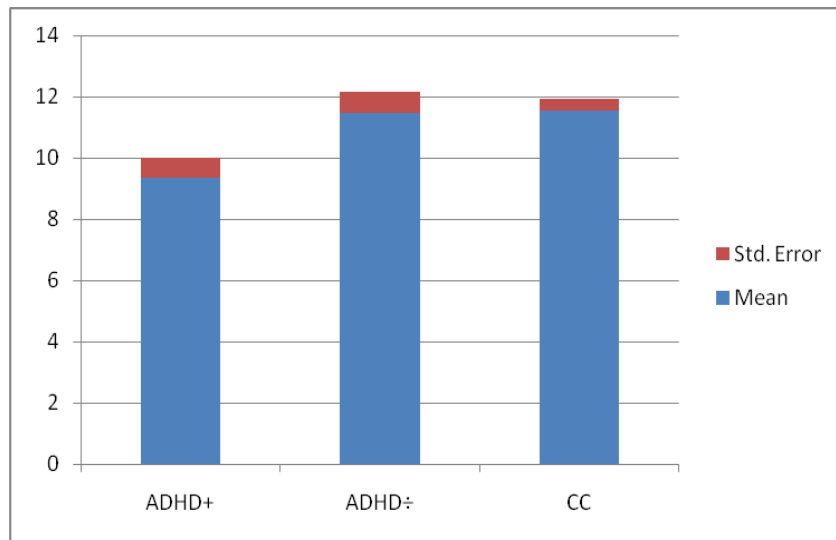
### Inhibition



*Each bar represents the Mean score and Standard Error for ADHD+, ADHD- and CC groups Statue-task is scored in such a manner that higher score indicates fewer errors made during task execution. The CC group significantly outperformed both ADHD-groups, as can be seen by a higher Mean score in the bar-graph.*

Figure 2.2

### Verbal Working Memory

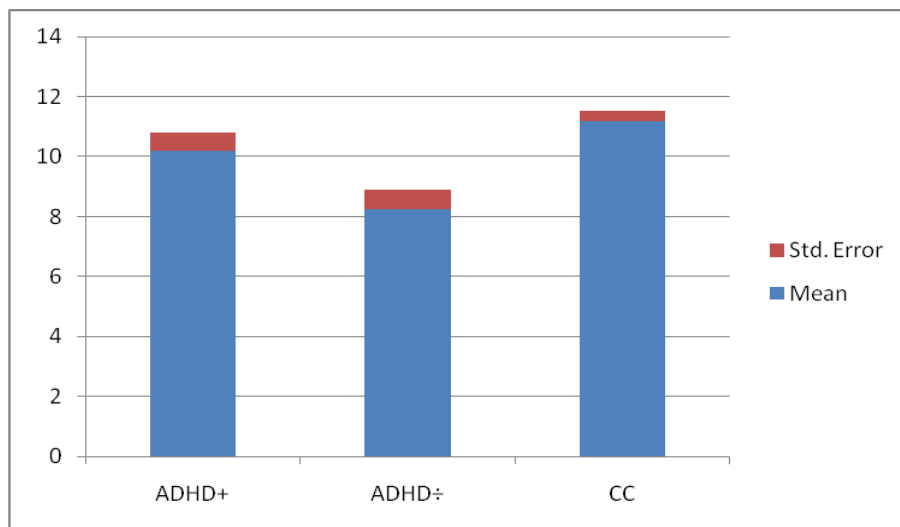


Bar-graphs representing the means and standard errors for the three groups. The ADHD+ differed significantly from the CC group. The ADHD- did not differ from neither the ADHD+ nor the CC-groups.

A statistical significant relationship was evident between the group-variable and NVWM:  $F(2, 93) = 7.94$ ;  $p = .001$ .  $\eta^2 = .15$ . According to Connor's suggestions, this is to be considered a strong relation. Post-Hoc analysis showed that this measure discriminated between the ADHD- and CC;  $p = .001$ . There was no significant difference between the ADHD- and ADHD+;  $p = .092$ , or between the ADHD+ and CC;  $p = .384$ . The means and SE for all groups are depicted in Figure 2.3.

Figure 2.3

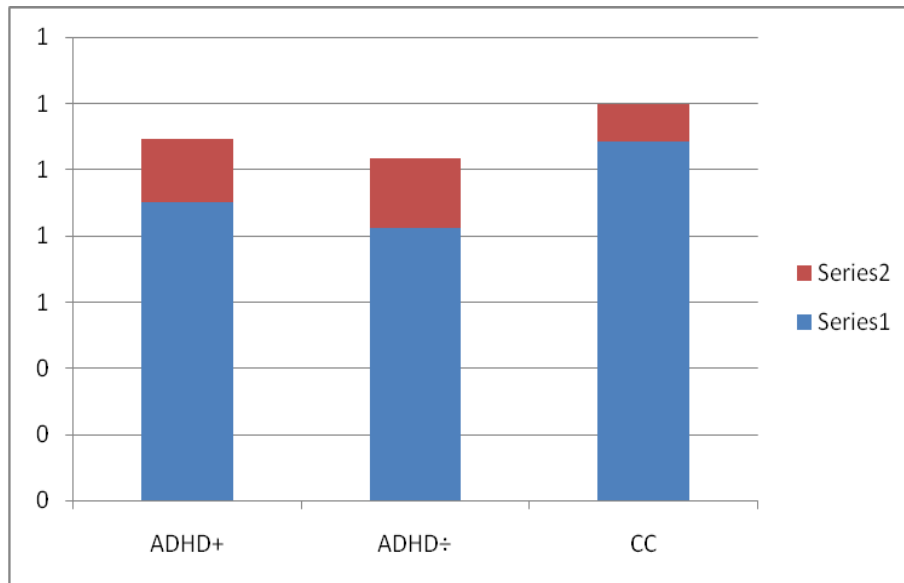
### NonVerbal Working Memory



The figure visually presents the results (means and Standard Errors) for the NVWM measure. The bars show that the ADHD- was significantly outperformed by the two other groups. No difference of significance was evident between ADHD+ and CC.

