Investigating executive functions as a target for psychological interventions in ADHD:

Exemplified through the use of Goal Management Training

Daniel André Jensen

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Scientific environment

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Abstract in English

Background

Attention-deficit/hyperactivity disorder (ADHD) is a prevalent, and often life long, disorder which may lead to impairments in many domains of life. Those affected often experience negative outcomes with regards to self-image, school achievement, employment, family- and intimate relationships, peer acceptance, as well as their physical and mental health. Current treatment, which is most often based on stimulant medications, can alleviate many of the symptoms and difficulties associated with ADHD. However, there is still a great need for alternative or additional treatment approaches to help those who are unable to use these medications, individuals who decide not to use pharmacological treatments, and for those persons who have inadequate response to pharmacotherapy. Furthermore, ADHD in both children, adolescents and adults is associated with a wide range of frequently occurring comorbidities. These include both emotional disturbances such as major depressive disorder and anxiety disorders, as well as disorders related to behaviour and dependence such as oppositional defiant disorder (ODD) and substance use disorders.

As such, the main aim of this thesis was to 1) investigate whether Goal Management Training (GMT) could potentially be a useful supplement to existing treatments for ADHD and 2) study the relationship between executive functions (EFs) and difficulties in emotional regulation.

Methods

In Paper I we investigated the relationship between one aspect of executive functioning, namely working memory (WM), and emotional lability in a sample of children with ADHD and a sample of typically developing children. To do so, we applied parent-report as well as neuropsychological measures. In Paper II we investigated the effects of an intervention, GMT, aimed at strengthening EFs, in a sample of adults with ADHD. We included neuropsychological tests as well as self-report measures of cognitive-, everyday- and emotional functioning. Finally, in Paper

III, we used the revised Attention Network Test (ANT-R) to investigate a potential mechanism which may underlie the changes found in Paper II.

Results

In Paper I, we found an inverse relationship between parent reported difficulties with controlling emotional expressions and measures of both verbal and spatial WM. That is, a higher WM capacity was associated with lower levels of parent reported emotional lability. However, only the complex measure of verbal working memory remained significant when controlling for symptoms of ADHD and ODD. In Paper II, we found improvements on several performance-based measures of EFs following GMT. The clearest improvements were found on measures of inhibitory control. The participating adults with ADHD also reported improvements on self-report measures of core symptoms of ADHD, everyday cognitive- and executive functioning, productivity and aspects of emotion regulation including reductions in emotional impulsivity and improved access to emotion regulation strategies. In Paper III we found improvements in an attentional network, namely the executive control network, following completion of GMT.

Conclusions

The current findings show support for GMT as a potentially useful intervention for adults with ADHD and indicate that beneficial effects may be related to a strengthening of inhibitory control, possibly as a result of improved functioning in the executive control network. Furthermore, results indicate that results generalize to other important aspects of everyday life. Findings from Papers I and II also indicate that further investigations of the relationship between aspects of executive functioning and emotion regulation may be beneficial for individuals affected by ADHD.

Sammendrag

Bakgrunn

Attention-deficit/hyperactivity disorder (ADHD) er en hyppig forekommende, og ofte livslang, tilstand som kan føre til vansker på mange områder. De som er rammet vil ofte oppleve negative utfall knyttet til selvbilde, utdanning, deltakelse i yrkeslivet, familie og nære relasjoner, sosial aksept, så vel som fysisk og psykisk helse. Nåværende behandling er typisk basert på behandling med sentralstimulerende legemidler som kan redusere mange av symptomene og vanskene forbundet med ADHD. Det finnes imidlertid fremdeles et stort behov for alternative, eller supplerende, behandlingsformer for de som ikke kan eller ikke ønsker å benytte slike medisiner, og for de som opplever en begrenset effekt av medikamentell behandling. ADHD hos barn, ungdom og voksne er videre forbundet med en lang rekke hyppig forekommende komorbiditeter. Disse inkluderer både emosjonelle forstyrrelser som depressive- og angstlidelser, så vel som tilstander knyttet til atferd og avhengighet slik som opposisjonell atferdslidelse (ODD) og tilstander som skyldes bruk av psykoaktive stoffer.

Målsetningene for denne avhandling var derfor å 1) undersøke hvorvidt Goal Management Training (GMT) kunne være et potensielt nyttig supplement til eksisterende behandling for ADHD og 2) undersøke forholdet mellom eksekutive funksjoner (EFs) og vansker med emosjonsregulering.

Metode

I Artikkel I undersøkte vi forholdet mellom ett aspekt av EF, nemlig arbeidsminne (WM), og emosjonell labilitet i et utvalg av barn med ADHD og et utvalg av barn med typisk utvikling. For å gjøre dette benyttet vi både foreldre-rapportering og nevropsykologiske mål. I Artikkel II undersøkte vi effekten av en intervensjon, GMT, som har som mål å styrke eksekutiv fungering, i et utvalg voksne med ADHD. Vi inkluderte nevropsykologiske tester så vel som selv-rapport knyttet til kognitiv-, hverdagslig-, og emosjonell fungering. I Artikkel III benyttet vi den reviderte

Attention Network Test (ANT-R) for å undersøke en mulig mekanisme som kan ligge til grunn for endringene vi fant i Artikkel II.

Resultater

I Artikkel I fant vi et omvendt forhold mellom foreldrerapporterte vansker med å kontrollere emosjonelle uttrykk og mål på både verbal- og spatial WM. Det vil si at høyere WM-kapasitet var forbundet med lavere nivåer av foreldrerapportert emosjonell labilitet. Det var imidlertid bare det komplekse målet på verbal WM som forble signifikant når vi kontrollerte for symptomer på ADHD og ODD. I Artikkel II fant vi forbedringer på flere utføringsmål knyttet til EF etter at deltakere hadde fullført GMT. De tydeligste forbedringene ble funnet på mål av inhibitorisk kontroll. Deltakerne rapporterte også om reduksjon i kjernesymptomer på ADHD, og forbedret kognitiv- og eksekutiv fungering i hverdagen, samt om en reduksjon i emosjonell impulsivitet og forbedret tilgang til emosjonsreguleringsstrategier. I Artikkel III fant vi forbedringer i et oppmerksomhetsnettverk knyttet til eksekutiv kontroll etter fullført deltakelse i GMT.

Konklusjon

De rapporterte funnene støtter at GMT kan være en mulig nyttig intervensjon for voksne med ADHD og indikerer at positive effekter kan være knyttet til økt inhibitorisk kontroll, potensielt som følge av bedret fungering i oppmerksomhetsnettverket knyttet til eksekutiv kontroll. Videre indikerer resultatene at effekter også generaliseres til andre viktige aspekter ved fungering i hverdagen. Funn fra Artikkel I og II indikerer også at videre undersøkelser av forholdet mellom aspekter av eksekutiv fungering og emosjonell regulering kan være til nytte for personer med ADHD.

Abbreviations

ACC	Anterior cingulate cortex
ADHD	Attention-deficit/hyperactivity disorder
ANT-R	Revised version of the Attention network test
BRIEF	Behavior Rating Inventory of Executive Function
BRIEF-A	Behavior Rating Inventory of Executive Function - adult version
DSM	Diagnostic and statistical manual of mental disorders
EF	Executive function
GMT	Goal management training
ODD	Oppositional defiant disorder
WM	Working memory

List of Publications

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1. Introduction

1.1 Attention-Deficit/Hyperactivity Disorder

Attention-deficit/hyperactivity disorder (ADHD) is among the most prevalent neurodevelopmental disorders with an estimated world-wide prevalence of 5.3-5.9% amongst children (Polanczyk et al., 2007; Willcutt, 2012) and 2.5-2.8% amongst adults (Fayyad et al., 2017; Simon et al., 2009). The disorder is associated with a wide variety of negative functional outcomes (Willcutt et al., 2012), executive and cognitive difficulties (Pievsky & McGrath, 2017), as well as alterations in brain structures and connectivity (Gao et al., 2019; Norman et al., 2016). The broad influence of the disorder is also reflected by the fact that there are three separate clinical presentations of ADHD described in the Diagnostic and Statistical Manual of Mental Disorders ([DSM] i.e., primarily inattentive, primarily hyperactive/impulsive, and combined presentation; American Psychiatric Association, 2013). Diagnostic categorization is based on the presence of at least six symptoms of inattention (primarily inattentive presentation), hyperactivity/impulsivity (primarily hyperactive/impulsive presentation) or six or more symptoms of both (combined presentation) for children and adolescents, whereas diagnostic criteria for adults require five or more symptoms. As the disorder can present in several different ways, and lead to impairment across a wide range of outcomes, it should not be surprising that the developmental trajectory of the disorder is characterized by a large degree of heterogeneity. Studies indicate that, for most affected children, there is a reduction in symptoms across adolescence and into adulthood (Faraone et al., 2006), especially with regards to hyperactive/impulsive symptoms (e.g., Hinshaw et al., 2006; Lahey & Willcutt, 2010). However, the findings also show that the majority of these children still suffer from a recognizable impairment in adulthood (Cherkasova et al., 2022; Faraone et al., 2006; Faraone et al., 2000). This finding has resulted in several studies aiming to understand the symptom trajectory of ADHD through adolescence and into adulthood (Caye et al., 2021; Caye et al., 2016). Severe symptom presentation and other comorbid psychiatric disorders (e.g., major depressive disorder, conduct

disorder) are identified as predictors of ADHD-persistence (Caye et al., 2016). As ADHD in childhood is known to be a risk factor for other comorbid disorders, such as major depressive disorder, anxiety disorders and externalizing disorders (e.g., Smalley et al., 2007; Yoshimasu et al., 2012), there is a high risk that such coexisting disorders will aggravate the affected individuals' impairments. Further emphasizing this point are findings showing an increased prevalence of comorbid psychiatric disorders among adults with ADHD (Fayyad et al., 2007; Yoshimasu et al., 2018).

Importantly, the prevalence estimates of ADHD vary significantly, and factors such as information source and diagnostic criteria used in individual studies have been shown to have a major impact on the observed prevalence (Polanczyk et al., 2014; Vitola et al., 2017). It is therefore important to acknowledge how changes in the diagnostic criteria resulting from the extensive research conducted during the last four decades may influence our understanding of the disorder. Among the most important of these changes has been an increasing acceptance of ADHD not only as a disorder of childhood. It should rather be considered a lifetime condition affecting both children, adolescents, and adults of all ages. This perspective has evolved gradually, with the DSM-IV (American Psychiatric Association, 1994) adding examples of difficulties at work and the DSM-5 (American Psychiatric Association, 2013) changing both the age of onset criterion and adjusting criteria for diagnosis in adulthood.

Early debates on this topic brought to the forefront discussions centred around topics such as the suitability of the diagnostic criteria of earlier editions of the DSM when applied to adults, the reliability of self- vs parent-report, and how childhood symptoms of the disorder are recalled (Barkley et al., 2002). These are factors that are still debated (Lundervold et al., 2021; Sibley et al., 2017; Vitola et al., 2017). Indeed, during recent years there has been a re-emergence of the discussion as to whether ADHD symptoms presenting during adulthood can be said to represent the same disorder as symptoms presenting during childhood and adolescence (Moffitt et al., 2015; Sibley et al., 2018). This discussion has contributed to the acknowledgement of the heterogeneity of developmental trajectories associated with the disorder,

including how the reduction in external support systems during the transition to adulthood poses a challenge for many individuals with ADHD. Many of those affected may experience an unexpected worsening in daily functioning during adolescence and in early adulthood as a result of this reduction in external support coupled with age related increases in life demands (e.g., Turgay et al., 2012). Furthermore, this discussion has underlined the importance of investigating interventions for individuals with ADHD of different ages (Posner et al., 2020). There has also been an increasing focus on non-pharmacological interventions targeting challenges associated with the disorder, such as emotional lability, and not only the core symptoms of ADHD (e.g., Carroll et al., 2023).

As briefly mentioned, ADHD will often have a profound impact on the lives of those affected (e.g., poorer physical and mental health, adverse socioeconomic and psychosocial outcomes; Agnew-Blais et al., 2018; Erskine et al., 2016; Instanes et al., 2018). Examples of the negative impact of the disorder are plentiful across different stages of development. Individuals with ADHD, particularly those affected by inattentive symptoms, are more likely to experience academic underachievement (Fleming et al., 2017; Lee & Hinshaw, 2006; Willcutt et al., 2012). Children with predominantly inattentive symptoms are more likely to suffer from shyness and to be ignored by their peers, and both those affected by inattentive symptoms and those affected by hyperactive/impulsive symptoms are more likely to be disliked by their peers (Becker et al., 2018; Ros & Graziano, 2018). Individuals affected by ADHD also seem to be at greater risk of experiencing somatic disease (Instanes et al., 2018). Children and adolescents, but particularly adults with ADHD, are more likely to be overweight (Nigg et al., 2016), to have type 2 diabetes mellitus (Chen et al., 2018), and increased subjective experience of disordered sleep (Lugo et al., 2020). Both children and adults with ADHD are also more likely to experience difficulties related to emotional dysregulation (Beheshti et al., 2020; Graziano & Garcia, 2016). Furthermore, adult ADHD is associated with reductions in positive occupational outcomes, such as a reduced probability of being employed (Halmøy et al., 2009), increased absence from work (de Graaf et al., 2008) and lower annual income (Jennum et al., 2020). Ultimately, ADHD is also associated with a lower experienced

quality of life for the individuals affected and their families (Dey et al., 2019; Lee et al., 2016) as well as with an increased risk of premature death (Dalsgaard et al., 2015).

As such, it is understandable that the condition has a long history within the fields of medicine and psychology (Barkley & Peters, 2012; Lange et al., 2010). Reflected in this history is also a variety of different views on the aetiology and understanding of the disorder, ranging from a defect of moral control via minimal brain damage and -dysfunction to a more specific focus on the behavioural symptoms characterizing those individuals who would today be said to have an ADHD-diagnosis (Barkley, 2006; Lange et al., 2010). From the publication of the third edition of the DSM (American Psychiatric Association, 1987) and until present day the diagnostic features of the disorder are readily recognizable. As with other psychological disorders, our understanding of ADHD and its causes is still evolving. Mirroring the heterogeneity of the symptoms and diagnostic criteria of the disorder, several different abnormalities seen in ADHD have been suggested to be the causal reason for the diagnosis. Among these views, one influential line of research has pointed to executive dysfunction as the cardinal feature of the disorder (Barkley, 1997; Rapport et al., 2001). The notion that executive functions (EFs) have a central role in explaining the symptoms of ADHD can be traced back to early descriptions of the disorder. A striking example is given by Bradley with reference to stimulant treatment of children with various disorders. When a positive effect was observed on school performance and aspects of behavioural regulation, Bradley speculated about the relationship between stimulants and higher order cognition:

> ‘‘It appears paradoxical that a drug known to be a stimulant should produce subdued behavior in half of the children. It should be borne in mind, however, that portions of the higher levels of the central nervous system have inhibition as their function, and that stimulation of these portions might indeed produce the clinical picture of reduced activity through increased voluntary control’’ (Bradley, 1937, p. 582 cited by Lange et al., 2010)

As is apparent in this quote, the notion that stimulants may reduce symptoms of ADHD through strengthening inhibition is in line with modern hypotheses about the mechanisms of action through which stimulants act (Rubia et al., 2014), although modern hypotheses also include an emphasis on inattention. This emphasis on inattentive symptoms is important as such symptoms are associated with important deficits in adaptive functioning and organisational skills (Willcutt et al., 2012). Thus, it should come as no surprise that studies investigating the role of EFs in ADHD have been plentiful (Pievsky & McGrath, 2017) and that theories have implicated dysfunction in EFs such as inhibition (Barkley, 1997) and working memory (WM; Rapport et al., 2008; Rapport et al., 2001) as a cardinal feature of the disorder. Findings indicating a large degree of individual variance with regards to EFs among those affected by ADHD (e.g., Doyle, 2006; Pievsky & McGrath, 2017) are, however, difficult to explain based on such singular cause theories. This has led to suggestions that the disorder may be attributable to changes in other important functions such as motivational factors, or indeed to changes affecting multiple systems in the brain, theories that can be described to involve multiple pathways. For instance, Sergeant et al. (Sergeant, 2000; Sergeant, 2005; Sergeant et al., 1999) have argued that individuals affected by ADHD experience difficulties in three separate systems (i.e., motor organization, arousal/activation and EFs). According to their view the difficulties related to EFs can be seen as secondary to the alterations in arousal/activation. The dual pathway model and its elaborations proposed by Sonuga-Barke (Sonuga-Barke, 2003, 2005) has also received widespread attention. This model proposes that ADHD can be caused by independent patterns of deficit in three separate systems. Briefly stated these deficits can be described as deficits in EFs including inhibition, deficits related to delay aversion and deficits in temporal processing (Sonuga-Barke et al., 2010). Another possible explanation for the difficulties experienced by individuals with ADHD has been given by Posner and colleagues (Berger & Posner, 2000). Building on the attentional network theory (Petersen & Posner, 2012; Posner & Petersen, 1990) they argue that difficulties associated with ADHD are related to alterations in the attentional networks of the brain. Attentional network theory argues for the importance of three separate, but

interacting, attentional networks. These are the alerting, orienting and executive control networks. The alerting network is responsible for maintaining an optimal level of vigilance during task performance and as such can be described both in terms of tonic (i.e., sustained attention tasks such as the continuous performance task) and phasic (i.e., changes in response times as a result of cueing) activity. The orienting network is responsible for selecting which sensory inputs are to be given priority and operates through the selection of modality or location. Finally, the executive control network operates on stimuli identified by these early-operating networks and is involved in processes such as conflict processing. Berger and Posner (2000) argue that ADHD symptomatology is consistent with disturbances in the alerting and executive control networks. Interestingly, this also allows for a possible explanation of the challenges related to emotional control experienced by many individuals with ADHD (e.g., Beheshti et al., 2020) as part of the core symptomatology of the disorder, and not just as a secondary effect. Posner and colleagues have argued that important emotional control mechanisms can be linked to the executive control network (Rothbart et al., 2007). Thus, indicating that this system is responsible for inhibiting "unwanted" emotional responses and reactions in much the same way as Gross and colleagues (2002; 2014) argue that cognitive reappraisal would work. That is, the executive control network acts as a gatekeeper with regards to which aspects of the environment an individual chooses to focus their attention on, whereas in the model of Gross et al. this filtering takes place through mental restructuring of one's environment through inner narratives (Gross, 2002; Sheppes et al., 2014). According to this view, a child's temperamental reactivity is moderated by its' ability to show effortful control. Effortful control, as defined by the authors (Rothbart et al., 2003; Rothbart & Rueda, 2005; Rothbart et al., 2007), is composed of a child's ability to focus and shift attention, exert inhibitory control to overcome dominant responses, and to take pleasure in low-intensity stimuli. As is apparent in this definition, conflict resolution and inhibition are central aspects of effortful control and as such there is a clear rationale for believing that this aspect of self-regulation should be closely linked to the executive control network. Indeed, research findings do show strong

correlations between measures of the functioning of the executive control network and parent reports of self-regulation through child development (Ellis et al., 2004).