Figure 2.4

Mental Set-Shift: Total success score



The bars visually present the results from the Trucks-task for the three groups in Mean and Standard Error scores. The task is scored as either 0 for total failure, 1 equal accomplished pre-shift phase but a failure to shift to the new rule. 2 represent successful rule-shifting and is an indicator for cognitive flexibility. This task did not differentiate between groups.

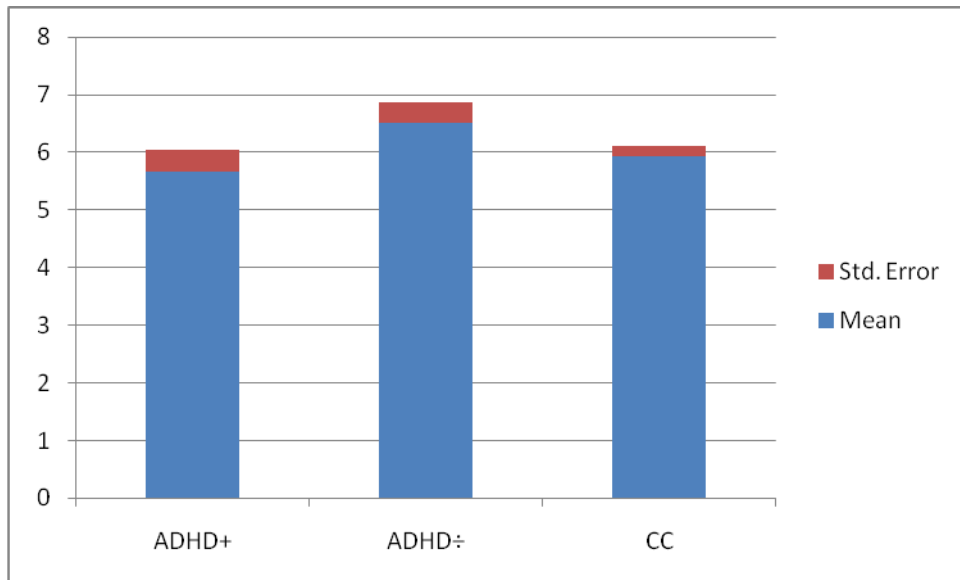
There was no significant difference between any of the groups on the measure of mental set-shifting when scored according to the number of rules passed:  $F(2, 93) = .779$ ;  $p = .46$ ;  $\eta^2 = .016$ . The Effect Size is small. The mean scores and Standard Errors are depicted in the bar-graphs in table 1.4 above this section.

The Truck-task also applies a second scoring-approach. Children are rated in regard to number of trials they need in order to fulfil the criteria for success in the post-shift phase. Scores can vary from four to eight. Success depends upon whether or not the child has chosen the correct truck either four times in a row or four correct picks during the last five trials. 38 children were able to successfully adapt to the new sorting rule in the post-shift phase and thus is included in the ANOVA. Twenty-six was identified as controls ( $M = 5.92$ ;  $SD = .935$ ). In addition, six children from the ADHD- ( $M = 6.50$ ;  $SD = .837$ ), and six children from the ADHD+ ( $M = 5.67$ ;  $SD = .816$ ) also managed to successfully shift to the new rule.

An ANOVA was conducted, using number of trials required to reach criterion as dependent variable and group membership as independent variable. Follow-up analysis was conducted using Scheffe and the Bonferroni correction to the alpha-level. There was

no significant differences between any of the groups in regard to number of trials required to successfully shift to a new mental set:  $F(2, 35) = 1.40$ ;  $p < .26$ ;  $\eta^2 = .07$ . Means and Standard Errors are depicted for each group in figure 2.5 below this section.

**Figure 2.5 Mental Set-Shift: Number of Trials to criterion**



*This figure visually presents the results for the children which successfully accomplished the post-shift phase in the Trucks-task. There was no significant difference between the groups in regard to how many trials needed in order to reach the criterion for success.*

### **Correlation between EFs in preschool**

The relationship between the dependent variables (Inhibition, VWM, NVWM and mental set-shift) was investigated by calculating Pearson Product-Moment correlation coefficients. A Bivariate correlation analysis was performed. A significant correlation was evident between inhibition and NVWM ( $r = .34$ ;  $p = .001$ ) and between inhibition and VWM ( $r = .264$ ;  $p = .009$ ). There was also a significant correlation between NVWM and VWM ( $r = .204$ ;  $p = .027$ ). No significant association was detectable for the relationship between inhibition and MSS ( $r = .005$ ;  $p = .96$ ), or for the MSS and VWM ( $r = .104$ ;  $p = .27$ ), or between MSS and NVWM ( $r = .082$ ;  $p = .37$ ). The correlation coefficients are outlined in the table 3.0.

Figure 3.0

Pearson Product-Moment Correlation Coefficients				
	Inhibition	VWM	NVWM	MSS
Inhibition	1.00			
VWM	<i>r = .264**</i> ( <i>p = .009</i> )	1.00		
NVWM	<i>r = .337**</i> ( <i>p = .001</i> )	<i>r = .204*</i> ( <i>p = .027</i> )	1.00	
MSS	<i>r = .005</i> ( <i>p = .961</i> )	<i>r = .104</i> ( <i>p = .270</i> )	<i>r = .082</i> ( <i>p = .372</i> )	1.00

\*Significant at  $p < 0.05$

\*\*Significant at  $p < 0.01$

*Pearson Product Moment Correlation Coefficients were calculated as to reflect the relationship between the four EF-components. The numbers typed in cursive indicates significant correlations.*

The relationship between the four EFs was further examined within each group separately. In addition to compare groups, this procedure also gives opportunity to investigate the relative fit for the model developed by Miyake and colleagues on a preschool sample. No significant correlations were evident for the ADHD÷, indicating that there is no interconnectedness between EFs at this symptom level. The Pearson Product-Moment Correlation Coefficients are depicted in the table 3.1 below.

Figure 3.1

ADHD÷ Pearson Product-Moment Correlation Coefficients				
	Inhibition	VWM	NVWM	MSS
Inhibition	1.00			
VWM	.224	1.00		
NVWM	.430	-.095	1.00	
MSS	.224	.141	.163	1.00

\*Significant at  $p < 0.05$

*Pearson Product Moment Correlation Coefficients were calculated as to reflect the relationship between the four EF-components in ADHD÷. None of the EFs came out a significantly correlated to each other, indicating that they rather represent a fragmented structure.*

When looking at the correlation matrix for the ADHD+, MSS showed a significantly correlation with the measure of VWM ( $r = .406$ ;  $p \leq .04$ ). Those children in the ADHD-group, least impaired in Verbal Working Memory skills, performed better on the mental set-shifting task. None of the other EF-components showed significant inter-correlations. The Pearson Product-Moment Correlation Coefficients is depicted in Figure 3.2 outlined below.

Figure 3.2

ADHD+: Pearson Product-Moment Correlation Coefficients				
	Inhibition	VWM	NVWM	MSS
Inhibition	1.00			
VWM	.243	1.00		
NVWM	.013	-.127	1.00	
MSS	.087	<b>.406*</b>	.243	1.00

\*Significant at  $p < 0.05$

Pearson Product Moment Correlation Coefficients, indicating the relation between the Four EFs in children with ADHD.

In the CC group, a significant correlation between NVWM and inhibition ( $r = .427$ ;  $p < .028$ ) and between NVWM and VWM ( $r = .385$ ;  $p = .001$ ) emerged. VWM and Inhibition skills increase concurrently to increased level of NVWM skills. The Pearson Product-Moment Correlation Coefficients is depicted in figure 3.3 outlined below.

Figure 3.3

CC: Pearson Product-Moment Correlation Coefficients				
	Inhibition	VWM	NVWM	MSS
Inhibition	1.00			
VWM	.279	1.00		
NVWM	<b>.427*</b>	<b>.385*</b>	1.00	
MSS	.069	-.074	.054	1.00

\*Significant at  $p < 0.05$

Pearson Product Moment Correlation Coefficients are outlined, indicating the amount of association between the four EFs in typically developing children. NVWM is significantly correlated to inhibition and VWM.



## Discussion

Much research attention has been devoted to identifying causal factors of the complex pathophysiology in ADHD. Currently, the evidence is mixed regarding the importance of an EF deficit in ADHD. In order to further illuminate the nature of the relationship between deficits in EF and the expression of ADHD in preschool, children with varying degrees of ADHD-symptoms were compared to controls on their respective performance on several neuropsychological tasks designed to measure four central EFs. The EFs under investigation were inhibition, nonverbal and verbal working memory and mental set-shifting. The inter-relations between these functions have also been investigated. In the sections below, the results will be reviewed and compared to previous empirical knowledge. Lastly, strengths and limitations of the present study will be outlined

### **The relation between EF and ADHD in preschool**

A significant difference between ADHD<sup>+</sup>, ADHD<sup>÷</sup>, and CC was evident on the measures of inhibition, VWM and NVWM. However, the relational pattern between these EFs and ADHD-symptoms differed.

Relative to children without ADHD-symptoms, children with ADHD symptoms, both above and below diagnostic threshold criteria, made significantly more movements, noises, and eye-blinks compared to the control group when measured by the Statue task. As mentioned elsewhere, this measure is designed to tap a child's ability to inhibit behavior inclinations during a limited time period, also when faced with interfering stimuli. This finding thus implies that inhibitory control is noticeably impaired in children with ADHD-symptoms in preschool. However, no significant difference emerged between the two ADHD symptom groups. Such findings indicate that difficulties with inhibitory control extend well beyond the clinical thresholds for ADHD.

The ADHD<sup>+</sup>, ADHD<sup>÷</sup> and CC-groups also differed significantly from each other on VWM. Here, a significant difference emerged between the CC group and the ADHD<sup>+</sup> group. This coincides with previous research findings. Researchers have also found ADHD to be accompanied by observable difficulties with the retention and reproduction of verbal

information extending beyond age appropriate variation (Martinussen et al., 2005; McInnes et al., 2002; Youngswirth et al., 2007). There was no significant difference in performance between the ADHD÷ and the two other groups in regard to VWM. This can be interpreted as reflecting a dimensional relationship, with increasing amount of ADHD-symptoms going together with lower achievements on VWM.

The lack of significant differences in inhibition and VWM between the ADHD+, and ADHD÷ groups was surprising. Research among adults with ADHD has found the subthreshold group to represent a less severe version of ADHD (Faraone et al., 2006). However, at preschool age, the two groups seem to be equally impaired.