As is apparent in this short review of some influential models of ADHD, there is consensus that difficulties affecting executive control are an important feature in understanding the challenges experienced by individuals affected by ADHD. The examples also underline the heterogeneity of the disorder, the many aspects of everyday behaviour that are affected, and the many potential targets of intervention implicated by these models.

1.2 Executive functioning and attentional control

EFs, interchangeably referred to as cognitive control or executive control, is a concept that refers to functions that contribute to the regulation or control of non-automatic behaviour (Cooper, 2010). Although there is no general consensus as to the exact composition of this control system, all models posit a set of separable functions that regulate other aspects of cognition, and that are vital for the individual to successfully overcome the challenges of everyday life (Cooper, 2010). Baddeley's model of WM (Baddeley, 1986) captures this interplay in an easily comprehensible manner. According to this model WM consist of four different subcomponents. These are the phonological loop, the visuospatial sketchpad, the episodic buffer, and the central executive. The phonological loop and the visuospatial sketchpad are slave systems used for the short-term storage of memory in their respective modalities, the episodic buffer acts as a multimodal storage allowing for the combination of information from the modality specific subsystems and long-term memory, and the central executive controls these other subsystems and manages their use in line with current goals. Thus, building on the "Supervisory Attentional System" of Norman and Shallice (Norman & Shallice, 1986), the model posits that the central executive acts as a control mechanism regulating the other components of WM much in the same way as EFs are assumed to regulate other cognitive functions.

In the first description of the model proposed by Norman and Shallice (1986) they described a system where behaviour is regulated by various levels of voluntary control. In unfamiliar or cognitively demanding situations, higher voluntary control is required, this control is exerted by the supervisory attentional system. When performing routine tasks, less voluntary control is needed, and such actions are carried out by way of contention scheduling. Behavioural schemas of previously learned behaviour will then predominantly be applied. Although initial accounts of this supervisory attentional system did not include a detailed description, the work outlines how the system affects contention scheduling through either activation or inhibition of active schemas (Norman & Shallice, 1986). In later works (e.g., Shallice et al., 1996), the subcomponents of the supervisory attentional system are described in more detail. Shallice and colleagues argue that the system must include components for maintaining goals and newly formed schemas aimed at reaching these, be able to withhold routine responses if these are not in line with active goals, and the system must also be able to make changes in these schemas if they are unsuccessful. Duncan (1986) also outlines a model consisting of a store of potential actions and a process by which a list of current goals gain control over action choices and compares the consequences of actions with these goal states in order to minimize mismatch. A particularly important emphasis of the model is on the ability of the current goal list to inhibit interference from environmental stimuli and potential actions that are not in line with current goals. As is apparent from these descriptions, both models assume that executive functioning is reliant both on the ability to maintain and manipulate relevant information, inhibit disruption caused by internal or external distractors and to alternate between different strategies, actions and goals when needed.

From the early development of models of EFs, such as Norman and Shallice's, to the current understanding of these executive control mechanisms, research can be said to have evolved into two partly separate traditions. In the first, based on neuroscience, there is a predominantly unitary focus on these functions as inhibitory control (e.g., Corbetta & Shulman, 2002; Miller & Cohen, 2001), whereas the second neuropsychologically oriented tradition focuses on the complexity and diversity of

these functions (e.g., Miyake & Friedman, 2012; Miyake et al., 2000; Stuss, 2011). Miyake and colleagues have addressed these two opposing views (Miyake & Friedman, 2012; Miyake et al., 2000), and capture both the complexity, as well as the unitary aspects, of EFs in their definition (2000, p. 50): "general purpose control mechanisms that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition". Based on their findings and subsequent studies, Miyake and colleagues (2012) argued that EFs are both separable and diverse, but also closely interrelated in that inhibition has a particularly central (unitary) role and may be viewed as a "common" EF.

Contrasting these earlier views of EFs as "pure" top-down control processes are models arguing for the continual interactions between the hypothesized control systems and the subsystems they are assumed to control. Such models indicate aspects of both top-down control and an emergent (bottom-up) component (e.g., Cooper, 2010; Mackie et al., 2013). This approach to executive functioning is illustrated by the work of Mackie et al. (2013). In their study the authors employed the attention network theory developed by Posner and colleagues (2012; 1990). Building on the work of Posner and colleagues, Mackie et al. (2013) suggest that these attentional networks contribute to executive control by reducing uncertainty. This is achieved through the alerting network contributing to increased temporal accuracy in information processing, the orienting network selecting the most relevant information, and the executive control network biasing information processing towards task-relevant information at later stages. Taken together, Mackie and colleagues suggest that these attentional networks are crucial in determining which information reaches consciousness and are allowed to influence responses.

The importance of EFs is supported by studies showing that measures of executive functioning predict outcomes such as academic achievement (Spiegel et al., 2021), emotional regulation (e.g., Gross, 2002) and physical health (Reimann et al., 2020).

1.3 Executive functioning, executive control and ADHD

As previously described, the emphasis on executive functioning as a causal pathway to ADHD (Barkley, 1997; Pennington & Ozonoff, 1996; Rapport et al., 2001) has led to a multitude of studies examining the relationship between ADHD and executive functioning. In an attempt to summarize this research, Pievsky & McGrath (2017) conducted a systematic review of existing meta-analyses. Their findings showed that the vast majority of the included meta-analyses found that individuals with ADHD had poorer results on measures of executive and cognitive functions than controls. However, they also showed that the size of these group differences is smaller than the differences typically found on measures of behavioural symptoms. These findings indicate that many individuals with ADHD have small or no neurocognitive deficits. With regards to the effect sizes of the variables examined, Pievsky & McGrath (2017) found that reaction time variability, intelligence/achievement, vigilance, WM and inhibition were the cognitive domains most strongly affected by an ADHD-diagnosis. These findings illustrate the multiple consequences of the disorder, but also the heterogeneity in affected functions. The total pattern of findings does not seem to support models proposing a single core-deficit underlying the disorder (e.g., Barkley's model), but may be more in line with accounts suggesting deficits in multiple systems (e.g., Sergeant, 2000) or multiple pathways to the disorder (i.e., Sonuga-Barke, 2002; Sonuga-Barke et al., 2010). Interestingly, several of the largest differences (e.g., reaction time variability, vigilance) were on measures related to attention. As such, the findings may be interpreted to be in line with the proposal of Berger & Posner (2000) which suggests that ADHD can be seen as a deficit of executive control and alerting and that such a model would account for both the views of Barkley (1997) and Sergeant et al. (2000). There are also findings indicating that WM measures are related to differences in the executive control network (i.e., Redick & Engle, 2006), thus potentially accounting for the views of Rapport and colleagues (Rapport et al., 2001) suggesting that inhibitory control is important for WM processing.

Given the emphasis on EFs in theoretical accounts of ADHD, as well as the findings showing that these functions are weakened in ADHD-samples as compared to typically developing individuals, one would expect ADHD to be related to abnormalities in the structure and functioning of frontal areas of the brain. Indeed, structural data show abnormalities in several frontal regions in ADHD (Norman et al., 2016). Furthermore, fMRI findings indicate hypoactivation in the frontoparietal network associated with executive functioning amongst both children and adults with ADHD (Cortese et al., 2012). These results are also supported by findings of abnormal connectivity between the frontoparietal network and the default-mode network in ADHD (Gao et al., 2019), a finding which may be compatible with the notion that mind-wandering generated by the default-mode network interferes with the EFs controlled by the frontoparietal network as suggested by Castellanos et al. (2008).

In addition to findings indicating abnormalities in brain regions associated with executive functioning, there is also solid evidence for abnormalities in regions associated with attention and the attentional networks described by Posner and colleagues. The same meta-analyses described above have shown decreases in the size of the anterior cingulate cortex (ACC) and insula in ADHD (Norman et al., 2016) and decreased activity in the insula and the remainder of the ventral attention network (Cortese et al., 2012; Norman et al., 2016). Data also shows reduced connectivity between the frontoparietal network and the insula/ventral attention network.

1.4 ADHD and gender effects

ADHD is also characterized by gender differences. Although it is amongst the most prevalent childhood disorders in both girls and boys, estimates indicate that it is 2-3 times more prevalent among boys (e.g., Polanczyk et al., 2007). Interestingly, this uneven distribution seems to be reduced during the transition to adulthood and in adult ADHD populations (Song et al., 2021). Various explanations have been proposed, and differences in symptom presentation has been suggested as one. This

suggestion is based on the fact that boys with ADHD will often show more externalizing symptoms and disruptive behaviour (Gershon & Gershon, 2002; Levy et al., 2005), whereas girls are more likely to be diagnosed with the primarily inattentive symptom presentation (Staller & Faraone, 2006). The same general pattern seems to hold true throughout adolescence and adulthood (Solberg et al., 2018) and is likely to bias the likelihood of being referred to health services at various stages of their lives. Furthermore, studies show that girls with ADHD will more often be affected by internalizing symptoms (Gershon & Gershon, 2002; Levy et al., 2005). This leads to the suggestion that boys are more likely to be referred to treatment and/or study participation as parents and schools are more likely to notice their symptoms and take an active part in this process. During the transition to adolescence and adulthood this pattern may then reverse as the affected individual is increasingly able to seek help on their own behalf, and as internalizing symptoms may cause a greater degree of subjective discomfort (Phares & Copas, 1990), resulting in girls being more likely to seek treatment. This same pattern may then also lead to greater treatment-seeking behaviour among adult females without prior treatment history. One line of research supporting such a view found that girls with childhood ADHD continue to be impaired across a wide range of areas when they reach adolescence (Hinshaw et al., 2006). Furthermore, those affected by severe ADHD symptomatology, i.e., girls who fulfil the diagnostic criteria for the combined presentation of ADHD during childhood, are more likely to rate themselves as more depressed than controls during adolescence (Hinshaw et al., 2006). Indeed, the same sample also showed continued impairment in early adulthood (Hinshaw et al., 2012) and into their 30s (O'Grady & Hinshaw, 2021), with those girls most strongly affected by ADHD symptoms showing an increased risk of severe self-injurious behaviour and suicide. Another possible mechanism which may influence this change in prevalence estimates is based on the notion that girls and women affected by ADHD are more impaired than boys and men. This suggestion is based on findings indicating that girls are more likely to experience social impairment such as peer rejection (e.g., Mikami & Lorenzi, 2011), possibly due to their behaviour being deemed more gender-atypical (Elkins et al., 2011). Referral rates among girls and

women with ADHD may also be influenced by the fact that girls and women seem to be at greater risk of developing internalizing disorders with the onset of puberty (for a review see Rapee et al., 2019), a pattern which may have even stronger implications for girls with ADHD due to the importance of peer relationships in this period (Rapee et al., 2019) and the increased risk of peer-rejection faced by these girls and young women (Mikami & Lorenzi, 2011).

1.5 Current treatment of ADHD

Current treatment options for ADHD in both children and adults are to a large degree based on use of medications (Kooij et al., 2010; NICE, 2008, 2018). The evidence for the short-term efficacy of typical medications (i.e., amphetamines, methylphenidate and atomoxetine) is strong (Cortese et al., 2018). However, due to various issues such as uncertainty regarding side-effects, tolerability, acceptability, lack of response, residual symptoms, or a wish for non-pharmacological treatment, as well as findings of improved outcome from multimodal treatment (Catalá-López et al., 2017; Cortese et al., 2018; Kooij et al., 2010; NICE, 2008, 2018; Nimmo-Smith et al., 2020), there has been an increasing interest in non-pharmacological treatment for ADHD in both children and adults. For instance, stimulant medication alone has been shown to have only a limited effect on typical co-occurring traits of ADHD in adults, such as difficulties with emotional regulation (Lenzi et al., 2018). In general, findings show some support for positive effects of non-pharmacological interventions on certain core-symptoms and associated difficulties amongst both children (Catalá-López et al., 2017; Lambez et al., 2020) and adults (López-Pinar et al., 2018; Nimmo-Smith et al., 2020). However, there are substantial differences in the effects reported by available studies. There is relatively solid evidence that cognitive behavioural therapy may have a positive effect on ADHD symptomatology and associated difficulties in both children and adults (Catalá-López et al., 2017; Nimmo-Smith et al., 2020). Various other psychological interventions, e.g., interventions based on dialectical behavioural therapy, mindfulness-based interventions, and psychoeducation, have also reported positive effects in adult ADHD-samples (e.g., Halmøy et al., 2022). The low number

and poor quality of many of these studies does, however, warrant caution and a need of replication of reported positive effects before they can be considered for inclusion in evidence-based guidelines (see Nimmo-Smith et al., 2020). Several approaches based on cognitive training (i.e., WM-training, neurofeedback) have also been applied to ADHD-samples. According to the meta-analysis of Catalá-López et al. (2017), such interventions cannot be recommended for children with ADHD at the current time due to lack of quality evidence for their effectiveness. This finding is in line with the limited number of studies assessed by Lambez et al. (2020) in their review of cognitive effects of non-pharmacological interventions in ADHD-samples of all ages, and with the studies identified by Nimmo-Smith et al. (2020), when reviewing evidence for efficacy of cognitive training amongst adults with ADHD. Nimmo-Smith et al. (2020) also included one study of therapist-delivered cognitive remediation (Stevenson et al., 2002) as a sub-group of cognitive training. This study reported positive effects on ADHD symptoms and organisational skills lasting 12 months, and approaches based on cognitive remediation are among those the authors deem promising, although further studies are needed.

1.6 Goal Management Training

Goal Management Training (GMT) is one such remediation approach which may be particularly relevant for treatment of ADHD. It is a structured, group-based, metacognitive remediation program which has shown positive effects across a wide range of other disorders (Stamenova & Levine, 2019). GMT has been developed based on Duncan's attentional control theory of goal neglect (Duncan, 1986; Levine et al., 2000; Robertson, 1996) and, thus, can readily be contextualized within the framework of existing theories of ADHD, as well as the work of Posner and colleagues (e.g., Posner & Petersen, 1990). Duncan's theory describes how goal management suffers if an individual is unable to maintain his or her current goal-set due to interference from ongoing activity or salient stimuli in the environment. As Duncan was concerned with the troubling effects seen after frontal lobe damage and the behavioural difficulties seen as a consequence of such damage, it is to be

expected that his theory contains references to several of the functions (i.e., executive functioning, attentional control) reviewed earlier. Duncan proposes both a general store of action alternatives, as well as a searching mechanism subserving the individual's current goal or goals and choosing those actions which would bring one closer to these goals. As such it is apparent that both WM and the executive control network described earlier would be important components in this process. It is also clear that the process would involve orienting towards relevant stimuli, and that a sufficient level of alertness would be required. Duncan also emphasizes the importance of inhibiting actions that will not bring the individual closer to his or her goals, thus showing the importance of inhibition and executive control. Building on this theory Robertson, Levine and colleagues (Levine et al., 2000; Robertson, 1996) have developed an intervention that emphasizes a flexible, five-stage strategy to increase goal-attainment. GMT is based on the assumption that sustained attention can be strengthened through changes in the underlying brain networks as a result of practice, and that such a change will support executive functioning. As such, the assumptions are closely related to Posner and colleagues' model in that they emphasize the importance of attention functions for the behavioural regulation of the individual. To achieve these changes GMT employs strategies aimed at the intermittent stopping of ongoing behaviour to assess whether this behaviour is in line with current goals and to re-orient towards these goals if necessary. Self-cueing is used to maintain an appropriate level of alertness, large goals are divided into smaller subgoals to keep these manageable, and mindfulness-based exercises are included to support awareness of one's own state and self-regulation. Furthermore, these strategies are combined with psychoeducation aimed at increasing awareness of attentional lapses and the possible negative consequences of poor attentional control. If the emphasis of GMT is to be situated within the context of the theories described above one could argue that practicing the intermittent stopping of ongoing behaviour would be important to counter poor inhibitory control (Barkley, 1997) or an inefficient executive control network (Berger & Posner, 2000; Petersen & Posner, 2012; Posner & Petersen, 1990). Subdividing large goals into smaller, more easily achievable sub-goals would be important if one is motivated by immediate rewards

(Johansen et al., 2002; Sonuga-Barke et al., 1994) or have difficulties maintaining relevant task-information in WM (Rapport et al., 2001), whether the reduced WM-capacity is a result of difficulties with executive control or not. Both self-cueing, mindfulness exercises and the mentioned strategies would likely be necessary to counteract the activation/arousal deficiencies and secondary executive dysfunctions described by Sergeant et al. (2003), and in a similar manner several strategies would be of high relevance to counteract the multiple deficiencies described by Sonuga-Barke and colleagues (Sonuga-Barke et al., 2010). Despite the relevance of both the theoretical underpinnings of the intervention and the seemingly high relevance of the emphasis of the intervention to difficulties experienced by individuals with ADHD, research on GMT in the context of ADHD is very sparse. In fact, only a single study could be identified at the time when work on this dissertation started (In de Braek et al., 2017). That study found positive effects of GMT and psychoeducation on clinician rated, everyday cognitive functioning when compared to psychoeducation alone. The relevance of GMT for treatment of ADHD-related difficulties is also supported by findings indicating a positive effect on aspects of executive functioning and attentional control in samples with frontal lobe damage (Levine et al., 2011; Tornås et al., 2016).

1.7 Aims of the thesis

The overall aim of the thesis was to investigate the link between EFs and emotional control in ADHD, as well as how cognitive remediation targeting executive functioning could lead to enhanced executive control and self-perceived emotion regulation abilities. The first specific aim of the thesis was to investigate whether executive control functions, including WM, are important for regulating strong, negative emotional expressions in children and adults with ADHD. The second aim was to investigate GMT as a potential treatment intervention for ADHD, and specifically whether GMT would have beneficial effects on executive control in adults with ADHD. A third aim of the thesis was to investigate whether the application of a theoretically based assessment of attentional control (i.e., the revised Attention

network test [ANT-R]; Fan et al., 2009) may improve our understanding of the mechanisms through which GMT achieves positive effects.

1.7.1 Specific aims

Paper I

The aim of the first paper was to investigate the relationship between an aspect of executive functioning (i.e., WM) and emotional regulation in children with ADHD. Based on the theories of Gross and colleagues (Gross, 2002; Sheppes et al., 2014), we expected that a higher verbal WM capacity would be associated with lowered levels of emotional lability.

Paper II

In the second paper the main aim was to investigate the effects of GMT in a sample of adults with ADHD. To achieve this, we used a neuropsychological test battery, as well as a range of self-report inventories, as effect measures following GMT. We expected that GMT would specifically enhance performance on measures of inhibition compared to performance on measures of other EFs, such as WM and general problem-solving, and that this change would be accompanied by improvements in self-reported everyday functioning.

Paper III

The aim of the third paper was to apply attention network theory to investigate a potential mechanism of change underlying the positive effects found in the second paper. Based on findings and theories presented in previous studies we expected that the adults with ADHD would show improvements on measures of executive control and alerting following the intervention and that the largest changes would be in the efficiency of the executive control network.

2. Materials and methods

2.1 Paper I

2.1.1 Participants

The 75 children participating in study I consisted of 41 children with an ADHD-diagnosis and 34 typically developing controls. Participants with an ADHD-diagnosis were referred from psychiatric outpatient clinics for children and adolescents in the municipality of Bergen, Norway, based on a suspected ADHD-diagnosis. Typically developing children were recruited from schools in geographical areas overlapping with the areas served by these clinics to serve as controls in the study. The children were diagnosed with ADHD following the diagnostic algorithm of the "Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version" (Kaufman et al., 1997). Based on parent reports of emotional control as assessed by the "Behavior Rating Inventory of Executive Functioning" (BRIEF; Gioia et al., 2000) 17 of the children with ADHD were classified as having difficulties related to emotional lability. One of these children was excluded from further analyses based on extreme values on the measured variables, and the final sample therefore consisted of three groups: Typically developing children (N = 34), ADHD without emotional lability (N = 24) and ADHD with emotional lability (N = 16).

2.1.2 Measures

Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version

The Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (Kaufman et al., 1997) was used for diagnostic assessment, this also included classification of the participating children with ADHD. The instrument is a semi-structured interview which is used to assess current and lifetime presence of symptoms of psychopathology. The interview is based on criteria

from the DSM-IV (American Psychiatric Association, 1994). The interview was administered by a clinical psychologist or psychiatrist. Parents were interviewed first; the interview was then administered to the child. Final diagnosis was confirmed by a board consisting of a child psychiatrist and a clinical psychologist.

Wechsler Intelligence Scale for Children – Fourth Edition

The Wechsler Intelligence Scale for Children - Fourth edition (Wechsler, 2003) was used to assess full-scale intelligence quotient and general ability index. The general ability index was calculated so that it could be used as a covariate in the later analyses. This was done as WM scores are included in the estimation of the full-scale intelligence quotient.

Working memory

The study included three measures of WM. These were included so that different aspects of WM (i.e., simple verbal- and spatial WM, complex verbal WM; Kasper et al., 2012; Shelton et al., 2009) could be assessed. Included measures were the backward conditions of the digit span and the spatial span tasks as well as the letter-number sequencing task (Kaplan et al., 2004; Wechsler, 2003).

Emotional lability

The emotional control subscale from the BRIEF (Gioia et al., 2000) was used to obtain parent-reported difficulties related to emotional control. Parents are asked to rate the frequency of various child behaviours, resulting in a T-score. Participating children were classified into groups with or without difficulties related to emotional lability using the cut-off T-score of 65 following the manual of the BRIEF.

Symptoms of ADHD and oppositional defiant disorder

The parent form of the Child Behavior Checklist from the Achenbach System of Empirically Based Assessment (Achenbach & Rescorla, 2001) was administered to obtain a dimensional score of ADHD symptoms and symptoms of oppositional

defiant disorder (ODD). Obtained scores were included in the analyses to control for the influence of such symptoms on difficulties related to emotional lability.

2.1.3 Statistical analyses

Stepwise linear regression analysis was used to assess the relationship between WM capacity and emotional lability. Controlling for the effects of age, gender, general ability index, symptoms of ADHD and ODD, the WM scores from the backward conditions of the digit- and spatial span as well as scores from the letter-number sequencing task were included as independent variables. Scores on the emotional control scale were used as the dependent variable. This was followed by an exploratory analysis where scores from the letter-number sequencing task was included as an independent variable whilst controlling for the effects of gender and symptoms of ADHD and ODD. Scores on the emotional control scale were once again used as the dependent variable. In a final, binary regression model emotional lability status, as defined above, was used as the dichotomous dependent variable whilst scores on the letter-number sequencing task was included as the independent variable. Age, symptoms of ODD and ADHD were included as covariates. This analysis was limited to the children with ADHD as all children classified as having difficulties related to emotional lability belonged to this group.

2.1.4 Ethics

The study was approved by the Regional Ethical Committee for Western Norway (REK-Vest, Bergen, Norway), and the parents of all participating children provided written informed consent in accordance with the Declaration of Helsinki. All participants could withdraw from participation at any time and without giving any reason. Participants were not placed at risk by participating in the study.

2.2 Paper II

2.2.1 Participants

Participants were recruited for an intervention study aimed at exploring GMT as an intervention for adult-ADHD. Participants were recruited through an existing study of adult-ADHD at the University of Bergen and through recruitment from psychiatric outpatient clinics in the municipality of Bergen. Inclusion criteria were a confirmed clinical diagnosis of ADHD and an age of 18 years or more, whilst exclusion criteria were a lifetime diagnosis of psychotic disorder, current diagnosis of substance or alcohol use disorder, severe ongoing psychiatric disorder (e.g., severe suicidality, severe social phobia) which would prohibit participation in the study, or a full-scale intelligence quotient below 80. In total, 36 participants volunteered for participation. Of these, 32 were included in the study as four participants were excluded due to the listed criteria or failure to complete the initial assessment. Analyses, with the exception of baseline characteristics, were based on the 21 participants that completed two or more assessments.

2.2.2 Measures

Clinician administered measures

Mini International Neuropsychiatric Interview Plus

The Mini International Neuropsychiatric Interview Plus (Sheehan et al., 2002) was administered by a clinical psychologist or by a clinical psychology student with experience from assessment under the supervision of a clinical psychologist. The Mini International Neuropsychiatric Interview Plus was used at baseline to assess participants for the presence or lifetime history of psychopathology both with regards to the exclusion criteria and to ascertain the clinical characteristics of the sample.

Performance based measures

Wechsler Abbreviated Scale of Intelligence

Matrix reasoning and Vocabulary from the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) were used to assess the full scale intelligence quotient of the participants.

Delis-Kaplan Executive Function System

Several subtests from the Delis-Kaplan Executive Function System (i.e., Trail Making Test, Color-Word Interference Test & Tower Test; Delis et al., 2001) were used to assess aspects of executive functioning. The Trail Making Test was used as a measure of attentional control and flexible control of processing speed while the Color-Word Interference Test was administered to assess inhibitory control, and the Tower Test to assess both inhibition and general problem solving.

Letter-Number Sequencing and Spatial Span

The Letter-Number Sequencing task from the Wechsler Adult Intelligence Scale – 4th edition (Wechsler, 2008a) and the Spatial span from the Wechsler Memory Scale – 3rd edition (Wechsler, 2008b) were administered to assess aspects of the participants' WM.

Hotel task

To assess generalization of effects, the Hotel task (Manly et al., 2002), an analogue of real-life problem-solving, was administered.

Self-report measures

Behavior Rating Inventory of Executive Function – Adult version

The Behavior Rating Inventory of Executive Function - Adult version (BRIEF-A; Gioia et al., 2000) was administered to explore the participants' own experiences of various aspects of executive functioning. In line with the emphasis of GMT the subscales Inhibit, Shift and WM in addition to the index scores and the Global executive composite score were included in the analyses.

Cognitive Failures Questionnaire

The Cognitive Failures Questionnaire (Broadbent et al., 1982) was used as a measure of everyday difficulties related to perception, memory and motor functioning.

Adult ADHD Self-report Scale

The Adult ADHD Self-report Scale (Kessler et al., 2005) was administered as a measure of the participants' experience of difficulties related to core ADHD symptoms.

Wender-Utah Rating Scale

The Wender-Utah Rating Scale (Ward et al., 1993) was administered to retrospectively assess childhood symptoms of ADHD and related difficulties. It was administered at baseline to characterize the sample.

Adult ADHD Quality of Life Inventory

The Adult ADHD Quality of Life inventory (Brod et al., 2005) was administered to assess aspects of experienced quality of life.

Dysregulation of Emotions Rating Scale

The Dysregulation of Emotions Rating Scale (Gratz & Roemer, 2004) was used to measure various facets of emotion regulation. Due to the content of the intervention, the subscales measuring difficulties engaging in goal-directed behaviour, impulse control difficulties and access to emotion regulation strategies when facing difficult emotions were included in the analyses. In addition, the total score was also included.

2.2.3 Statistical analyses

R version 4.0.2 (R Development Core Team, 2020) and SPSS version 25 (IBM Corporation, 2017) were used for the statistical analyses. Analyses in R also made use of the lme4 package (Bates et al., 2015). Variables containing missing items were subjected to Little's missing completely at random test (Little, 1988) and outliers were identified using median absolute deviation and a cut-off of three times this value (Leys et al., 2013). Comparisons between those participants who completed their

participation and those who withdrew or dropped out were performed using two-sided t-tests.

For the main analyses, linear mixed-effects regression was used to explore changes in the outcome measures across time. Models included assessment-session as the independent variable. Due to the limited number of participants who completed two or more assessments and power analyses performed during planning of the study which indicated that a minimum of 27 participants would be needed to achieve sufficient power, no covariates were included in these analyses. However, in follow-up analyses, those effects which were found to be significant in the first set of analyses were used as outcome measures in models that also included medication status and age as covariates.

Significance tests were adjusted using false discovery rate as described by Benjamini and Hochberg (i.e., $p < d \times i/n$; Benjamini & Hochberg, 1995).

2.2.4 Ethics

The study protocol was approved by the Regional Committee for Medical and Health Research Ethics, West Norway (Study number 2015/2325). All participants provided written informed consent and had the opportunity to withdraw at any time without stating a reason. Participants were not placed at risk by participating in the study.

2.3 Paper III

2.3.1 Participants

Participants in Paper III were the same individuals included in the main analyses of Paper II.

2.3.2 Measures

Attention Network Test – revised

The ANT-R (Fan et al., 2009) was used to assess the three attentional networks described by Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen,

1990). Reaction time measures for these three networks, the orienting, alerting and executive control network, were included in the analyses.

The ANT-R was performed on a desktop computer using E-Prime™ software (Psychology Software Tools, Pittsburgh, PA).

Other measures

As in Paper II, the Adult ADHD Self-report Scale (Kessler et al., 2005) was used to assess the participants' experience of core ADHD symptoms, while the Mini International Neuropsychiatric Interview Plus (Sheehan et al., 2002) was used to assess participants for eligibility and to characterize the sample with regards to the presence of other psychiatric disorders. Estimates of full-scale intelligence quotient obtained using the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) were also included.

2.3.3 Statistical analyses

All analyses for Paper III were conducted using R version 4.0.2 (R Development Core Team, 2020) and the packages ggplot2, lme4, lmerTest, SIMR and tidyverse (Bates et al., 2015; Green & MacLeod, 2016; Kuznetsova et al., 2017; Wickham, 2016; Wickham et al., 2019). Data were prepared by removing responses with reaction times below 100 ms. As visual inspection of the data did not indicate a normal distribution, reaction time data were transformed using an inverse gaussian transformation and multiplied by -1000 following the procedure described by Baayen and Milin (2010). Linear mixed-effect modelling was once again used for the principal analyses. Reaction times for the measures of the alerting, orienting and executive control networks were used as outcomes in separate models which included random intercepts and slopes. A model including the random effect of session was compared to a baseline model including no predictors. Fixed effects for the covariates age, sex, IQ and medication status were included and backwards tested. Models were compared using likelihood-ratio tests and covariates were retained if these tests indicated a significantly better fit to the data. Moderating effects of the included covariates were then assessed by including the interaction between these and

assessment to the models. Finally, the results were visually inspected to examine the patterns of change on ANT-R scores that exhibited significant change after the intervention.

2.3.4 Ethics

The study was approved by the Regional Committee for Medical and Health Research Ethics, West Norway (Study number 2015/2325). All participants gave written informed consent, and were informed that they could withdraw from participation at any time and without stating a reason. Participants were not placed at risk by participating in the study.

3. Results

3.1 Paper I

The aim of the first paper was to investigate whether there is a relationship between WM and emotional functioning in children with ADHD. More specifically, we expected that there would be an inverse relationship between a measure of complex verbal WM and parent reported emotional lability in this group. Indeed, we found an inverse correlation between both measures of verbal and spatial WM and parent reported emotional lability, but only the expected complex measure of verbal WM remained significant in a linear hierarchical regression analysis controlling for the effects of symptoms of ADHD and ODD. In a follow-up binary logistic regression analysis limited to the children with ADHD we found that parent reported symptoms of ODD predicted higher scores on parent reported difficulties related to emotional lability, whereas scores on the complex measure of verbal WM remained a significant predictor of lower levels of emotional lability.

3.2 Paper II

The aim of the second paper was to test a neuropsychological model used to measure the effects of GMT in a sample of adults with ADHD. To do so, a number of performance-based measures of executive functioning and attention were administered to a sample of adults with ADHD before, immediately following and six months after they underwent GMT. In addition, several self-report measures were included to assess the participants' experience of generalization of effects to their everyday life. Results showed improvements on several measures, particularly on performance-based measures of inhibitory control. In addition, the sample of adults also improved on performance-based measures of shifting and general problem-solving. The self-report measures showed improvements on scales assessing core ADHD symptoms, productivity, everyday cognitive functioning as well as on measures of everyday executive functioning and aspects of emotion regulation (i.e.,

access to emotion regulation strategies, impulse control and reduced difficulties in engaging in goal-directed behaviour when experiencing emotional distress).

3.3 Paper III

The aim of the third paper was to investigate whether changes in the attentional networks described by Posner and colleagues could be a potential mechanism explaining the findings from Paper II. We hypothesized that adults with ADHD would exhibit improvements in measures of the executive control- and alerting networks following the intervention as GMT emphasizes techniques and strategies to increase executive control and maintain appropriate levels of alertness. This would also be in line with the findings from the second paper. Findings showed a significant improvement on the measure of the executive control network, but no change on the measure of the alerting network. Furthermore, there was a trend towards a significant improvement on the measure of the orienting network. The results showed that medicated participants and older participants performed better on the measure of the executive control network, but that there were no significant interactions between medication status or age and the assessments following GMT. Findings also indicated significant individual variation with regards to results on the measures of attentional control.

4. Discussion

The present thesis investigated potential relationships between cognitive and emotional control in children with ADHD, the feasibility of GMT as an intervention for adults with ADHD, as well as a potential mechanism of GMT in enhancing executive functioning, and by this improve our understanding of how GMT may alleviate some of the challenges associated with ADHD in adults. Linear and mixed effects regression models have been used to analyse the collected data.

Overall, the results from the different papers included in this thesis showed a link between EFs and emotional regulation in ADHD. In Paper I, the results showed a link between poorer WM, an EF, and emotional lability in children with ADHD. Furthermore, in Paper II and III, GMT as a cognitive remediation enhanced inhibitory control as shown by pre-post effects in adults with ADHD, and the adults with ADHD reported reduced difficulties with emotion regulation and improved quality of life after completing the GMT intervention.

The following section will discuss how the findings of the thesis can be related to models of ADHD, cognitive-, emotional- and attentional control. First it will focus on the potential relationship and/or overlap between inhibitory/executive and emotional control. Secondly, the results from Paper II and III will be discussed in light of findings from previous research on the relationship between ADHD symptoms, executive control and difficulties of everyday life. Thirdly, the section will consider methodological limitations and concerns of the results presented in the thesis and in the general literature. Finally, clinical implications of the findings will be discussed.