In regard to the NVWM, only the ADHD÷ group displayed impairments. The CC and ADHD+ groups performed equally. The inverse relationship between ADHD-symptom severity and NVWM is somewhat difficult to explain. This result is contrary to findings of significantly impaired spatial working memory in ADHD-children (Martinussen et al., 2005). In addition, NVWM was not related to intellectual skills, gender or age. There might be characteristics in children of the ADHD÷ that have not been accounted for in this study that make these children more prone for such impairment. It is plausible that this group of children will be prone for a later onset ADHD, and thus represent one branch of ADHD that is characterized by a discrete set of symptoms and a distinct profile of associated difficulties. It would perhaps be interesting to further investigate this specific group in longitudinal follow-up studies

No differences were found between any of the three groups on the MSS measure when investigating number of rules successfully passed. As such, the present study was not successful in illuminating this particular branch of the field. It has been proposed that other mechanisms might be of interest when measuring rule-shifting tasks among children with ADHD. The necessity for future research on underlying mechanisms, validity and reliability of this particular measure will be further highlighted in the limitation-section towards the end of the paper.

### **Inhibition and VWM Deficits in ADHD: How to interpret the findings**

The current findings can only partly support the hypothesis of ADHD as growing out of a general underlying deficit in EF. If impairments to EF should adequately represent

causation, the study should be able to reveal significant deficits to all the EFs included. In addition, the expected Effect Sizes should be stronger. Especially since the ADHD-group is highly symptomatic, the final results should reveal substantial differences. However, neither the MSS-measure, nor the NVWM-measure seems to represent associated impairments in ADHD at this age. However, both Inhibition and VWM seem to be weakened in preschool children with ADHD-symptoms.

The finding that inhibition seems to be a central feature in ADHD is in line with both theoretical and empirical work. Barkley (1997) claimed in his theory that ADHD mostly grows out of a malfunctioning inhibition mechanism. According to him, the ability to inhibit behavior is necessary for setting the stage for other EFs to fully operate. As such, a deficient inhibition mechanism would be the first one to be identified in ADHD-children. Following this, secondary impairments to other EFs will emerge. Such a causal chain-reaction might explain why there are no differences between the groups in regard to the MSS and NVWM at this point. Research on slightly older children and adolescents has found broader impairments in EF, revealing what might be interpreted as a developmental sequel of this initial inhibitory deficiency (Nigg et al., 2004).

The primacy of this deficit is further supported by empirical studies on clinically referred preschool-aged children. Even after controlling for important third factors, such as lower-order cognitive processes and IQ, inhibition still remains significantly associated to ADHD (Byrne et al, 1998; Mariani & Barkley, 1997; Ozonoff & Jensen, 1999; Perner et al., 2002; Sonuga-Barke et al., 2002; Quai, 1997). As for the other EFs, results are often of mixed nature. As mentioned in the introduction, researchers have been able to reveal significant impairments to multiple EFs in this group (Sonuga-Barke et al., 2003) On the other hand, some have failed to find any relations at all (Jonsdottir et al., 2006; Marks et al., 2005). However, following Barkley's arguments, differences between typically developing children and ADHD-children on the other EFs will be detectable as the impaired inhibition mechanism no longer exerts the necessary support needed for proper functioning.

## **The possibility for multiple causal pathways in ADHD**

There are some doubts regarding the primacy of EF as being solely responsible for causing all cases of ADHD (Castellanos et al., 2006). A meta-analysis was conducted in order to investigate the validity of the EF-model as the primary cause of ADHD (Wilcutt et al., 2005). Important differences between individuals with and without ADHD were clearly evident in regards to measures of planning, inhibition, verbal and nonverbal working memory, as well as on measures of vigilance. However, the differences between groups were judged as small and inconsistent. The authors ended up concluding that deficits to EF were not sufficient in accounting for all the ADHD-cases. As such, a model embracing multiple causal factors could probably aid in explaining more of the diversity in the ADHD population (Wilcutt et al., 2005a).

A shift in research attention has been made from focusing on a single cause towards exploring the possibility for multiple-deficit models. Sonuga-Barke, Dalen, Daley & Remington (2003) suggested that a dual pathway model best explains the development of ADHD. Given the diversity in symptom constellations across individuals, they found it to be rather unlikely that only one single causal mechanism could account for all cases. They further suggested that a motivational style referred to as *delay aversion* also represents one central causal pathway in addition to the one of an executive dysfunction. The dual pathway theory has further been fuelled by research pointing to important differences in regard to EF impairments across ADHD sub-types (Brocki et al., 2010; Martel, Nikolas & Nigg, 2007). Deficits in EF have been linked to inattention, and Delay Aversion has been independently associated with the hyperactive/impulsive sub-domain (Thorell, 2007). The inattentive group is not included in the present study due to few subjects identified with this symptom constellation. Inclusion of such a group in future studies could thus perhaps nuance the results even further.

Other attempts to account for the heterogeneity seen in ADHD usually state that the disorder is a result of multiple deficits to different neural substrates that interact or add on to each other. As mentioned in the introduction, the Cognitive Effort Model states that ADHD stems from underlying disturbances in several neural networks that host so called “energetics”, such as activation, arousal and effort (Sergeant, 2003). The model operates on three hierarchical levels. On the top level, there is an overarching executive system, associated with such functions as planning, monitoring and error detection/correction. The

second level consists of the already mentioned energetics (e. g., activation, arousal and effort). The lowest level consists of so called computational mechanisms, such as response output. The model does not point to a single cause leading to ADHD. Further, it states that different disruptive disorders might all share deficiencies to EFs, but these deficiencies might be unequally related to either the energetic, or more basic, lower cognitive processes. The dysfunctional inhibition mechanism often found in ADHD is considered to be due to a dysfunction to the energetic component. More precisely, what is causing inhibitory deficiencies in ADHD is thought to be due to a disrupted reward mechanisms (Oosterlaan & Sergeant, 1998).