4.1 Findings of Paper I, II and III

4.1.1 Relationship between cognitive and emotional control

Difficulties related to emotional regulation have increasingly been accepted as an important feature of having an ADHD diagnosis (Astenvald et al., 2022; Sobanski et al., 2010). This is reflected in the inclusion of emotion dysregulation as an associated feature in the updated diagnostic criteria of the disorder (American Psychiatric

Association, 2013). The aim of Paper I was to investigate whether the known difficulties related to executive functioning in ADHD would associate with difficulties in emotional regulation. Indeed, the findings from Paper I indicated an inverse relationship between EF, i.e., a complex measure of verbal WM, and emotional regulation as rated by parents: a lower verbal WM capacity was associated with higher parent scores of emotional lability or dysregulation. The general pattern of this association was, however, not exclusive to those children with an ADHD diagnosis. As such, this finding is in line with general models proposing a close relationship between executive control and emotional regulation (Gross, 2002; Rothbart et al., 2007; Rothbart et al., 2011). As described in Paper I, Gross and colleagues (Gross, 2002; Sheppes et al., 2014) have suggested that certain emotion regulation strategies, such as cognitive reappraisal, rely heavily on cognitive resources, and that verbal WM-capacity is central to such strategies. According to this view, the relationship may be explained by the fact that those individuals with a higher WM-capacity are more able to simultaneously maintain information about an event, as well as various possible explanations for this event, in their WM. As a result of this, they may be more capable of considering different alternatives, and by doing so, reduce their emotional reactivity. Such an interpretation is in line with other theoretical suggestions that individuals with ADHD experience emotional dysregulation due to reduced EFs (e.g., reduced WM-capacity; Nigg et al., 2004). The findings may, however, also be interpreted in line with the work of Rothbarth and Posner (Rothbart et al., 2003; Rothbart et al., 2007; Rothbart et al., 2011) who argue that differences in WM-capacity are secondary to individual differences in executive control of attention. Furthermore, that executive control of attention is central not only with regards to an individual's executive functioning, but also with regards to that individual's control over their experienced distress. According to this line of reasoning, enhanced executive control may influence both the individual's engagement with the distressing stimuli, their capacity to regulate the experienced distress, as well as their control over the behavioural reaction to this experienced distress. That is to say, they state that an increased capacity for executive control may alter an individual's experience of a situation even before stimuli from that situation

enter WM. Also worth noting, is the fact that other studies indicate that executive control continues to develop through childhood, and that one should expect substantial individual differences in the age group studied in Paper I. More so in children with ADHD, if one assumes that children with ADHD are more susceptible to uneven maturation (i.e., "maturational lag"; Hoogman et al., 2017; Kinsbourne, 1973). The close relationship between executive control and WM is supported by Miyake and colleagues (2012). The work of Redick and colleagues (Redick & Engle, 2006) also illustrates this close relationship by showing that participants who achieved high and low scores on a complex WM-measure differed accordingly on the original Attention Network Test (Fan et al., 2002), with high WM scores associating with high executive control scores.

In summary, Paper I provides support for the notion that there is an important correlation between aspects of executive functioning and emotional control in children with ADHD. The design of the paper does not allow for conclusions with regards to the directionality of the association. Future studies should aim to investigate whether the reported association holds true for various age-groups (i.e., children, adolescents and adults) and, using longitudinal designs, attempt to ascertain the directionality of the effect. If the reported findings can be replicated, and if the directionality can be ascertained, such findings could hold important implications for clinical interventions.

4.1.2 Cognitive remediation as a potential intervention for ADHD-related challenges

After investigating the potential associations between aspects of executive functioning and emotional regulation in Paper I, we intended to investigate whether GMT would serve as a feasible intervention for adults with ADHD and whether such an intervention targeting EFs would also provide beneficial effects for aspects of emotional regulation. This investigation was also in line with calls for further studies of alternative, or supplemental, treatment strategies to pharmacological treatment for this population (e.g., Franke et al., 2018; Nimmo-Smith et al., 2020). In line with our hypotheses, Paper II showed improvements on both performance-based

neuropsychological tests and self-report inventories among adults with ADHD following GMT. These improvements were to a large degree stable over a relatively long time period as shown at the follow-up six months after completion of the intervention. With regards to results on neuropsychological tests, the largest and most stable changes were found on measures of inhibition. This is in line with the emphasis of the intervention (Levine et al., 2000), and as described previously also a central target of ADHD-interventions according to prominent theoretical accounts (e.g., Barkley, 1997). Importantly, participants also reported improvements in everyday functioning, quality of life and core ADHD symptoms. Further analyses also revealed self-reported improvements on aspects of emotional regulation following the intervention. Participants reported immediate improvements in impulse control with regards to emotional control, and at follow-up they also reported improvements in maintaining goal directed behaviours when faced with difficult emotions as well as improved access to emotion regulation strategies. As such, the results of Paper II may support the findings from Paper I showing a close relation between EFs and emotional regulation. Furthermore, we interpret the fact that there were no significant changes in measures of WM in Paper II as supportive of the interpretation based on the work of Rothbart & Posner (Rothbart et al., 2007). That is, the association between aspects of emotional regulation and executive functioning may be found at an earlier level than that of WM. As proposed in their work, strong executive control may act both as a filter with regards to which emotional stimuli gain access to conscious awareness, as well as contributing to voluntary processing of this information by enabling an individual to disregard irrelevant or competing stimuli.

Although the results of Paper II must be interpreted with caution due to the relatively small number of participants, we believe that the findings call for further investigations of GMT as an intervention for ADHD. Furthermore, we interpret the findings to support the hypothesis that GMT specifically targets inhibitory control as opposed to executive functioning in general. We also propose that the use of the same or a similar neuropsychological test battery in studies of other patient samples may further improve our understandings of the effects of GMT. The future use of case-

control samples may also lead to greater certainty with regards to how the positive, self-reported changes are to be interpreted as the lack of a control group does not allow for the exclusion of explanations such as spontaneous improvement and group processes being the cause of change.

4.1.3 Increased attentional control as a potential mechanism through which improvements may be understood

The aim of Paper III was to employ attention network theory to investigate whether changes in attention network efficiency could provide further information with regards to how the results from Paper II can be interpreted. Building on existent theories and findings from other samples, as well the findings from Paper II, we expected to see consistent changes in the executive control network as well as some improvement in the alerting network. Results from the study showed improvements in executive control as measured by the ANT-R following GMT, possibly indicating that changes in executive control contribute to the improvements found in Paper II. Contrary to our expectations, we found no changes in the alerting network and a change in the orienting network at follow-up.

Although the reported improvements in the executive control network must be interpreted with caution, we believe they provide one potential mechanism through which positive effects of GMT in our sample as well as other studies may be explained. We believe that existing studies indicating the ACC and the insula in the operation of the executive control network (Botvinick et al., 2004; Ham et al., 2013), as well as findings showing that activation in these areas may differentiate between individuals with and without ADHD, may provide important directions for future studies. Replication of the reported results, ideally in combination with the use of fMRI, may further clarify both the method of action of GMT as well as clarifying whether improvements in the connectivity and functioning of these areas are central to ADHD symptom perseverance or remittance.

Furthermore, as noted in Paper III, a small number of participants showed changes in executive control which deviated from the results of the majority. As such, replication would also offer an opportunity to investigate whether individual differences in

changes in scores from the ANT-R are also associated with altered patterns on other outcome measures than those included in the mentioned paper. Such an investigation could contribute to a deeper understanding of individual differences in response to interventions.

4.2 Methodological considerations

4.2.1 Clinical features

ADHD is a heterogeneous and clinically diverse disorder affecting individuals across the lifespan. This is reflected in the various theoretical models presented above (Barkley, 1997; Sergeant, 2000; Sonuga-Barke, 2002; Sonuga-Barke et al., 2010) as well as in various studies of risk factors (e.g., Castellanos et al., 2008; Cortese et al., 2012; Samea et al., 2019), symptom expression and trajectories across the lifespan (Franke et al., 2018; Polanczyk et al., 2010) and neuropsychological profiles (Doyle, 2006; Nigg et al., 2005; Pievsky & McGrath, 2017). Further complicating research on ADHD is the high prevalence of comorbid disorders, with findings showing that a majority of children (Joelsson et al., 2016), adolescents (Yoshimasu et al., 2012) and adults (Sobanski et al., 2007; Torgersen et al., 2006; Yoshimasu et al., 2018) referred to treatment for ADHD have one or more comorbid disorders. The most common of these comorbid disorders include learning disabilities, anxiety and mood disorders, oppositional behaviour disorders, as well as substance use disorders (Torgersen et al., 2006; Yoshimasu et al., 2012, 2018).

With regards to the findings of Paper I, the results showed a significant correlation between aspects of WM and emotional control in children with ADHD. As difficulties related to expression of emotions has become an established associated feature of the ADHD-diagnosis (American Psychiatric Association, 2013; Faraone et al., 2019), but with competing models attempting to explain the relationship (Shaw et al., 2014), we believe these findings are highly relevant. Although the cross-sectional nature of the data from Paper I limits the possibility of investigating the developmental ordering of the symptoms investigated, and the possibility to investigate whether changes in cognitive functioning over time would also be related

to an improvement in emotional control, we believe the findings represent a potential target for future studies. The applied measures are also easily accessible and frequently used in day-to-day clinical practice. All participants in the diagnostic group were referred from public outpatient clinics in the municipality of Bergen whilst the control group was recruited from schools in the same geographical region. As such, the participating children should be representative for the patient population of this area.

With regards to research on psychological treatment, there has long been a concern that reported effects may not be generalizable to the general population of patients due to the use of various exclusion criteria (Seligman, 1995; Stirman et al., 2003; Zimmerman et al., 2005). A primary concern is exclusion due to comorbid disorders. Such concerns have also been addressed in research on ADHD (e.g., Stevens et al., 2007), with Stevens and colleagues including some possible factors which can contribute to generalizability of findings from clinical trials. We therefore included several of these factors in the design of Papers II and III, namely: limiting exclusion criteria to those that would result in inclusion being contra-indicated or inappropriate due to clinical or ethical considerations, open recruitment from public outpatient clinics in the geographical area where the study took place and a possibility for self-referral. Furthermore, we included detailed information regarding both comorbidities and exclusions made during the study to maintain transparency with regards to generalizability (e.g., Stirman et al., 2003). We also included a description of characteristics for those participants in Paper III which showed a decline in results on the primary outcome measure. In summary, we believe this suggests that the findings obtained in papers II and III may generalize to a large proportion of adults with ADHD seeking treatment at outpatient clinics. Caution is, however, warranted when interpreting the findings in relation to patients presenting with ADHD and comorbidities such as ongoing substance use disorders, severe social anxiety, intellectual disability or with regards to adults with ADHD not seeking treatment.

A related issue with regards to the findings from Papers II and III, warranting a certain degree of caution with regards to interpretation of the findings, is the decision

to recruit participants based on an existing diagnosis of ADHD. As such, participants were diagnosed in public outpatient clinics, and diagnoses were confirmed using a somewhat simplified procedure (i.e., participants completed the Mini International Neuropsychiatric Interview Plus and ASRS as part of the pre-screening process). As there is compelling evidence that diagnostic procedures impact the likelihood of receiving an ADHD diagnosis (Polanczyk et al., 2014), there is a risk that some participants may not have fulfilled the criteria for an ADHD diagnosis if a more stringent diagnostic evaluation had been used. However, as there are national guidelines in place to ensure that proper diagnostic assessments are made (i.e., Helsedirektoratet, 2016) in the outpatient clinics from which participants were recruited, we believe this risk was acceptable.

Due to the liberal inclusion criteria applied in papers II and III, most of the participants did indeed fulfil criteria for one or more comorbid disorders. The most prevalent comorbidity in the sample was various anxiety disorders. Interestingly, some lines of research indicate that children with comorbid ADHD and anxiety are equally likely to respond to behavioural and pharmacological treatment whereas those children with both a comorbid anxiety and other externalizing disorders are most likely to respond to a combination of behavioural and pharmacological interventions (Jensen et al., 2001). As such, there is a possibility that this could also apply to adults with ADHD in which the high prevalence of comorbid anxiety disorders in the samples studied in Papers II and III may have had a positive impact on the reported pre-post changes following GMT. However, it is also worth repeating that anxiety disorders are amongst the most prevalent comorbidities seen in ADHD-research (Franke et al., 2018). As presented in Paper III, qualitative inspection of participants who seemed to experience a decline in executive control during their participation showed that two out of three of these participants also had a comorbid antisocial personality disorder, possibly reflecting the mentioned finding that individuals with ADHD and comorbid externalizing disorders respond more positively to combined treatment.

Future studies including a larger number of participants would allow for a more thorough investigation of the relationships between aspects of cognitive functioning and reported symptoms. Inclusion of participants of varying ages in a study with a longitudinal design, preferably employing an intervention targeting cognitive functioning, would also allow for an investigation of the hypothesis that enhanced cognitive functioning would also result in improved emotional regulation for children and adolescents. The inclusion of participants of varying ages would also allow for an investigation of whether early treatment can be expected to result in greater changes, in line with findings showing marked periods of increased brain plasticity (Laube et al., 2020). Such studies would also provide an opportunity to investigate whether the reported features associated with a negative outcome are replicable, and which factors improve or decrease the effects of treatment with GMT.

4.2.2 Behavioural and neuropsychological changes

Both Paper I and II employed neuropsychological as well as self- or parent-report measures in an attempt to investigate possible relations between these. As such, it is important to keep in mind the inherent uncertainties when employing informant- and self-report measures. Examples include answers being influenced by social desirability and recollection bias. With regards to social desirability in parent-reports, there are indications that this factor may have a limited impact (Johnston et al., 2004). That is, even though there seems to be a correlation between measures of impression management and parental-reports related to ADHD, the relationship seems to be of a modest magnitude and the reports remain reflective of actual behaviours.

In Paper I, the groups were defined using parent-reports on the BRIEF (Gioia et al., 2000). More specifically, we employed the emotional control subscale as a measure of emotional lability. As the measure of emotional lability was based on parent-reports, as was the measure of ODD symptomatology, there is a risk of common-method variance (Podsakoff et al., 2003). Furthermore, the cross-sectional design of the study does not allow for conclusions regarding the ordering of symptoms (i.e., emotional lability and ADHD). However, the findings do underline the importance of nuancing the use of complex constructs such as WM. Findings showed no significant

correlations between “simple” WM measures and the measure of emotional lability, but a significant correlation when a “complex” measure of WM was employed. Indeed, the difference between such measures was also underlined by the fact that there was a gender difference on the simplest WM measure, but not on the more complex measures employed. We believe that these findings, especially seen in the greater context of findings of heterogeneous neuropsychological functioning amongst individuals affected by ADHD (Pievsky & McGrath, 2017), are important arguments for efforts to develop common neuropsychological test batteries for use in future studies of ADHD.

In Paper II we employed such a neuropsychological test battery in an investigation of GMT as a possible treatment for adults with ADHD. Following the work of Miyake et al. (2012), we employed measures of inhibition, shifting and WM. Our findings showed that measures of inhibition were the most sensitive with regards to capturing change following the intervention, potentially supporting the arguments of Miyake and colleagues that this is a unifying construct underlying executive functioning.

Future studies employing the same test battery in studies of interventions for ADHD, as well as in intervention studies examining the effects of GMT in other patient populations, may further improve our understanding of the patterns of changes in executive functioning associated with symptom reduction. Such studies may also allow for firmer conclusions with regards to which executive functioning changes are associated with various aspects of behavioural change.

4.2.3 Potential mechanism

In Paper III we set out to investigate a potential mechanism of change underlying the findings from Paper II. Building on the work of Posner and colleagues (Petersen & Posner, 2012; Posner & Petersen, 1990) we wanted to investigate whether the participants from Paper II had experienced changes in their attentional networks during the intervention period and the six months following completion of the intervention. To do so we applied the ANT-R (Fan et al., 2009).

Our findings showed improvements in the executive control network immediately following the intervention, and that these changes were maintained at follow-up. Such changes are in line with the suggestion of Berger and Posner (2000) that ADHD is a disorder primarily associated with disturbances in the executive control network.

Future research including a higher number of participants could potentially provide more conclusive evidence with regards to whether the reported changes in executive attention are, indeed, a mechanism which can explain the positive changes reported by the participants of Paper II with regards to various aspects of everyday functioning and reflected in neuropsychological measures of inhibition and problem solving. Another important aspect of the findings, which could potentially be elucidated through future studies is related to the hypothesis that improvements in executive attention is related to altered functioning in brain areas such as the insula and ACC. These areas have been implicated in both ADHD symptom remittance (Francx et al., 2015), and response to cognitive rehabilitation (Kim et al., 2009; Parisi et al., 2014) in previous studies.

4.3 Implications for future research

We believe that the findings from the current work underline the importance of studies employing outcome measures targeting different levels of explanation (i.e., behavioural, neuropsychological and experimental) to further our understanding of the complex clinical realities affecting individuals with ADHD. Future studies replicating the effects of GMT as an intervention for ADHD may have a large impact on further development of treatment options for adults with ADHD, and by this potentially improving outcomes for individuals who currently experience limited effects of available treatments (i.e., due to a wish for non-pharmacological treatment, low tolerance for medication or similar reasons; Cortese et al., 2018; Nimmo-Smith et al., 2020; Solberg et al., 2019). Expansion of the studied age group to children and adolescents with ADHD provides another important avenue for future research, potentially providing even greater benefits for participants if one assumes that increased brain plasticity (Laube et al., 2020) can lead to greater effects. The need for

investigations of alternate and/or supplementary treatment options for individuals affected by ADHD is emphasized by the recent changes made to the diagnostic criteria for the disorder (American Psychiatric Association, 2013). As the majority of studies included in the cited estimates have used earlier versions of diagnostic manuals (i.e. DSM-II, DSM-III, DSM-III-TR, DSM-IV, DSM-IV-TR, International Classification of Diseases [ICD]-10; American Psychiatric Association, 1968; American Psychiatric Association, 1980, 1987, 1994, 2000; World Health Organization, 1992) and not the latest versions of these manuals, there is a distinct possibility that there will be an increase in the number of individuals receiving the diagnosis, at least amongst adolescents and adults. This is due to changes in the diagnostic criteria in updated revisions (i.e., a reduction in the number of inattentive or impulsive/hyperactive symptoms required for a diagnosis in adulthood, and the acceptance of a somewhat later age of onset of such symptoms). This is also in line with earlier studies using DSM-IV criteria showing that a large proportion of adults diagnosed with ADHD in childhood continue to show ADHD-related functional deficits (e.g., Faraone et al., 2006). Furthermore, employing measures such as the ANT-R in combination with measures of day-to-day functioning and fMRI or similar measures of brain functioning may well provide paramount insight into models proposing that alterations in specific brain areas (e.g., ACC or insula; Francx et al., 2015) are associated with the symptoms of ADHD, and by this potentially offering more specific targets for interventions and outcome measures in the future.

4.4 Clinical implications

The current work contributed to the existing literature by emphasizing the close relations between aspects of executive functioning and difficulties related to emotion regulation amongst those affected by ADHD. Furthermore, it has provided initial support for GMT as a potential intervention for adults with ADHD. Participating adults reported improvements on measures of daily functioning related to quality of life, productivity, cognitive slip-ups, as well as ADHD symptoms and certain aspects of emotional regulation. We interpret these findings to indicate that the participants

have been able to generalize the concepts from the intervention and utilize these in their everyday lives. Furthermore, the results indicate that behavioural changes are most closely connected to changes in neuropsychological measures of inhibition, and that these changes happen in parallel with an improvement in the executive control network. As such, the current work has contributed to highlighting potential outcome measures for future studies aiming to understand mechanisms contributing to the various functional outcomes associated with ADHD.