The findings in the present article further support this point of view. Important unknown variables, not accounted for in the present study, might help shed more light on the investigation of causal and maintaining mechanisms in ADHD in preschool and childhood.

Following the reflection made above, it might be interesting to further investigate whether there are commonalities between those ADHD-children with impaired EF in contrast to the children diagnosed with ADHD with no such cognitive deficit. Previous findings indicate that children identified with both ADHD and executive dysfunction is inclined to experience greater academic difficulties than ADHD children without such impairments (Biederman, Monuteaux, & Doyle, 2004).

### **ADHD: Continuum vs. category**

This study partly supports the idea of ADHD as representing extreme points on behavior dimensions. ADHD children show clear deficit to both VWM and inhibition when compared to typically developing children. However, the ADHD+ group did not differ significantly from the ADHD÷ group. That is, the two groups are differently affected by ADHD symptoms, but not significantly differently impaired in VWM and inhibition. However, the CC was not significantly different from the ADHD÷ on VWM skills as well, implying that this group performs somewhere in between two endpoints. Previous research on twins and siblings has concluded that traits associated with ADHD are genetically present in the entire population (Levy, Hay, McStephen, Wood, & Waldman, 1997). What is identified as ADHD is by this account, best seen as extreme endpoints on a continuum

rather than a categorical state with distinct causes. Neuropsychological studies on the relationship between ADHD and EF have also found the performance of ADHD-children to best represent the continuum approach to the disorder (Sonuga-Barke et al., 2003). The same picture has also been revealed in an adult sample, also when including an ADHD subthreshold group (Faraone et al., 2006). Perhaps by utilizing a more nuanced behavior rating system instead of only three groups, like in the present study, a more representative picture of a dimensional relation might emerge.

However, the necessity of the categorical approach used in diagnostic manuals is substantial. Especially in regard to the use of stimulant medication in ADHD, the use of highly restrictive diagnostic criteria is reasonable. On the other hand, it is important to recognize that associated difficulties may be significantly present in children not reaching the full diagnosis as well. This means that impairments extend beyond clinical cut-offs for ADHD in preschool. Because of uncertainty due to the developmental trajectories of ADHD in preschool, it is possible that the below-threshold group might reach the full diagnosis later on. The importance of investigating children with varying degree of symptom severity may shed more light on the nature and development of ADHD.

### **The organization of EF in preschool: A theoretical overview**

Pearson Product-Moment Correlation Coefficients was calculated using Bivariate correlation analysis, in order to investigate the relationships and the amount of shared variance between EF-components in preschool. The rationale for this is to investigate whether EF is organized in the same manner in preschool as it is suggested to be in older people. The theoretical model which this study is based on, considers EF to consist of several clearly distinct cognitive functions that are moderately correlated to each other (Miyake et al., 2000). However, this model was derived through studies on an adult population. The question investigated in the current study concerns whether this organizational pattern is the same in preschool, or whether it rather represents a fully mature EF-structure.

When investigating the group of typically developing children, some of the EF-components were in fact found to be moderately correlated to each other. Only MSS did not correlate with any of the other EFs. However, the inter-relational pattern was not entirely of such nature as described in the model by Miyake and colleagues (2000). NVWM was significantly associated with both inhibition and VWM. The relation between

the two WM components is not surprising. They both subsume the same functional domain (e. g., the central executive) (Baddeley, 2004). The different holding and manipulating of either verbal or visual/spatial material might make up for some of the distinctiveness. Inhibition and NVWM also seem to partly rely on each other. It might be that the ability to repress automatic behavior, or keep intruding stimuli out of mind, is crucial in order to successfully accomplish this NVWM-task. It might also be the other way around, that the ability to keep representations of relative body posture readily in mind over time, and that continual monitoring of this is necessary in order to succeed on the statue task. The inter-relation between WM and inhibition has been addressed in previous work. Nigg (2000) claimed that inhibitory control is necessary in order to protect the workings of WM from intruding factors. Following Barkley's approach to EF, a relationship between inhibition and WM is expected, given the central role of inhibition in setting the stage for other EFs to unfold (Barkley, 1997). Wiebe, Espy & Charak (2008) found inhibition and working memory tasks to be measuring the same underlying cognitive ability in typically developing preschool-aged children. As such, an observed relationship might be due to a third variable not accounted for. Anyway, several dissociable EF-components were clearly evident in the present study, and thus question the validity of the perspective of EF as a unitary construct in preschool, as stated in other research papers (Sonuga-Barke et al., 2003; Wiebe, Espy & Charak, 2008). Instead, it might look like the different EFs are distinctive processes that do share a limited amount of common variance. How this inter-relational pattern evolves during childhood and into adulthood should be further investigated in relation to the fit to an integrative framework.

One final comment regarding the inter-relational patterns is necessary. Correlations such as those outlined in the present study, are basically correlations between the respective tasks that are supposedly measuring identifiable underlying EFs. However, this is not necessarily the intended EF in question. Other processes might influence the observed relations and effects. Such variables give some uncertainty due to which processes that really account for the observed relation. One explanation for the discrepancy in test results across studies might be due to the use of different tasks with varying degree of discriminative utility. The use of sensitive tasks that isolate the specific EF of interest is needed in future research.