5. Conclusions

The main aim of this thesis was to investigate whether a group-based intervention aimed at improving executive control, namely GMT, would represent a promising treatment alternative for adults with ADHD. The results of the two included papers focusing on GMT indicate that the intervention holds promise as a potentially useful intervention for individuals affected by ADHD. Furthermore, we believe that these papers underline the potential role of attentional control in our understanding of the disorder, and as a target of interventions.

A secondary aim of the present work was to investigate the relationship between aspects of executive functioning and emotion regulation. We believe that the findings from Paper I and II emphasize the importance of attempting to improve our understanding of this relationship, and that the results provide insights with regards to measures that can be employed in future studies which can untangle the directionality of this relationship.

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Paper I

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Keeping Emotions in Mind: The Influence of Working Memory Capacity on Parent-Reported Symptoms of Emotional Lability in a Sample of Children With and Without ADHD

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Emotional lability (EL) often co-occurs with attention-deficit/hyperactivity disorder (ADHD) in children. However, difficulties of regulating intense emotions in ADHD are still poorly understood. We investigated the potential role of working memory (WM) as a protective factor against EL in children with ADHD by building on models describing the close relationship between WM and regulation of emotions. The parents of 41 children with ADHD and 34 typically developing children (TDC) filled out the emotional control scale (ECS) from the Behavior Rating Inventory of Executive Functioning and the child behavior checklist (CBCL). The children themselves completed the backward conditions of the digit span (DS) and spatial span (SS) tasks as well as the letter–umber sequencing (LNS) task. The results of a stepwise regression analysis confirmed the negative relationship between parent reported EL measured using the ECS and scores on the LNS, when controlling for symptoms of ADHD and oppositional defiant disorder (ODD). WM thus seems to be important for the ability of the children to express emotions in an adaptive and flexible way. We therefore suggest that a poorer WM capacity, which is often found in children with ADHD, may be a predictor of high levels of EL.

Keywords: working memory, attention-deficit/hyperactivity disorder, emotional lability, emotion regulation, letter– number sequencing

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a frequent neurodevelopmental disorder present in around 5% of children (Polanczyk and Jensen, 2008; Willcutt, 2012). Problems of self-regulation associated with the disorder include difficulties in both cognitive (Willcutt et al., 2005) and emotional (Shaw et al., 2014) control functions (see Nigg, 2017). Typical difficulties include a reduced performance on working memory (WM) tasks, which measure the capacity to monitor and modulate incoming information (see the meta-analyses of Martinussen et al., 2005; Kasper et al., 2012). At the same time, parents of children with ADHD tend to report that their children have problems controlling their emotional expressions (Skirrow et al., 2009). This has been described as emotional lability (EL; e.g., Sobanski et al., 2010), which includes frequent expressions of high intensity (negative) emotions (Skirrow et al., 2009; Shaw et al., 2014). Such difficulties can be assessed with parent reports on the emotional control scale (ECS) of the Behavior Rating Inventory of Executive Function that measures the ability to modulate emotional responses, with high scores indicating a high level of EL or explosiveness (BRIEF; cf. page 18 of Gioia et al., 2000). The ability to monitor and modulate incoming information (WM capacity) is believed to be very important for the adaptive perception, experience, and expression of emotions (i.e., level of EL) (e.g., Gross, 2002; Sheppes and Gross, 2011; Sheppes et al., 2014; Smith and Lane, 2015).

Baddeley's (Baddeley, 1986, 2000, 2002) WM model can be used to understand the role of WM in emotional experiences and the modulation of these experiences. He describes WM as a hierarchical system comprising a central executive that regulates and controls the storing (the phonological loop and the visuospatial sketchpad) and integration (the episodic buffer) of information from multiple modalities. The central executive is, as such, essential for monitoring and

modulating incoming information by regulating the allocation of attention in accordance with goal-oriented behavior. A higher WM capacity can help a child to modulate an emotional reaction by taking into perspective the situational expectancies (e.g., such as downregulating the emotional impact of a situation; Knudsen, 2007). Previous studies have shown that the contribution of the capacity to modulate the meaning and importance of emotional experiences is important in pursuing goal-oriented behavior (Gross, 2002; Sheppes and Gross, 2011; Bridgett et al., 2013; Sheppes et al., 2014; Smith and Lane, 2015). Gross (2002), Sheppes and Gross (2011), McRae et al. (2012), and Sheppes et al. (2014) have focused on the role of verbal WM in the experience, expression and regulation of emotions in typically developing adults and concluded that the ability to cognitively reappraise experiences eliciting negative emotions is related to better performance on verbal WM tasks. Typically, participants have been exposed to emotional stimuli with varying valence, such as emotion eliciting images, with the instruction to actively reduce the emotional impact of the stimuli by constructing alternative interpretations. One study finding supporting evidence in typically developing, young adults showed that the distribution of pre-made reappraisals, assumed to decrease the cognitive cost of reappraisal, increased the ability to down-regulate the intensity of negative emotions and thus facilitated the reappraisal process (Sheppes et al., 2014). Similarly, research investigating the role of cognitive control in emotional experience from a developmental perspective (i.e., based on the model of Posner and Rothbart, 2000), have also implicated the importance of verbal WM capacity (Bridgett et al., 2013). This is in line with work suggesting a relationship between reduced WM capacity, as part of executive functioning, and emotional difficulties in children with ADHD (e.g., Nigg et al., 2004; Sheppes et al., 2015).

The high prevalence of EL difficulties in children and adults with ADHD (Skirrow et al., 2009) has been noted over time (Wender, 1972), and has been included as an associated feature to ADHD in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013). Previously, efforts to explain this association have predominantly focused on poorer inhibitory control (Barkley, 1997) and high levels of oppositional defiant disorder (ODD; e.g., Sobanski et al., 2010) as predictors of EL.

Only one prior study (Banaschewski et al., 2012) has, to the best of our knowledge, investigated how inhibitory control and WM relate to EL in ADHD. They found no significant association between these functions and parent-reported levels of EL after controlling for ADHD symptoms. However, the WM task applied, the digit span (DS), is probably not as sensitive as other measures of verbal WM in assessing the capacity to modulate incoming information (i.e., simple reversal of a single stimulus category may not be sufficiently cognitively demanding; Shelton et al., 2009; Kasper et al., 2012). We therefore wanted to investigate a possible link between verbal WM and parentreported EL by including a WM task that is assumed to place a higher load on the modulation of incoming information than the digit span, namely the letter–number sequencing (LNS) task (e.g., a "complex" task; Shelton et al., 2009). The LNS requires the participant both to remember (store, i.e., the phonological loop) and to sequence the digits and letters that are presented according to numerical and alphabetical order (integrating stored information and modulating it according to knowledge of the alphabet, i.e., the episodic buffer). Thus, introducing a greater processing demand and reliance of the central executive than simple reversal. It is important to note that WM, together with inhibitory control and cognitive flexibility, are suggested to comprise the subfunctions of cognitive control (Miyake et al., 2000). WM is thus

shown to load on inhibitory control, however, not on cognitive flexibility (see Miyake and Friedman, 2012). Following Baddeley (1986) model, the central executive acts as an inhibitory control component. However, there is ample evidence of the importance of WM – and not inhibitory control alone – in several emotion regulation strategies (Smith and Lane, 2015), including cognitive reappraisal (McRae et al., 2012). This may be because these processes involve multiple components of WM. In addition to inhibitory control (i.e., central executive), the information is modulated by holding it in temporary storage (i.e., the phonological loop and the visuospatial sketchpad) at the same time as the information is integrated with existing knowledge and experience (i.e., the episodic buffer) (Baddeley, 2000, 2002).

Therefore, based on the theories of Gross (Gross, 2002; Sheppes and Gross, 2011; Sheppes et al., 2014) and Posner and Rothbart (Posner and Rothbart, 2000; Rueda et al., 2005; Rothbart et al., 2011; Bridgett et al., 2013) as well as a recent review (Smith and Lane, 2015), we expected an inverse relationship between verbal WM and parent reported difficulties related to EL. To examine this hypothesis we used three WM tasks – the DS and SS which can be described as "simple reversal" verbal and visuospatial span tasks, respectively, and the LNS which can be described as a complex verbal WM task – and only expected verbal WM capacity to associate with EL, and then only with the WM task with the highest load on modulation of incoming information (i.e., the LNS; Shelton et al., 2009). We also wanted to explore whether this association was independent of parent reported symptoms of ADHD and ODD, and diagnostic status. As the reviewed studies (e.g., Gross, 2002; Sheppes and Gross, 2011; McRae et al., 2012; Sheppes et al., 2014) indicate an inverse relationship between EL and WM capacity in healthy samples, this inverse relationship may not distinguish between the ADHD group and the typically developing children (TDC). However, we

expected higher levels of parent reported EL symptoms and a poorer WM capacity in the ADHD group than among the TDC. Furthermore, due to the noted association between WM and inhibition, as well as prior theories emphasizing the importance of difficulties related to inhibition, we also conducted supplementary analyses to investigate whether inhibition would be a significant contributor to the current results (see **Supplementary Materials**).

MATERIALS AND METHODS

Participants

The current study included 75 children between 8 and 12 years old, and consisted of 41 children with an ADHD diagnosis and a control group of 34 TDC. There were no group differences in sex or age distributions between the two groups (**Table 1**).All participating children had a full-scale intelligence quotient (FSIQ) above 75, however, the children with an ADHD diagnosis had lower FSIQ than the TDC. The study was carried out with the approval of the Regional Ethical Committee for Western Norway (REK-Vest), and written informed consent in accordance with the Declaration of Helsinki was obtained from all parents.

Children with a suspected ADHD diagnosis were referred from outpatient child and adolescent psychiatric clinics serving the municipality of Bergen, Norway. A control group of TDC was recruited from schools in geographical areas overlapping with the areas served by the above mentioned outpatient clinics.

Exclusion criteria for both groups were an existing ADHD diagnosis and prior use of psychostimulant medicine due to the wish to study cognitive functions that had not been modulated by treatment effects (Eichele et al., 2016; Plessen et al., 2016; Sørensen et al., 2017). Further exclusion criteria were, suspicion of an autism spectrum disorder, or a prior head injury with loss of consciousness. The diagnosis of ADHD was given following the algorithm of the

"Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version" (K-SADS-PL; Kaufman et al., 1997). Clinical professionals interviewed the children and their parents using the K-SADS-PL, and a board consisting of a child psychiatrist and a clinical psychologist finally confirmed the diagnostic evaluations. Only children with a primary diagnosis of ADHD were included in the clinical group (n = 41), 26 children fulfilled the diagnostic criteria for the combined subtype, 12 had the predominantly inattentive subtype, and three the hyperactive/impulsive subtype on the basis of a best estimate diagnosis reviewing all available materials (Leckman et al., 1982). Comorbidities affected several of the participating children. Among the children with ADHD, ODD was the most common comorbidity (n = 17) with three of these children also fulfilling the criteria for a conduct disorder. Furthermore, 15 of the children with ADHD also fulfilled the criteria for an anxiety disorder and three the criteria for a tic disorder. One of the TDC fulfilled the criteria for a specific phobia. FSIQ was assessed using the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2003). The general ability index (GAI) score was also included as a measure of intellectual level in the current study, because WM scores are included in the calculation of the FSIQ scores (**Table 1**).

Working Memory

Working memory was assessed with the backward conditions of the DS and the spatial span (SS) tasks, as well as the LNS task (Kaplan et al., 2004; Wechsler, 2003). In the backward conditions of the DS and the SS, children are instructed to recall and reproduce a list, or touch blocks, in the opposite order of that presented by the examiner (i.e., for the DS the examiner may read the sequence 2-7-1 and the child is to respond by reversing this sequence into 1-7-2), whereas the LNS requires the children to recall, rearrange, and reproduce a sequence of letters and numbers presented aloud by the examiner by

first repeating the numbers in ascending order and then the letters in alphabetical order (i.e., the sequence E-1-F is to be rearranged into 1-E-F; Kaplan et al., 2004). The DS and SS have been described as "simple" span tasks (i.e., even though the tasks include reversal of stimuli this may not be sufficiently demanding to categorize such tasks as encompassing a high load on the central executive component of WM), whereas the LNS is the clinical measure which is most closely associated with laboratory measures of WM (i.e., additional processing of the stored information is required to correctly sort numbers by size and letters by alphabet placement; Shelton et al., 2009; Kasper et al., 2012).

Emotional Lability (EL)

Emotional lability was measured with parent information on the emotional control subscale from the Behavior Rating Inventory of Executive Functioning, which "addresses the manifestation of executive functions within the emotional realm and measures a child's ability to modulate emotional responses. Poor emotional control can be expressed as EL or emotional explosiveness" (Gioia et al., 2000, p. 18). This subscale asks the parents how they experience their children typically acting when they are upset, angry, or sad. Each item is evaluated according to a Likert-scale with three response alternatives: "often" (score 3), "sometimes" (score 2), or "never" (score 1). Internal reliability, as estimated by Cronbach's alpha, is high (0.92; Gioia et al., 2000), also in a Norwegian sample in a comparable age group (Ranging from 0.80–0.98 for all subscales; Sørensen et al., 2011), and in the current sample (0.94 for the ECS). In the linear statistical analyses, we used the raw scores to secure a higher variability in scores (i.e., standardized scores are centralized around the mean).

TABLE 1 | Descriptive characteristics of the sample.
FSIQ, full scale IQ; GAI, general ability index; ADHD, scores on the attention deficit/hyperactivity problems scale of the CBCL; ODD, scores on the oppositional defiant problems scale of the CBCL; DS, score on the digit span backward condition; SS, score on the spatial span backward condition; LNS; score on the letter–number sequencing task; TDC, typically developing children; ODD-diagnosis, oppositional defiant disorder-diagnosis.

	TDC		ADHD		Between-group effects			
	M	SD	*M*	SD	*F/chi square*	*Df*	*p*	*Post hoc*
Age (years)	9.47	1.08	9.65	1.25	0.43	1/72	ns	
FSIQ	105.76	11.07	91.15	7.33	4.71	1/72	<0.001	TDC > ADHD
GAI	111.94	12.47	95.60	8.85	2.85	1/72	<0.001	TDC > ADHD
ADHD	1.00	1.33	9.34	2.47	310.16	1/72	<0.001	TDC < ADHD
ODD	0.76	1.28	4.49	2.95	46.88	1/72	<0.001	TDC < ADHD
ECS	12.68	3.21	19.75	5.63	41.99	1/72	<0.001	TDC < ADHD
DS	6.74	1.69	6.03	1.33	4.08	1/72	<0.05	TDC > ADHD
SS	7.41	2.00	5.80	1.42	16.32	1/72	=0.001	TDC > ADHD
LNS	15.85	4.05	12.55	3.62	13.72	1/72	=0.001	TDC > ADHD
Boys/Girls	20/14		29/11		1.54	1	ns	
ODD-diagnosis (number/total)	0/34		16/40		17.35	1	<0.001	Pearson X^2

Dimensional Symptom Scales of ODD and ADHD

We used the parent form of the child behavior checklist (CBCL), part of the Achenbach System of Empirically Based Assessment (ASEBA; Achenbach and Rescorla, 2001), to investigate the predictive validity of symptoms of ADHD and ODD on EL. The subscales of interest in the current study were the oppositional defiant problems scale (ODD symptom scale) and the attentiondeficit/hyperactivity problems scale (ADHD symptom scale). The CBCL is a highly validated and reliable measures in this age group (Achenbach and Rescorla, 2001), and also for use with clinical populations, including children and youth with ADHD and comorbidities (Achenbach and Rescorla, 2001; Krol et al., 2006; Biederman et al., 2008).

Statistical Analyses

All statistical analyses were conducted using IBM SPSS, version 25. Bivariate correlation analyses were conducted among all variables of interest. To test our main hypothesis, we conducted a linear stepwise regression analysis that included EL scores from the ECS as the dependent variable, and age, gender, symptoms of ODD and ADHD, GAI scores, and WM scores of DS, SS, and LNS scores as the independent variables. FSIQ was not included as it has been argued that controlling for it as a covariate is likely to distort findings (Dennis et al., 2009).

The stepwise regression analysis was followed by a moderation analysis as described by Kraemer et al. (2002) and Hayes (2012) building on the model of Baron and Kenny (1986). In our study this comprised a regression approach including the independent variable of the LNS scores (IV), a moderator variable of diagnostic status of ADHD versus TDC (M), and an interaction variable of the LNS scores by moderator variable of diagnostic status (IV × M) with the EL scores from the ECS as the dependent variable.

To investigate the potential influence of inhibition on the relationship between WM-scores and EL scores

from the ECS we repeated the primary stepwise regression with the StopSignal Task score as an independent variable together with WM scores, symptoms of ADHD and ODD, age, and gender (see **Supplementary Materials**).

Missing data for one child each on ADHD symptoms, ODD symptoms, and GAI were replaced with the series mean. Furthermore, an inspection of the studentized residuals showed that one participant belonging to the group of children with ADHD was an outlier (Aguinis et al., 2013). This child's data were therefore omitted from the analyses.

RESULTS

Preliminary Results

Preliminary correlational analyses of the relationship between age and the variables of EL and the WM scores (LNS, SS, and DS), showed that age correlated significantly with the WM scores of SS and LNS (**Table 2**). Age did, however, not correlate with the DS scores. Gender appeared to only be significantly correlated with the DS scores and not with the other WM scores (LNS and SS). The parent-reported symptoms of EL, ODD and ADHD were not significantly correlated with either age or gender (See **Table2**). All three WM scores of LNS, SS, and DS correlated significantly with each other.