The two symptom-groups were also investigated in regard to the inter-relation between EFs in order to see if these relations are affected by psychopathology. Surprisingly, MSS showed a significant correlation with VWM in the pure ADHD-group. It might be that verbal ability varies in severity in the ADHD-group, and that performance on tasks such as the Trucks-task requires a certain level of lingual sophistication. None of the EFs were correlated when investigating the fit for the model for the ADHD÷ independently. It would be of interest to see if the lack of relations in these groups represents some sort of developmental delay or if it is the result of an underlying third variable that break up the interconnected orchestra seen in typically developing children. A longitudinal design could be useful in order to follow the developmental trajectories of the different EFs in relation to each other as the children grow older. A cohort study, comparing groups of children at different ages, is less time consuming and expensive, and could also prove to be valuable in future studies investigating this subject in particular.

Overall, the trend towards the conceptualization of EF in accordance with Miyakes model is clearly present. The fact that none of the EFs covaried with the MSS measure could be due to the task used and thus should be interpreted with caution. The other three measures did in fact show acceptable inter relations. In addition, the results do not fit previous research revealing a unitary EF-construct in childhood. However, the fully integrative structure found in older samples might be the result of cognitive maturation. If this is true, it anticipated that a concordant EF-structure in the present sample will be detected as the children reach into the latter stage of childhood.

### **Strengths of the present study**

*Subjects, clinical evaluation, and multiple sources:* The use of strict DSM-IV-TR based diagnostic evaluations represents an advantage when seeking to discriminate between clinical and non-clinical groups. When applying such stringent group inclusion-criteria, the likelihood of revealing a potential difference, between the clinical group and children without ADHD-symptoms, is maximized. Further, the utilization of a multi-method procedure in assessing the child's psychopathological status, adds confidence to the use of diagnostic tests. By collecting information through different sources, such as parents, teachers, observations in the test-setting, and from the PAPA-interview, the



resulting conclusion will not be subjected to potential evaluation bias that might surface by using single sources of information.

*Task-related benefits:* It has been argued that associated impairments to ADHD represent developmental delays (Barkley, 1997). In order to capture such a delay, a given task must be easy enough such that normal children will succeed, but sufficiently complex in order to discriminate between what is age-typical performance and the underdeveloped performance level of ADHD-children. NVWM and VWM-tasks, the intelligence indexes, and the inhibition measure, belongs to large test-batteries. These have previously been thoroughly investigated for psychometric properties, such as reliability and validity, lending them a high level of credibility. In addition, these tasks are based upon a large normative sample, and are considered to be age-adequate (Korkman, Kirk & Kemp, 1998; Roid, 2003). The tasks were also successful in discriminating between the groups (e. g., ADHD+, ADHD÷ and CC) in the present study. However, less confidence is embedded in the Trucks-task designed to tap MSS. This task should be investigated more thoroughly in regard to psychometric characteristics, such as validity, age-adequacy and sensitivity.

### **Limitations of the present study**

*Methodical approach and task related-issues:* First, only one EF index was used to represent the EFs under investigation. The use of several different tasks measuring the same EF has been implied as preferable. Such an approach gives the opportunity to draw out what is the common or shared variance. This proportion of shared variance is thought to be a more precise index for the EF of interest. In this manner, the influence of lower cognitive processes that is not due to the EF of interest will be separated out in further analysis. This is the issue of *task impurity*, a central topic when developing neuropsychological tasks from the bottom up. However, this procedure was not applied in the present study. As such, it could be that the selected tasks also are susceptible for the impact of other, third factors. Despite this uncertainty, all tasks (except the Trucks) are drawn from well validated, reliable test batteries, lending them an acceptable degree of confidence. The NEPSY-battery has been the subject of much research focus in regard to validity and reliability. There has been some concern due to a lack of sensitivity and predictive power of the different subtests. The lack of sensitivity has been addressed for the statue task in particular (Youngswirth et al., 2007). To counter this, it was suggested that the task should be applied in conjunction with other measures. As mentioned, there

was only one task addressing each EF, implying that other processes might not be properly accounted for.

*Issues related to the Trucks-Task:* It is interesting to see that the trucks-task did not discriminate between any of the groups. In addition, it did not share any variance with any of the other measures. Given the finding of impairments in inhibition and VWM in ADHD, it may look like the task is successful in separating out the influence of the two processes. As such, it may well indicate that MSS belongs to a separate cognitive domain in preschool which is relatively intact in ADHD, despite the presence of other cognitive difficulties found in this group.

Another explanation for the results derived from the Trucks-task, concerns features of the task, and the applied scoring-procedures. It is a possibility that this task in reality measures other processes than the MSS function it is designed to tap. In addition, the influence of other EFs as well as non-executive processes might mask the true ability of interest (Burgess, 1997; Phillips, 1997). More research should be aimed at investigating the exact underlying processes at work that contribute to successful performance on this task. One approach could be to compare this task with others, more well-established MSS-tasks in both control and pathological samples in order to see if there is concordance between them.

A lack of sensitivity, leading to a failure in discriminating between groups also is a possible explanation for the inability to find group differences on this task. However, MSS might be fairly immature at this developmental stage. Building upon the proposition made by Barkley (1997) of a developmental delay in ADHD, a difference in performance between groups might become detectable as the normative group develops a more complex cognitive flexibility. Discrepancy in task performance will thus be evident as the ADHD-children fail to follow these developmental trends. As such, the results in the present study are not necessarily contradictory to previous results which claim to find MSS to be impaired in ADHD. However, the present results still question the involvement of a deficient MSS mechanism as a precursor to ADHD. Others have also have failed to find a weakness on tasks designed to measure this EF (Ozonoff & Jensen, 1991; Rommelse et al., 2007). However, given the finding of significant group differences in regard to inhibition, it might be that such a deficit will lead to problems with cognitive flexibility at a later stage, given the suggested involvement of inhibitory control on such task performance

(Simpson & Riggs, 2005). At this stage in development, however, no association was found for inhibition and MSS in the present study which can supports this reflection.

*Diagnostic evaluations in preschool:* Second, the application of diagnostic labels in preschool is a rather complicated and problematic procedure. In Norway, it is common that the ADHD-diagnosis is obtained between six and twelve years of age. In addition, it takes approximately four years from when parents apply for clinical help until the diagnostic evaluation is accomplished (SINTEF-Helse, 2004). The instability of the behaviour traits during preschool and childhood makes a diagnostic decision somewhat ambitious. Follow up examination of the children is highlighted. However, predictive value of the diagnosis has been detected already in preschool samples (Lahey et al., 2005).

*Limitations due to lack of ADHD sub-type comparisons:* The inability to classify ADHD into the clinically distinct sub-groups presented in the DSM-IV-TR is also a shortcoming. Due to small sample sizes, it was impossible to sub-divide the clinical ADHD group in this study. Instead, all individual cases meeting an ADHD-diagnosis were included into the same ADHD group. Because surprisingly few individuals met the inattentive type diagnosis in the initial screening, these individuals were all excluded from the analysis. The resulting ADHD-group thus consists of children with predominantly hyperactive/impulsive traits and the combined type. It would be of interest to investigate the sub-groups separately in order to see if the EF profiles differ according to more specific symptom constellations. Previous research has indicated that impairments to EF is related to the inattentive feature of ADHD, and not the hyperactive/impulsive-type (Chabildas, Pennington, & Willcutt, 2001; Nigg, et al., 2005; Willcutt et al., 2005b; Whålstedt et al., 2008).

*Study procedures:* A third issue of concern is the fact that all measures were obtained during one single day. Measures of the children's performance during the day might be precluded by other, non controllable factors. Children this young may for example be especially prone for fatigue. In addition, ADHD children have been found to be particularly difficult to engage in task situations, perhaps making the obtainment of data even more challenging (DuPaul et al., 2001). In order to counter this issue, the tests were administered in a quasi-randomized order. Some of the neuropsychological tasks were rated as more essential and central in order to obtain the necessary information in regard to ADHD. Much effort was made in order to get the child to complete these tasks. Test-

breaks were allowed when thought necessary, such as if the child became highly restless, distracted or tired. Also, all tasks of short duration, making it easier for the child to keep track. Such optimal test conditions are highly valued. However, more effort should be made in order to randomize the administration of the tasks.

*Lack of control for comorbidity:* The present study did not control for typically comorbide conditions. There is always a possibility that the obtained results may partly be due to such co existing disorders and not ADHD per se. However, previous research has found EF dysfunction to be specific to ADHD when investigating the contribution of coexisting disorders such as ODD, CD, Tourettes, and Reading disorders (Harris et al., 1995; Oosterlaan, Scheres & Sergeant, 2004; Thorell & Whålstedt, 2006).

*Age-related issues:* The age- span in the included samples range from 38 to 45 months. This is a rather important age-difference. Similarity in age is thought to be necessary when conducting studies on young children, given the rapid maturation of cognitive skills and other processes during the preschool years (Carlson, 2005). Comparing children separated by a few months can be a source of bias. Thus, the in-group age should be quite homogenous in order to perfectly represent the functional presence of EF at the given stage. However, age did not yield a significant effect in the present study.

*Alternative Statistical procedures:* There are other ways to handle the data in the present study. The application of a Logistic Regression analysis can investigate which variables best predicts performance on the different EF-measures. However, the MANOVA is considered to be a rather stringent and sophisticated way to handle data. The other analysis would probably yield additive information already revealed in the MANOVA. Lastly, the Trucks- task was handled in SPSS according to a total success scale, and a score representing total trials required reaching criterion for success in the post-shift phase. The total success scoring procedure was to divide performance into either a total failure (0), failure to adapt to new rule, (1) or successful accomplishment of the task (2). This task can also be scored according to a pass/fail-approach (Hughes & Ensor, 2002). An additional way to score these data would be to calculate the number of perseverative errors. The true difference between the groups may lie in the ability to inhibit a previous reinforced response patterns.

## Future research

This study demonstrates that impairments in Inhibition and VWM are evident in preschool samples with ADHD. Further research is needed in order to investigate how this relationship evolves as a function of age, and whether such deficits will affect the child in social and academic adjustments.

Longitudinal designs are also necessary for establishing whether there is predictive validity to the ADHD diagnosis given at this age. Finding early predictors for later onset ADHD might have important clinical value. Research on this subject has already found early predictions to stand correct (Harvey et al., 2009; Lahey et al., 2006), but more research is needed as the diagnostic evaluation is a serious and complex matter. As for the validity of the EFs in predicting ADHD, longitudinal studies have been able to reveal that poor inhibitory control in preschool predict later hyperactivity and inattention (Berlin, Bohlin & Rydell, 2003). Further, it would be interesting to use a longitudinal design in order to investigate the children in the ADHD group identified *with* executive dysfunctions in particular. Perhaps there are certain traits common amongst children in this group that distinguish them from other children with ADHD, but with no impairments to EF. Such findings may provide support for the hypothesis that dysfunctions in EF might represent one out of several potential trajectories leading to ADHD, which can be identified in preschool. A similar approach could be to investigate the children with dysfunction to EF in the ADHD- in order to see whether this group will be prone for later onset ADHD or other psychopathologies. This is especially interesting because of the findings that these children did not significantly differ from the ADHD+ group in regard to both Inhibition and VWM. In addition, this particular group was accompanied by a significant deficit to NVWM, indicating that there are features to this group that warrant further illumination. The ADHD-study, from which these data belongs, applies such a longitudinal approach. Participating children will receive a new invitation to a follow-up study at the age of seven. Perhaps this follow-up study will shed further light on some of the questions that arise from the present findings in children in preschool.