The Relationship Between WM Capacity and Parent-Reported Emotional Lability

All three WM scores of LNS, SS, and DS were inversely correlated with the parent-reported EL scores on the ECS. The forward linear stepwise regression model including the EL scores from the ECS as the dependent variable and the independent variables of age, gender, ADHD symptoms, GAI scores, and the WM scores of LNS, DS, and SS, showed that only symptoms of ODD and the LNS scores significantly predicted the parent-reported scores of EL on the ECS, and not age, gender, GAI, symptoms of ADHD, scores on the

DS or scores on the SS (see **Table 3**).

The results of the moderation analysis, investigating the interaction between ADHD diagnostic status and the LNS scores on the EL scores from the ECS, showed that there were no significant interaction between the LNS scores and diagnostic status (see **Figure 1**).

TABLE 2 | Correlations among the examined variables.

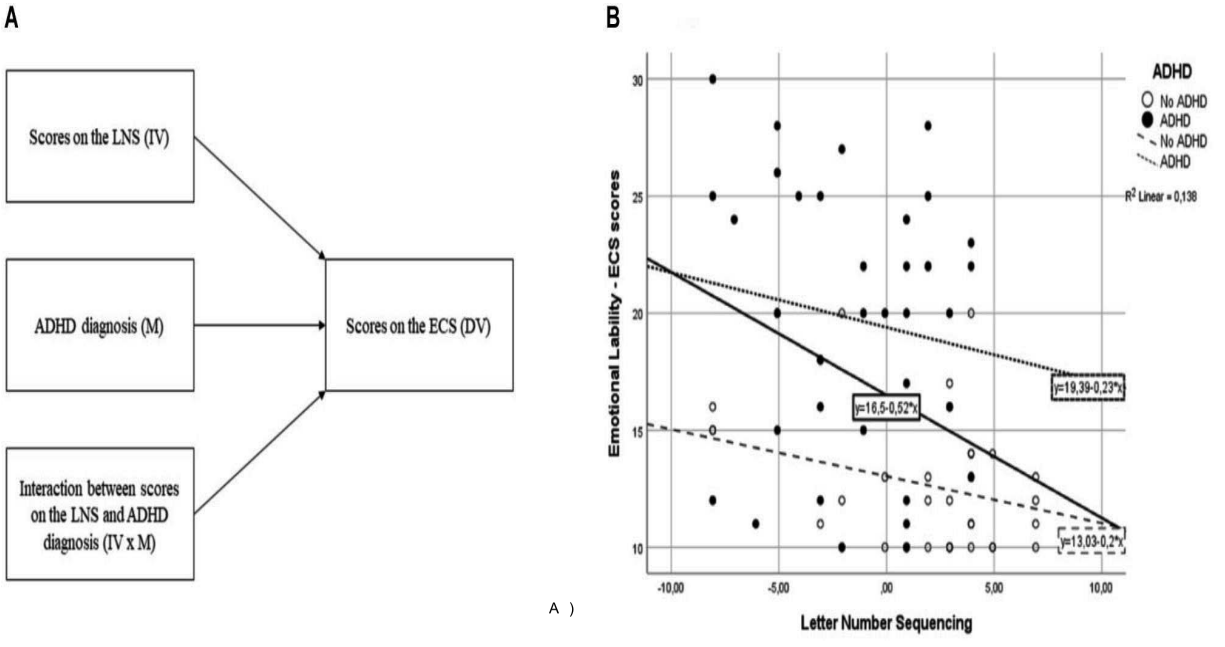
	1	2	3	4	5	6	7	8
(1) EL	–	−0.37**	−0.31**	−0.21*	0.84**	0.70**	0.05	0.05
(2) LNS		–	0.53**	0.49**	−0.24*	−0.40**	0.33**	0.03
(3) SS			–	0.36**	−0.24*	−0.47**	0.36**	−0.05
(4) DS				–	−0.09	−0.19	0.14	−0.21*
(5) ODD					–	0.72**	0.15	0.08
(6) ADHD						–	0.09	0.10
(7) Age							–	0.18
(8) Gender								–

*EL, score on the emotional control scale of the BRIEF; ADHD, score on the attention deficit/hyperactivity problems scale of the CBCL; ODD, score on the oppositional defiant problems scale of the CBCL; DS, score on the digit span backward condition; SS, score on the spatial span backward condition; LNS, score on the letter–number sequencing task. **Correlation is significant at the 0.01 level (1-tailed); *correlation is significant at the 0.05 level (1-tailed).*

TABLE 3 | Results from the forward stepwise regression model showing the prediction of EL based on symptoms of ODD and LNS-scores.

		Model summar		y df		ECS			
		Adjusted R^2	*1*R		*p*	B	SE B	β	*p*
Model 1	ODD	0.70	0.71	1/72	<0.001	1.65	0.13	0.84	<0.001
Model 2	ODD	0.73	0.03	1/71	<0.01	1.56	0.12	0.80	<0.001
	LNS					−0.26	0.09	−0.18	<0.01

ECS, score on the emotional control scale of the BRIEF; ODD, score on the oppositional defiant problems scale of the CBCL; LNS, Score on the letter–number sequencing task.



A)

FIGURE 1 | A graphical representation of the moderation analysis (A), and a scatterplot showing the distribution of scores on the Letter-Number Sequencing task (LNS) and Emotional Control Scale (ECS) as well as the equations describing the relationships between these for the group with attention-deficit/hyperactivity disorder (ADHD), the No ADHD as well as the whole sample (B). Note: IV, independent variable; M, moderator; DV, dependent variable. Letter Number Sequencing = Centered scores on the Letter Number Sequencing task (i.e., individual scores minus the sample mean)

DISCUSSION

In line with our hypotheses, we found an inverse relationship between children's verbal WM scores and parent reported EL.

As expected, higher LNS scores were related to lower EL symptoms after controlling for parent-reported ADHD and ODD symptoms. The follow-up moderation analysis supported that this relationship was independent of diagnostic status, although the levels of both WM capacity and EL differed between the groups (i.e., children with ADHD had lower WM scores and higher EL scores than TDC, but the relationships between these scores did not significantly differ between groups).

The current findings are in line with previous studies in healthy samples (e.g., McRae et al., 2012; Sheppes et al., 2014) in that a lower WM capacity seems to be related to an increased probability of experiencing and expressing emotions in a way which is described as problematic by the children's parents. Overall the current findings are therefore also in line with the model proposed by Gross and colleagues (Gross, 2002; Sheppes and Gross, 2011) and the previous findings that verbal WM is involved in expressing one's emotions in an adaptive and goaloriented way (Smith and Lane, 2015). The current findings can also be linked to similar findings from temperamental research showing an overlap between WM and efficient control of one's emotions (Bridgett et al., 2013). This may suggest that a higher WM capacity acts as a protective factor against developing clinically significant difficulties in expressing one's emotions (i.e., difficulties in controlling strong emotional outbursts – EL).

The findings may also be seen in connection with research on ADHD. There is a known relationship between ADHD and lower WM capacity (Martinussen et al., 2005). This lower WM capacity may be one of the factors contributing to the high prevalence of clinically significant levels of EL in this group

(Skirrow et al., 2009; Sobanski et al., 2010). This is also in line with the suggestion that there may be a connection between difficulties in cognitive and emotional control (Nigg et al., 2004), although the current results cannot give any indication on the causal relationship between these difficulties. Important to note, though, is that the inverse relationship found between a lower WM capacity and higher levels of parent-reported ***EL*** did not appear to be restricted to children with ADHD. Rather this was shown to be a dimensional relationship true for the whole sample. The results, therefore, indicate that the findings regarding a relationship between WM and emotion regulation from studies on typically developing adult populations reviewed in this article are also applicable to children, both with and without ADHD. However, the children with ADHD showed poorer WM capacity on the LNS (and the SS) and a higher frequency of parentreported EL symptoms than the TDC, indicating that the inverse relationship between EL symptoms and WM capacity may be more significant for their everyday functioning than for the group of TDC. Future studies may therefore want to investigate whether this holds true in other populations with elevated levels of EL, such as in children with anxiety disorders (Maire et al., 2017) and in adults with bipolar disorders (Phillips et al., 2003), borderline personality disorder (Schoenleber et al., 2016) and post-traumatic stress disorder (Schoenleber et al., 2018). Interestingly, in the current study, neither age nor gender affected the relationship between WM capacity as measured with the LNS and the level of parent-reported EL. This indicates that a poorer WM capacity seems to relate to higher levels of EL in general, independent of diagnosis, age and gender of the child. However, both an ADHD diagnosis and age showed an expected association with the performance on the WM tasks, with the exception that age did not correlate with the performance on the DS task. A differential effect of gender on the WM task scores also

appeared, with boys scoring lower on the DS task compared to the girls, whereas such a difference did not appear on the SS and LNS. Previously, small age related improvements have been reported on the DS task in samples with similar age ranges as included in the current study (see Brocki and Bohlin, 2004; Lensing and Elsner, 2018). These findings seem to indicate two distinct periods of marked development in the ability to answer the task requirements of the DS, with one period ending around the age of ***8–9*** years, and the second commencing around 12–13 years of age. The period between these, spanning the age range of our participants, seems to be characterized by small developmental changes, and this may therefore be the explanation for the lack of association found between age and DS scores. With regard to gender effects on WM capacity in ADHD, previous studies show mixed results depending on the percentage of females included (Kasper et al., 2012). In studies with a more balanced gender distribution, as in the current study, smaller between-group effect sizes appear related to the WM capacity.

It is also worth mentioning some contrasts and similarities between the current findings and the findings of Banaschewski et al. (2012), as they found no association between WM and EL in children with ADHD. As stated in the introduction, we believe this may be due to the measure applied. The DS was the only measure of WM included in the study of Banaschewski et al. (2012), and our results support their conclusion that this measure is not closely associated with EL. However, we believe that the current results support the assumption that WM is in fact meaningfully associated with EL, and that WM as measured using the LNS specifically, seems to be particularly important. Another distinction between the two studies is the inclusion of a measure of ODD in the current work. Given that findings show that EL in ADHD seems to be more closely associated to ODD than to ADHD (Sobanski et al., 2010), we believe

that the significance of the current findings even when controlling for symptoms of ODD further supports the notion that WM capacity may be an important protective factor against the development of EL. It is, however, worth noting the possibility that the close association between the LNS and EL may not be due to it being a specific measure of verbal WM, but of general WM capacity due to its' higher demands on the modulation of information (Kasper et al., 2012).

The current findings highlight some interesting possible directions for future work. If the current results can be replicated in a larger sample we believe that this would also merit an investigation of whether measures of verbal WM could also be used to direct the implementation of clinical interventions aimed at reducing the impact of EL as an associated feature of ADHD, and at reducing the risk for comorbid difficulties related to EL (i.e., ODD; Sobanski et al., 2010). One potential intervention in this regard could be emotional WM training, which consists of a dual n-back task presenting a combination of auditory and visual stimuli where a majority of the stimuli have a negative emotional valence (Schweizer et al., 2011). Such training has been shown to have an effect on a frontoparietal network assumed to underlie both WM and affective control (Schweizer et al., 2013). Furthermore, results show that the effects of such training generalizes to traditional measures of emotion regulation (Schweizer et al., 2013). Another potential area of investigation is whether a screening of verbal WM can help inform the pharmacological treatment of ADHD. Building on the study by Cubillo et al. (2013) showing a differential effect of methylphenidate and atomoxetine, in combination with findings indicating an anatomical overlap between WM and self-regulation (e.g., Bridgett et al., 2015), it seems plausible to hypothesize that atomoxetine might be particularly beneficial for the subgroup of children with ADHD who also have a low WM capacity. This is due to

differential effects showing that atomoxetine has a pronounced activating effect on the dorsolateral prefrontal cortex, a region which has been shown to be involved in both WM and executive attention (Bridgett et al., 2015).

Strengths and Limitations

The current study had several important strengths and limitations. It employed neuropsychological measures which are often used in clinical practice (i.e., subtests from the WISC-IV and WISC-IV-Integrated) in combination with well validated and widely accessible questionnaires, thereby obtaining results which are available in, and transferable to, day-to-day clinical practice and may be replicated in many clinical settings. We also regard the use of dimensional analyses as a strength, as these allowed us to investigate the hypothesized pattern of results in both the children with ADHD and the TDC. This is in line with our expectations as the hypothesis was, to a large degree, based on studies of typically developing individuals.

The main limitations of this study are the limited sample size and the cross-sectional nature of our data. Due to these limitations all of our participants with high levels of EL belonged to the diagnostic group, thus limiting the generalizability of our conclusions. Furthermore, the use of cross-sectional data does not allow for investigation of the developmental ordering of the children's difficulties, which would be highly relevant with regards to the model proposed by Nigg et al. (2004). A closer examination of whether the results reported here are mainly due to the use of a measure of verbal WM or a WM task with high demands on the modulation of information is also necessary to improve our understanding of the relationship between WM and EL. At the current time it could equally well be argued that a complex visuospatial WM task would be equally as predictive of parent reported EL scores, and a direct comparison of two complex WM tasks where one is assumed to

be reliant on the verbal and one on the visuospatial component of WM would, therefore, help to clarify this issue. The results would also have been strengthened if the investigation had included a measure of task switching, as this executive function may associate with level of EL (e.g., Dickstein et al., 2007). There is also the issue of a significant difference in FSIQ between the two groups. Although this is common in studies of ADHD, and related to the known difference in WM capacity as well as likely to be related to testtaking behavior (Dennis et al., 2009), the findings should ideally be investigated in a sample with matched FSIQ scores. Lastly, the use of the same informant report when collecting information about symptoms of ADHD and ODD as well as EL may have reduced the statistical power of WM in the analyses (i.e., due to common-method variance; Richardson et al., 2009). Ideally, the investigation should be replicated with the inclusion of observer measures of emotional reactions to reduce the impact of this limitation.

CONCLUSION

The current study found support for the hypothesis that WM is a protective factor against elevated levels of EL in children, thus supporting previous findings showing the importance of high (verbal) WM capacity in the adaptive display of emotions. The results, if replicated, may represent an approach to understanding the functional heterogeneity associated with ADHD.

AUTHOR CONTRIBUTIONS

KP and LS conceived and designed the study. MH, NM, HE, SA, KP, and LS acquired the data. DJ and LS analyzed and interpreted the data. DJ, MH, TE, KP, and LS wrote the manuscript. All authors contributed to manuscript revision, read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.01846/full#supplementary-material

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Paper II

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An Exploratory Investigation of Goal Management Training in Adults With ADHD: Improvements in Inhibition and Everyday Functioning

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Background: Adults with attention deficit/hyperactivity disorder (ADHD) are predominantly treated with medication. However, there is also a need for effective, psychologically based interventions. As ADHD is strongly associated with reduced inhibitory control, cognitive remediation approaches should be efficient. Goal management training (GMT) aims at enhancing inhibitory control and has shown positive effects on inhibitory control in non-ADHD patient groups. The aim of the current study was to explore whether GMT would specifically enhance inhibitory control in adults with ADHD, and if such an enhancement would lead to secondary improvements in self-reported everyday functioning.

Methods: Twenty-one participants with ADHD (mean age: 39.05 years [SD 11.93]) completed the intervention and assessments pre-, post- and 6 months after the intervention. Measures included neuropsychological tests and self-report questionnaires pertaining to cognitive- and executive functioning, emotion regulation, quality of life, and ADHD symptoms.

Results: Compared to baseline, the participants showed enhanced inhibitory control on performance-based measures at post-assessment and 6-month follow-up. The participants also reported increased productivity and reduced cognitive difficulties in everyday life at both assessments post-treatment, as well as improvements in aspects of emotion regulation and a reduction in the severity of core ADHD-symptoms at 6-month follow-up.

Conclusion: Our exploratory study showed that GMT seems to specifically improve one of the core executive dysfunctions in ADHD, namely inhibitory control, with a positive effect lasting at least 6 months post-treatment. The adults with ADHD also reported improved self-regulation in their everyday life after completing GMT, providing strong arguments for further investigations of GMT as a treatment option for this group of adults.

Clinical trial registration: The study was registered under ISRCTN.com (ISRCTN91988877; https://doi.org/10.1186/ISRCTN91988877)

Keywords: ADHD, goal management training, treatment, intervention, inhibition, non-pharmacological, executive functioning

INTRODUCTION

Attention deficit/hyperactivity disorder (ADHD) is a common neurodevelopmental disorder affecting individuals of all ages with an estimated prevalence of 2.5–4.4% among adults (DSM5; Kessler et al., 2006; Simon et al., 2009; Badre, 2011; American Psychiatric Association, 2013; Polanczyk et al., 2014). Many negative consequences of ADHD have been documented ranging from difficulties regulating automatic and controlled cognitive processes, including reading, in childhood (Capri et al., 2020; Mohammadhasani et al., 2020) to underachievement in work and education later in life (Biederman et al., 2006; Halmøy et al., 2009; Klein et al., 2012; Halleland et al., 2015), difficulties related to social functioning (Biederman et al., 2006; Klein et al., 2012), and even increased mortality (e.g., Dalsgaard et al., 2015). These difficulties are partly related to the core ADHD symptoms of inattention, hyperactivity and impulsivity (Badre, 2011; American Psychiatric Association, 2013). However, they have also been linked to another frequently observed characteristic of ADHD, namely reduced executive functioning (e.g., reduced academic achievement, reduced occupational attainment; Barry et al., 2002; Doyle, 2006; Raggi and Chronis, 2006; Sarkis, 2014; Halleland et al., 2015; Fabio and Caprì, 2017).