Future research may also benefit from distinguishing between the different clinical sub-types identified in the ADHD-population. Much research up to date has been able to demonstrate basic differences between these groups (Applegate et al., 1997; Martel, Nikolas & Nigg, 2007). Identification of diverse clinical symptom constellations,

associated impairments, and age of onset across the sub-groups indicates that there might be different precursors at work that should be further investigated (Klorman et al., 1999).

The advantage of utilizing multiple measures on the same underlying EF construct has been mentioned elsewhere in this text. Following the development of a multitude of new experimental tasks, it is reasonable to question what underlying processes are activated and thus measured using these on preschool-aged children. The combination of tasks and the following extraction of the common variance that represents the latent variable (The “pure” EF index) might help elucidate the nature of EF in preschool children by separating out the effect of other active processes that are at work in a given task.

### Concluding remarks

Still, much is uncertain in regard to the causal precursors that set an individual at risk for developing ADHD. Eventually, with the development of a sufficiently broad body of age-sensitive neuropsychological tasks, typical and atypical neuropsychological development in preschool can be more thoroughly investigated. Early identification of atypical development increases the ability to develop more effective intervention procedures which can counter the potential negative sequels associated with the disorder. The construction of training programs for specifically increasing EF-skills in preschool and elementary school might be valuable, both in a normal developing population, as well as in groups identified with cognitive deficits. Also, additional knowledge about the emergence and normative developmental trajectories of EFs during preschool can contribute to improvements of scholastic programs in preschool and primary school.

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## APPENDIX

Instructions to the TRUCKS REVERSAL LEARNING TASK (in Norwegian).

Undersøker evne til fleksibilitet (set shift), det vil si barnet skal lære en regel først, og deretter bytte til motsatt regel)

### **Del 1. Innlæringsrunde:**

To sett kort, gule og grønne, med bilder av to biler på hver. Gule kort brukes i første runde; **innlæringsrunden**. Kortene er nummerert 1-4 og vises i nummerert rekkefølge, 12 ganger til sammen. Første kort er prøvekort og valgt bil er alltid rett. Vis deretter kort 2-3-4-1-2-3-4-1-2-3-4-1; jfr. scoringskjemaet. Kortene er merket med en rød og en blå fargeprikk på baksiden. Fargen som tilsvarer den bilen barnet peker på første gang, indikerer regelen for hva som er riktig for resten av testen. Det vil si: peker barnet på bil med blå prikk, er denne alltid den ”riktige” og videre valg av bil med blå prikk på baksiden belønnes.

Vis først gult kort nr. 1 legg dette ned på bordet rett foran barnet. La barnet se på lastebilene i 3 sekunder.

*- Nå skal vi leke en lek og du kan vinne mange .....* (vis frem rød eske med.....)

***Her er noen gule kort med bilder av biler. På hvert kort får du .....for den ene bilen, men ikke for den andre. Du må finne ut hvilken bil som du vil få ..... for.***

Barnet velger alltid rett på første bildet, så si når barnet har gjettet:

*- Bra valg!! Prøv å huske den der!* Dette kan sies EN gang. (Legg en ..... på det valgte kortet). *Nå la oss ta et kort til!*

Dette første kortet er en prøveomgang og er alltid korrekt. Notér fargen på prikken bak lastebilen (RØD/BLÅ). Hvis barnet velger rød, så er rødt valg alltid korrekt, hvis blå, så er blå

alltid korrekt. Prinsippet i denne første fasen er at barnet skal lære seg de individuelle lastebilene. Legg belønningen oppå bildet av bilen og la så barnet ta belønningen.

Hvis barnet velger feil bilde, si hver gang:

***Å, det var ikke bilen med premien, men det gjør ikke noe, la oss prøve et annet kort!***

Scoring:

Så snart barnet scorer riktig på 4 kort etter hverandre etter gul strek (dvs. fra og med testrunde 5) så gå videre til å reversere oppgaven.

Fortsett å presentere kort inntil barnet oppnår fire rette etter hverandre eller inntil 12 omganger (etter prøvekortet). Noter om det var en vinner eller ikke.

Scoringsregler:

Score for innlæringsoppgaven = 12 - antall feil

Antall trials til kriterium: (dvs. min 8 forsøk): =

Klarte ikke første runde = ja / nei

## **Del 2. Testrunde etter regelendring (set-shift) (OBS! ALLE RUNDER TAS)**

Grønne kort, nummerert 1-4. I denne runden gjelder motsatt regel for barnet og valg av bil som er rett er merket med den samme fargen som før for å gjøre det enkelt for testleder. Merk altså: Kortene er laget slik at det er den samme fargeprikken som under innlæringen er rett. Presenter kortene i nummerert rekkefølge, 8 ggr til sammen (1-2-3-4-1-2-3-4).

***Nå er det de andre bilene sin tur til å vinne. Se nå har vi grønne kort og denne gangen er det de andre bilene som kan gi deg ..... La oss se hvor mange du kan vinne nå?***

Hvis valg av riktig bilde: - ***Kjempebra! Prøv å huske den der! Dette kan sies EN gang. Nå la oss ta et kort til.***

Ved valg av feil kort si hver gang: - ***Å, det var ikke vinner bilen, husk at de har skiftet nå. La oss prøve et annet kort.***