The main treatment for adults with the disorder is pharmacotherapy with stimulant drugs (Kooij et al., 2010; Faraone et al., 2015; NICE, 2018). Despite strong evidence for its effectiveness (e.g., Cortese et al., 2018), pharmacological treatment of ADHD does not seem to fit all. In fact, a substantial number of patients continue to struggle with their symptoms, are ineligible or do not tolerate the side effects of the medication, opt out of such treatment, or discontinue the prescribed treatment (Lopez et al., 2018; NICE, 2018; Mohr-Jensen et al., 2020). Among the most frequent side effects of such treatments are loss of appetite, headaches,

abdominal pain, increased heart rate and blood pressure, and available findings indicate that a significant number of those receiving medication discontinue treatment due to such adverse effects (Cortese et al., 2018; Storebø et al., 2018; Elliott et al., 2020). Other investigations also indicate that medication use is associated with psychological adverse effects such as an experience of altered cognition, reduced creativity, increases in emotional difficulties, reduced engagement in activities and a sense of changing as a person (Kovshoff et al., 2016). There is also a lack of knowledge regarding long term tolerability and effects of ADHD-medication, and the risk of less common side effects (Elliott et al., 2020). Development of other treatment alternatives is, therefore, warranted. This is also in line with the stated wishes of adults with ADHD, and with findings showing that patients who are offered treatment options in addition to pharmacotherapy are more satisfied with the health services they receive compared to adults without such options (Solberg et al., 2015). Thus, there has been an increasing effort to develop psychologically based treatment alternatives for adults with ADHD (Kooij et al., 2010; Franke et al., 2018; Lopez et al., 2018; López-Pinar et al., 2018; Lam et al., 2019; Nimmo-Smith et al., 2020), most of which are based on cognitive-behavioral approaches. Findings indicate that such interventions may lead to reductions in core symptoms, and further, that cognitive remediation interventions may specifically improve the ability to organize everyday activities (e.g., Stevenson et al., 2002; De Crescenzo et al., 2017; Nimmo-Smith et al., 2020). The evidence in favor of these interventions is, however, still scarce.

This has led to efforts aimed at exploring whether psychological interventions can ameliorate difficulties in executive functioning in individuals with ADHD. Procedures to improve working memory functioning have been

investigated in children (e.g., Melby-Lervåg and Hulme, 2013) and adults with ADHD (e.g., Dentz et al., 2020). Although some studies show positive short-term effects on working memory functioning, long-term effects are uncertain and there is limited support for generalization to other aspects of executive functioning (Melby-Lervåg and Hulme, 2013; Dentz et al., 2020). The viability of applying existing working memory training programs on a population of adults with ADHD has also been questioned due to indications of limited tolerability (Marcelle et al., 2018). Similarly, studies of neurofeedback as a treatment for ADHD in children have yielded mixed findings with regards to effects on core symptoms and executive functioning (Cortese et al., 2016; Van Doren et al., 2019), while studies of neurofeedback in adults with ADHD are still limited.

In an effort to further the understanding of whether psychological interventions targeting executive functioning in adults with ADHD would be an efficient treatment alternative, we wanted to examine the effects of goal management training (GMT; Robertson, 1996; Levine et al., 2000, 2011). GMT is a group-based, metacognitive remediation protocol with an emphasis on strengthening inhibitory- and attentional control to support participants in employing strategies to maintain goal-directed behavior over time. Thus, the choice of GMT in the current study was based on the fact that poor inhibitory control has been described as a predominant causal factor of ADHD (e.g., Barkley, 1997; Sonuga-Barke et al., 2010), in addition to being conceptualized as a core component of executive functioning (Badre, 2011; Miyake and Friedman, 2012). It is also a strength that GMT has been shown to ameliorate executive dysfunction, including inhibitory control, in other groups (e.g., older adults, patients with substance use disorders) experiencing some of the same challenges as adults with ADHD (van Hooren et al., 2007; Alfonso et

al., 2011; Stamenova and Levine, 2019). To the best of our knowledge, GMT for adults with ADHD has only been tested in a small-scale pilot study (In de Braek et al., 2017). In that study, a modified manual consisting of GMT and psychoeducation (n = 12) was compared with the effect of psychoeducation without GMT (n = 15), and it included outcome measures focusing predominantly on everyday cognitive functioning according to the Cognitive Failures Questionnaire (CFQ; Broadbent et al., 1982) and a clinician-rated evaluation of everyday cognitive functioning (see Schneider et al., 1997). Only one performance-based measure, assessing everyday problem-solving, was included (Zoo Map From the Behavioral Assessment of the Dysexecutive Syndrome; Krabbendam et al., 1999). A positive effect of GMT was found only on the clinician-rated evaluation of cognitive functioning in everyday life (In de Braek et al., 2017). Importantly, the study employed a modified version of GMT which included several sessions of psychoeducation and an individual session in addition to the sessions that are part of the GMT manual. As such, it is difficult to draw conclusions about the specificity of the reported effects to GMT as psychoeducation may also have made significant contributions (e.g., Vidal et al., 2013).

The aim of the current study was to follow up on the pilot study by In de Braek et al. (2017) by employing an unmodified version of GMT. We aimed to test a neuropsychological model of how to measure effects of GMT in adults with ADHD by including performance-based measures of attention and executive functions, and by this provide a model that can guide future randomized controlled studies of GMT. Previous studies in other patient groups have found significant improvements following GMT on several performance-based measures of inhibitory control and related constructs (e.g., Levine et al., 2011; Stubberud et al., 2013; Hagen et al., 2020),

including on a self-report measure of inhibitory control and executive functioning (Stubberud et al., 2014). We therefore wanted to test whether GMT specifically targets the typically found reduced inhibitory control characteristic of adults with ADHD. To do so, we conducted an exploratory pilot trial of GMT in adults with ADHD, focusing specifically on effects on inhibitory control compared to effects on other aspects of executive functions such as working memory, flexible control of processing speed, and general problem-solving. We expected to find significant effects of GMT predominantly on test measures assessing inhibitory control, such as the Color Word Interference Test (CWIT) and the Tower test (Delis et al., 2001). These are tests that have previously shown that adults with ADHD tend to have impaired inhibitory control (see Young et al., 2007; Halleland et al., 2015). As secondary aims, we wanted to examine aspects of everyday functioning and expected that improved inhibitory control following GMT would be reflected in self-reports of executive-, behavioral-, and emotional control, as well as in improved quality of life.

MATERIALS AND METHODS

Participants

In total, 36 potential participants were recruited for the present study through two different approaches. A small subset of participants (N = 7) were recruited through an existing study of ADHD in adults at the University of Bergen (see Halleland et al., 2012 for a description of this study), while the majority of participants (N = 29) were recruited through local outpatient clinics in the municipality of Bergen. Recruitment was conducted by distributing a short information letter about the project, i.e., inclusion and exclusion criteria, the GMT intervention, assessments as well as a prompt to contact members of the project staff for further information. Upon contacting a project member, interested individuals were screened for

eligibility and given further information about the study as well as an informed-consent form in accordance with the Helsinki declaration. The study protocol was approved by the Regional Committee for Medical and Health Research Ethics, West Norway (2015/2325). All participants were compensated with 1000 NOK (approximately 110 USD) at the completion of the follow-up assessment to cover travel expenses.

Inclusion criteria for the study were an age of 18 years or older and a clinical diagnosis of ADHD (obtained prior to the project). Participants on medication were asked to avoid changes in dosage during the project period unless necessary. Exclusion criteria for the project were a lifetime history of psychotic disorder or an ongoing, severe psychiatric illness (i.e., moderate to severe suicidality, severe depression, severe social anxiety preventing participation in group sessions), ongoing substance use disorders and a full-scale intelligence quotient (IQ) below 80.

Procedure

All potential participants completed the Mini International Neuropsychiatric Interview Plus (M.I.N.I. Plus; Sheehan et al., 1998) as the first step of the baseline assessment to screen for severe psychiatric disorders or substance abuse. The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to estimate the participants' IQ. After completion of this introductory step, eligible participants were asked to complete the assessment procedure (see details below). With one exception (i.e., one participant had to be moved to a different group due to scheduling conflicts and therefore completed the assessment 5 weeks before attending the first session of GMT), all assessments were conducted within 3 weeks prior to the first session of GMT. Post-treatment assessments were conducted within two weeks following the last group session, and the follow-up

assessment was conducted six calendar months after completion of the intervention (±2 weeks).

Goal Management Training

Goal management training is a group-based metacognitive remediation program developed by Robertson (1996), Levine et al. (2000) based on Duncan (1986). According to Duncan's theory goal management fails as a result of the individual being unable to maintain current goals when faced with competing demands in the form of external or internal stimuli. GMT therefore emphasizes a five-stage strategy aimed at supporting the processes needed for goal achievement. These stages include the intermittent stopping of ongoing behavior to assess whether this is in line with current goals and, indeed, whether current goals are clear, structuring goals as a manageable set of subgoals, self-cueing to regulate alertness and attentional control, and regular reassessment of goal list and the progress made as a result of current behavior. Mindfulness-based exercises are also included to support sustained attention, help participants maintain a present centered focus and selfregulation. The intervention followed a manualized protocol used in earlier studies (e.g., Stubberud et al., 2013; Tornås et al., 2016) consisting of PowerPoint slides and a participant workbook. The materials used in this study were translated into Norwegian and back-translated to English as part of the study conducted by Stubberud et al. (2013). Minimal adjustments were made to the materials in order to adapt the educational part to participants with ADHD (i.e., mention of brain injury and its consequences were replaced with references to ADHD). The intervention consisted of nine weekly 2-h group sessions (see **Table 1**). Of note, participants had to attend a minimum of six out of the nine group sessions to be classified as completers. Each group had four to eight participants and was led by a clinical psychologist and a co-therapist who was either a clinical psychologist or

a clinical psychology student with clinical experience. The sessions were conducted during nine consecutive weeks when possible, or over a maximum of 11 weeks when holidays made this necessary. The sessions consisted of lectures, discussions and skill training intended to increase participants' awareness of their own attention as well as their awareness of the skills and techniques included in GMT. The included strategies are aimed at promoting goal-directed behavior through increasing executive and inhibitory control, stressing participants to periodically stop ongoing behavior ("stop-andthink"), monitor performance, and employ a stepwise approach to problem-solving (Levine et al., 2011). Furthermore, the element of sustained attention runs continuously through GMT, and is reinforced through mindfulness exercises (Kabat-Zinn, 1990). Participants were also encouraged to practice between sessions and to employ the workbook to structure these efforts. Homework assignments included monitoring everyday behavior, recording absentmindedness as well as goal attainment, and mindfulness exercises. These assignments were the basis for in-group discussions of the participants' experiences related to executive difficulties in their everyday life.

Clinician Administered Measures

The M.I.N.I. Plus (Sheehan et al., 1998) was used to assess potential participants for severe psychiatric illness necessitating exclusion from the project. The M.I.N.I. Plus was administered at baseline by project members who were either a licensed clinical psychologist or a clinical psychology student with experience from clinical practice and the use of diagnostic interviews under the supervision of a clinical psychologist.

Performance-Based Measures

Wechsler Abbreviated Scale of Intelligence

Performance on two subtests from WASI (Matrix reasoning and Vocabulary: Wechsler, 1999) were used to estimate the participants' IQ score. Participants completed this measure at baseline.

Delis-Kaplan Executive Function System: Trail Making Test

The Trail Making Test (TMT) from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001) was administered to assess the executive functions of attentional control and cognitive flexibility (switching). The fourth task is of special interest in the current study. Here, the participants are asked to connect circles with numbers and letters in an ascending and alternating pattern. Completion time and number and type of errors are recorded.

Delis-Kaplan Executive Function System: Color-Word Interference Test

The CWIT (Delis et al., 2001) was administered to assess the executive function of inhibitory control. The test consists of 4 different subtasks. Of interest to the current investigation are conditions three and four where participants are instructed to name the color of a color-word printed in a color that does not match the color-word, or to switch between naming the unmatched, printed color and reading the color words. Completion times and errors are recorded.

Delis-Kaplan Executive Function System: Tower Test

The Tower Test (Delis et al., 2001) was administered to assess inhibition. In the test, subjects are asked to recreate a model based on a picture of the required outcome. To do so they are asked to use a specified number of disks of varying sizes and place them in the depicted pattern. They may only move one disk at a time, all disks must always be placed on one of

TABLE 1 | An overview of the nine GMT sessions as well as the main content.

GMT session	Description and content
Session 1: The Present and the Absent Mind	Introduction of the concepts of present- and absentmindedness, as well as relating absentmindedness to failure of goal-attainment in everyday life. Introduction of Mindfulness ("body scan") as a tool to promote present-mindedness. Participants are asked to monitor absentmindedness and to practice mindfulness between sessions
Session 2: Absentminded Slip-Ups	Factors which promote or reduce the likelihood of absentminded slip-ups and consequences of such slip-ups are discussed. Participants are asked to continue their monitoring. Mindfulness exercises extended by introduction of a breathing exercise which they are asked to practice between sessions for the remainder of the intervention
Session 3: The Automatic Pilot	"The automatic pilot" is introduced as a descriptor of absentmindedness characterized by following existing routines. Discussion of how this may lead to unwanted responses. Participants are asked to log situational factors which increase the chances of slip-ups between sessions
Session 4: Stop the Automatic Pilot	"STOPPING!" the automatic pilot is introduced as a strategy for increasing present-mindedness and monitoring current behavior and mental content. "STOPPING!" is practiced between sessions
Session 5: The Mental Blackboard	Checking is introduced as a metaphor for working memory and as another key concept for increasing goal-attainment. The notion of limited capacity and the risk of having important information overwritten is emphasized. Checking the content of working memory is introduced along with a shortened breathing exercise in the "STOP!-FOCUS-CHECK" technique
Session 6: State Your Goal	Explicitly STATING relevant goals and behaviors is introduced as a strategy to promote retention of goals in working memory. "STOP!-STATE" cycle practiced
Session 7: Making Decisions	The concept of goal-conflict is introduced and discussed, as well as practical and emotional consequences. A To-Do list is introduced as an aid both for retention of goals and to alleviate decision-making. Use is incorporated in the "STOP!-STATE" cycle
Session 8: Splitting Tasks into Subtasks	Modification of overwhelming tasks by dividing these into manageable subtasks is discussed and practiced using the "STOP!-STATE-SPLIT" technique. Participants are asked to continue practice between sessions
Session 9: Checking (STOP!)	Checking, or the concept of adapting current goals and ongoing behavior as a result of changes in the external or internal environment, is discussed and practiced. Content and experiences from the program are summarized

three pegs, and larger disks may not be placed on top of smaller disks. Participants are asked to complete the depicted model in as few moves as possible, while attending to the rules. Time of first move, number of moves, rule violations, completion time and performance (i.e., completion of correct model) are recorded.

Letter-Number Sequencing and Spatial Span

The Letter-Number Sequencing task from the Wechsler Adult Intelligence Scale – 4th edition (Wechsler, 2008a) and the Spatial span from the Wechsler Memory Scale – 3rd edition (Wechsler, 2008b) were used to assess the participants' working memory functions. In the Letter-Number Sequencing an increasing number of letters and numbers are read to the participant, the participant is

then asked to repeat the sequence by arranging the numbers in increasing order followed by the letters in alphabetical order. In the Spatial span task, the examiner touches a sequence of blocks in a specified order and the participant is asked to copy the sequence (i.e., forward span) or to do so in the opposite order (i.e., backward span).

Hotel Task

The Hotel task (Manly et al., 2002) was administered as an analog of real-life problem-solving and a measure of generalization. The Hotel task consists of six different subtasks, and the participant are asked to distribute the allotted time of 15 min as evenly as possible across five of these while also completing the sixth task at two specified time points. Deviations from ideal time (e.g., 300 s) spent on the five time-demanding subtasks are recorded, so is deviation from the specified time when completing the sixth task, as well as total number of tasks attempted. The Hotel task has been shown to be sensitive to executive dysfunction and to have acceptable ecological validity (Roca et al., 2009).

Self-Report measures

Cognitive Failures Questionnaire

The CFQ (Broadbent et al., 1982) is a 25-item self-report questionnaire where respondent are asked to rate each statement using a scale from 0 (never) to 4 (very often). Higher total score indicates a higher number of difficulties related to failures in perception, memory, and motor functions.

Adult ADHD Self-Report Scale

The Adult ADHD Self-report Scale (ASRS; Kessler et al., 2005) is an 18-item symptom checklist assessing the presence of core symptoms of ADHD during the last 6 months prior to evaluation. Respondents are asked to scale each item from 0 (never) to 4 (very often). The checklist consists of nine statements related to symptoms of inattention and nine statements related to symptoms of

hyperactivity/impulsivity. Both sub-scores for these two domains as well as a total sum score are calculated.

Wender-Utah Rating Scale

The Wender-Utah Rating Scale (WURS; Ward et al., 1993) is a 25-item retrospective self-report checklist assessing the presence of various difficulties associated with ADHD in childhood based on the Utah criteria (Wender, 1972). Respondents are asked to respond to each item using a scale ranging from 0 (not at all, or just a little) to 4 (very much). The WURS was used to characterize the sample and was only administered at baseline.

Adult ADHD Quality of Life Inventory

The Adult ADHD Quality of Life inventory (AAQoL; Brod et al., 2005) is a 29-item questionnaire were participants were instructed to respond to each item using a 5-point scale ranging from 1 (not at all/never) to 5 (extremely/very often), resulting in four subscales (Life Outlook, Life Productivity, Psychological Health, and Relationships) as well as a total score.

Behavior Rating Inventory of Executive Function – Adult Version

The Behavior Rating Inventory of Executive Function Adult version (BRIEF-A; Gioia et al., 2000) is a 75-item self-report measure of everyday executive function. Participants are asked to rate each item is frequency of occurrence on a 3-point Likert scale from 1 (never) to 3 (often). The instrument yields nine clinical scales, as well as two broad index scores. Of particular interest to the current study are the subscales Inhibit, Shift and Working memory, as well as the index scores for Behavior regulation and Metacognition. The Global executive composite score is also reported.

Dysregulation of Emotions Rating Scale

The Dysregulation of Emotions Rating Scale (DERS; Gratz and Roemer, 2004) is a 36-item questionnaire where participants

are asked to rate each item using a 1 (almost never) to 5 (almost always) scale. The DERS consists of six subscales as well as a total score. For the present study, subscales measuring difficulties engaging in goal-directed behavior, impulse control difficulties and access to emotion regulation strategies when experiencing challenging emotions as well as total score, were employed.

All tests and questionnaires, except the WASI and the WURS, were administered at all assessments. Cronbach's αs ranged from acceptable to excellent (between 0.87 and 0.96).

Analyses

Preliminary Analyses

Statistical analyses were conducted using R version 4.0.2 (R Development Core Team, 2020) and SPSS version 25 (IBM Corporation., 2017). For all variables containing missing items, comparisons of means and covariances were conducted using Little's missing completely at random test (Little, 1988). Outliers were identified using median absolute deviation (MAD) and a conservative cut-off of ± three times the MAD (Leys et al., 2013). Independent sample, two-sided *t*-tests were conducted as preliminary analyses to compare the baseline characteristics of those participants who completed the intervention and those who dropped out with regards to self-report- and performancebased measures.

Main Analyses of Treatment Effects

Linear mixed-effects regression was performed using the lme4 package for R (Bates et al., 2015). Random intercepts were specified, and restricted maximum likelihood (REML) was used. Assessment session was used as the metric of time in the analyses, and coefficients represent change from baseline. Due to the limited statistical power of the study, these analyses were conducted without controlling for covariates. In a second step, exploratory analyses including medication status and age as covariates were conducted on

those measures showing a significant effect in the principal analyses. Significance tests were adjusted using false discovery rate control due to the number of tests performed following the procedure of Benjamini and Hochberg (i.e., $p < d \times i/n$; Benjamini and Hochberg, 1995; Glickman et al., 2014). Power-analyses conducted using G*power (Faul et al., 2007) prior to the study indicated that with an assumption of medium effect sizes and an α of.05 a total sample size of 27 participants would be required to reach a power of.80 if employing *t*-tests.

RESULTS

Completion

Thirty-six potential participants volunteered for the study. Four participants were excluded, one due to psychotic disorder, one due to ongoing substance abuse, and two participants because they failed to complete the pre-assessment. The remaining 32 participants were included in the study.

Twenty-three participants completed the intervention, of which 21 completed the post-intervention and follow-up assessments. Of the 11 participants who dropped out, nine did so without giving notice or answering phone calls attempting to reestablish contact. Of these, one did so before the first treatment session, three participants attended one session prior to dropping out, one participant attended two sessions, two participants attended three sessions, and two participants completed the intervention but did not attend the posttreatment assessment. The two drop-out participants who gave notice both reported changes in their work schedules as the reason for drop-out after attending two and three sessions, respectively. All participants who completed the intervention attended a minimum of seven of the nine group sessions (see **Figure 1**).

Missing Data and Outliers

The dataset had 16 missing single items from questionnaires (totaling 1% or less of total item responses

per questionnaire). Little's missing completely at random test showed that all missing items were randomly distributed. Missing items were therefore replaced using the expectation maximization algorithm in SPSS. One participants' BRIEF-A-questionnaire from the preassessment was missing, assessment data from one participant was also missing for most measures of the post-assessment, and for another participant on all measures of the followup assessment. Complete questionnaires that were missing were not replaced.

In addition, 32 scores were identified as outliers (approximately 1% of total scores), and were replaced with ± MAD.

Participant Characteristics

Table 2 shows baseline characteristics of the complete sample, in addition to the subgroups who completed the intervention (completers) and those who did not (non-completers). Noncompleters were significantly younger and reported lower quality of life at baseline compared to completers. Regarding comorbidities there were no significant differences between completers and non-completers, but a non-significant trend toward non-completers reporting higher symptom severity.

Treatment Effects – Completer Sample

An overview of changes in the included variables from preto post- and follow-up assessments among participants who completed GMT is shown in **Table 3**.

Primary Outcome Measures – Performance-Based Tests of Executive Functions Analyses of scores on the performance-based measures of executive functions and problem solving showed improved efficiency in inhibitory control from baseline to post-assessment, as evidenced by a significant reduction in completion times on the third and fourth conditions of the CWIT (*M*s = 55.55 and 62.47 at baseline, *M*dif = −4.48 and −8.64 for the third condition and fourth condition, respectively).

These changes were maintained at follow-up 6 months later (*M*dif = −5.60 and −9.33, respectively). The participants also increased their achievement scores on the Tower test at the followup assessment relative to baseline (*M* = 19.38 at baseline, *M*dif = 2.12 at follow-up) and improved their performance on the fourth condition of the TMT (*M* = 72.03 at baseline, *M*dif = −11.37 at follow-up), thus showing further improvements in inhibition in addition to attentional control and cognitive flexibility. No significant changes were detected on the other performance-based measures of executive function. However, on the Hotel task, an improvement in general problem solving was shown in a reduction in deviation from the ideal time from pre- to follow-up assessment (*M* = 352.71 at baseline, *M*dif = −117.59 at follow-up).

The exploratory analyses investigating the potential effects of age and medication status did not show any significant effects of these covariates (all *p*s ≥ 0.09 without correction for multiple comparisons).

Secondary Outcome Measures of Self-Reported Symptoms, Quality of Life, and Everyday Functioning

As secondary effects, the participants reported a significant reduction of cognitive functioning difficulties in their everyday lives, as measured by the CFQ (*M* = 61.41 at baseline, *M*dif = −6.75 and −7.61 at post and follow-up, respectively).

The participants further reported a significant reduction of ADHD symptoms on the ASRS at both time points. They also reported increased quality of life following GMT as measured by the Life productivity subscale of the AAQoL (*M* = 42.32 at baseline, *M*dif = 11.89 and 12.52 at post and follow-up, respectively). This subscale assesses functioning in school/work and everyday task accomplishment. The remaining subscales of the AAQoL showed no significant

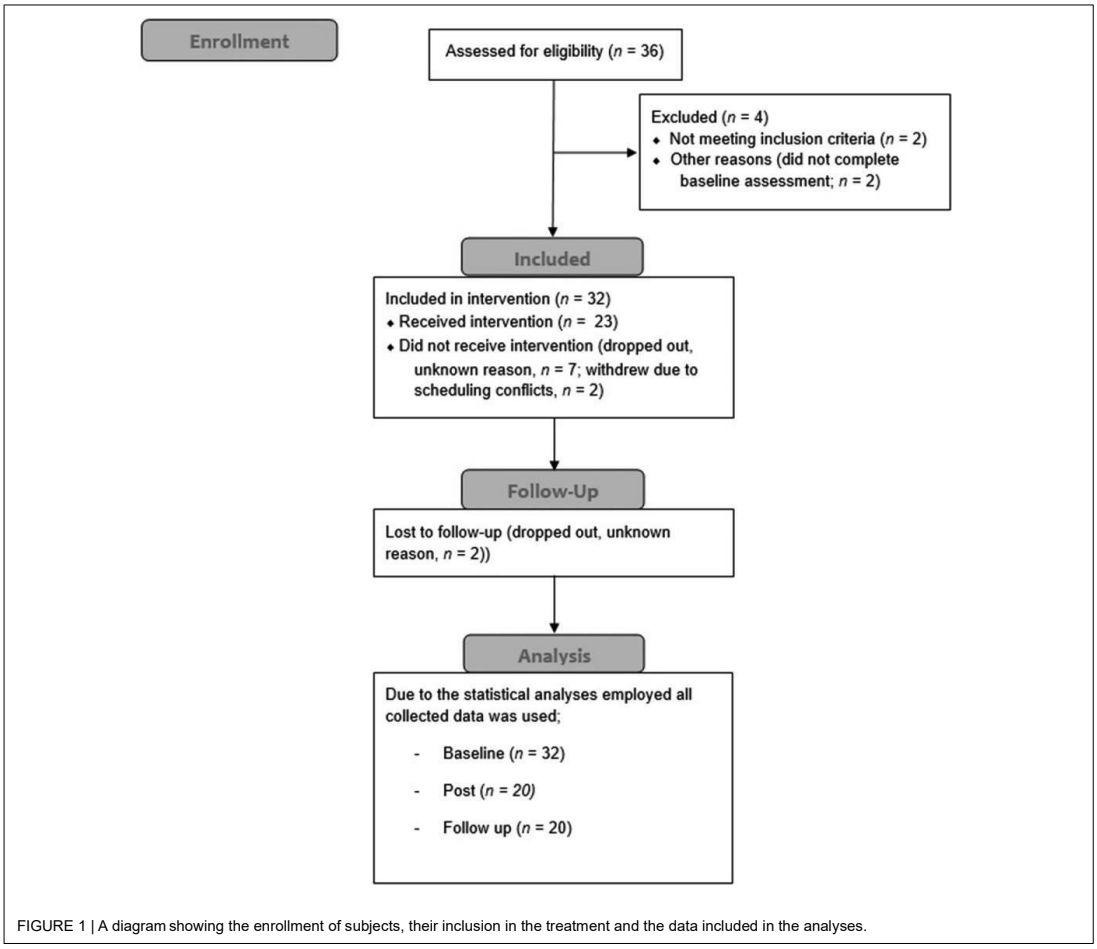

FIGURE 1 | A diagram showing the enrollment of subjects, their inclusion in the treatment and the data included in the analyses.

changes, but there was a significant change to the total score (*M* = 49.36 at baseline, *M*dif = 6.95 and 8.24 at post and follow-up, respectively). Please see **Table 4** for further information.

In addition to these self-reported changes, the participants also reported significant improvements on measures of everyday executive functioning and aspects of emotion regulation (see **Supplementary Table 1**).

	Total sample (*N* = 32)	Completers (*N* = 21)	Non-completers (*N* = 11)	*P*-values
Number of males (%)	18 (56.25%)	12 (57.14%)	6 (54.55%)	1.00
Age in years, mean (SD)	35.75 (11.87)	39.05 (11.93)	29.45 (9.25)	0.02*
Years of education, mean (SD)	13.88 (2.96)	14.33 (2.01)	13.00 (4.22)	0.34
Full-scale intelligence quotient, mean (SD)	118.25 (11.66)	120.14 (10.08)	114.64 (14.02)	0.27
Currently receiving medication, number (%)	16 (50.00%)	10 (47.62%)	6 (54.55%)	1.00
Currently receiving other therapy, number (%)	16 (50.00%)	9 (42.86%)	7 (63.64%)	0.46
Total ASRS score, mean (SD)	46.97 (10.07)	44.33 (8.91)	52.00 (10.63)	0.06
Total WURS score, mean (SD)	44.03 (19.44)	40.05 (16.55)	51.64 (22.97)	0.16
Comorbidities				
Mood disorders, ongoing. Number (%)	5 (15.62%)	2 (9.52%)	3 (27.27%)	0.37
Mood disorders, previous. Number (%)	28 (87.50%)	16 (76.19%)	12 (109.09%)	0.38
Anxiety disorders, ongoing. Number (%)	26 (81.25%)	18 (85.71%)	8 (72.73%)	0.39
Anxiety disorders, previous. Number (%)	16 (50.00%)	11 (52.38%)	5 (45.45%)	0.93
Alcohol or substance use disorders, previous. Number (%)	8 (25.00%)	6 (28.57%)	2 (18.18%)	0.07
Antisocial personality disorder, ongoing. Number (%)	4 (12.50%)	3 (14.29%)	1 (9.09%)	1.00
Other disorders, ongoing. Number (%)	8 (25.00%)	5 (23.81%)	3 (27.27%)	0.25
Self-reported executive difficulties				
BRIEF-A GEC, mean (SD)	147.03 (23.30)	142.57 (24.01)	155.55 (20.22)	0.12
CFQ, mean (SD)	61.41 (13.34)	58.33 (13.90)	67.27 (10.89)	0.06
Emotion regulation				
Total score – DERS, mean (SD)	97.91 (23.88)	95.19 (25.02)	103.09 (21.70)	0.36
Quality of life				
Total score – AAQoL, mean (SD)	49.89 (14.24)	54.19 (14.21)	41.69 (10.57)	0.01**
Executive functions				
Letter Number Sequencing, mean (SD)	19.38 (2.62)	19.57 (2.71)	19.00 (2.53)	0.56
Scaled scores, mean (SD)	10.41 (1.70)	10.62 (1.77)	10.00 (1.55)	0.36
Spatial span, mean (SD)	15.90 (2.72)	16.08 (2.82)	15.55 (2.62)	0.60
Scaled scores, mean (SD)	10.25 (2.33	10.57 (2.29)	9.64 (2.38)	0.32
CWIT. Condition 3 completion time, mean (SD)	55.58 (13.86)	54.26 (15.42)	58.09 (10.44)	0.41
Scaled scores, mean (SD)	9.69 (3.33)	10.19 (3.56)	8.73 (2.72)	0.19
CWIT. Condition 4 completion time, mean (SD)	62.47 (10.44)	61.19 (11.31)	64.91 (8.49)	0.31
Scaled scores, mean (SD)	9.47 (2.30)	9.86 (2.43)	8.73 (1.90)	0.08
CWIT. Total errors conditions 3 and 4, mean (SD) [*N* = 31/21/10]	2.21 (2.15)	2.02 (1.97)	2.60 (2.55)	0.54
TMT. Condition 4 Completion time, mean (SD)	70.98 (26.88)	69.97 (29.20)	72.91 (23.00)	0.76
Scaled scores, mean (SD)	10.38 (2.99)	10.67 (3.04)	9.82 (2.96)	0.56
TMT. Condition 4 Total errors, mean (SD)	0.75 (0.80)	0.86 (0.91)	0.55 (0.52)	0.23
Tower task. Total achievement, mean (SD)	19.36 (4.02)	19.12 (4.51)	19.82 (3.03)	0.61
Scaled scores, mean (SD)	11.69 (2.76)	11.62 (3.06)	11.82 (2.23)	0.53
Hotel task [*N* = 31/21/10]				
Total time deviation. Mean (SD)	342.26 (230.25)	330.96 (216.66)	366.00 (267.36)	0.72
Tasks attempted. Mean (SD)	4.71 (0.82)	4.71 (0.78)	4.70 (0.95)	
Total score, garage. Mean (SD)	6.51 (2.05)	6.65 (2.11)	6.21 (2.01)	0.58

TABLE 2 | Descriptive characteristics of the sample and the subgroups of completers and non-completers at baseline.

*Full-scale intelligence quotient based on two subtests of the Wechsler Abbreviated scale of intelligence. ASRS, Adult ADHD Symptom Rating Scale; WURS, WenderUtah Rating Scale for ADHD, other disorders include body dysmorphic disorder, bulimia nervosa, and premenstrual dysphoric disorder. BRIEF-A GEC, Global Executive Composite from the Behavior Rating Inventory of Executive Function; CFQ, Cognitive Failures Questionnaire; DERS, Dysregulation of Emotion Rating Scale; AAQoL, Adult ADHD Quality of Life inventory, Letter Number Sequencing from the Wechsler Adult Intelligence Scale – 4th edition, Spatial span from the Wechsler Memory Scale – 3rd edition. CWIT, Color-Word Interference Test; TMT, Trail Making Test, these and the Tower all from the Delis-Kaplan Executive Function System. Reported scaled scores have a normative mean of 10 and SDs of 3 for all reported measures (Delis et al., 2001; Wechsler, 2008b,a). P-values for continuous variables based on Welch's two sample t-test, p-values for discrete variables based on Pearson's Chi-squared test. *p < 0.05, **p < 0.01.*

	Session	β	SE	*t*	*p*		β	SE	*t*	*p*
Primary measures										
CWIT. Condition 3 completion time	Pre	55.55	2.14			Letter Number Sequencing, total score§	19.38	0.43		
	Post	−4.48	1.95	−2.30	0.022*		−0.82	0.43	−1.88	0.060
	Follow up	−5.60	1.98	−2.82	0.005*		−0.76	0.44	−1.72	0.086
CWIT. Condition 4 completion time	Pre	62.47	1.91			Spatial Span, total score§	15.93	0.50		
	Post	−8.64	2.00	−4.31	<0.001*		0.87	0.53	1.65	0.099
	Follow up	−9.33	2.04	−4.58	<0.001*		0.31	0.53	0.59	0.558
CWIT. Condition 3 and 4, total errors	Pre	2.37	0.38			Hotel task. Total time deviation	352.71	37.40		
	Post	−0.32	0.37	−0.89	0.375		−26.34	44.08	−0.60	0.550
	Follow up	−0.21	0.37	−0.57	0.570		−117.59	44.87	−2.62	0.009*
TMT. Condition 4. Completion time	Pre	72.03	4.81			Hotel task. Total tasks attempted§	4.71	0.11		
	Post	−7.78	4.54	−1.71	0.087		0.20	0.17	1.17	0.244
	Follow up	−11.37	4.63	−2.46	0.014*		0.29	0.17	1.71	0.087
TMT. Condition 4. Total errors	Pre	0.75	0.17			Hotel task. Total score, garage§	6.10	0.44		
	Post	−0.16	0.24	−0.67	0.503		0.84	0.48	1.77	0.076
	Follow up	0.06	0.24	0.22	0.822		0.34	0.48	0.70	0.484
Tower task. Total achievement§	Pre	19.38	0.68							
	Post	0.30	0.70	0.42	0.672					
	Follow up	2.12	0.71	2.99	0.003*					

TABLE 3 | Simplified outputs from Linear Mixed-Effects Regressions of performance-based measures examining change from baseline to post intervention and 6-month follow-up assessments.
*Letter Number Sequencing from the Wechsler Adult Intelligence Scale – 4th edition, Spatial span from the Wechsler Memory Scale – 3rd edition. CWIT, Color-Word Interference Test; TMT, Trail Making Test, these and the Tower all from the Delis-Kaplan Executive Function System. P-values estimated using Satterthwaite's method. *p < 0.05 after application of control for false discovery rates. §Hypothesized increase in scores from pre-assessment, remaining measures are hypothesized to decrease.*

	Session	β	SE	*t*	*p*
Secondary measures					
ASRS total score	Pre	46.97	1.85		
	Post	−3.70	1.52	−2.43	0.015*
	Follow up	−5.28	1.52	−3.47	<0.001*
CFQ total score	Pre	61.41	2.43		
	Post	−6.75	2.09	−3.23	0.001*
	Follow up	−7.61	2.09	−3.65	<0.001*
AAQoL Life Outlook	Pre	53.13	2.70		
	Post	5.38	2.67	2.02	0.044
	Follow up	5.02	2.67	1.88	0.060
AAQoL Life Productivity	Pre	42.32	3.01		
	Post	11.89	3.79	3.14	0.002*
	Follow up	12.52	3.79	3.31	<0.001*
AAQoL Psychological Health	Pre	54.30	3.65		
	Post	0.43	4.17	0.10	0.917
	Follow up	4.87	4.17	1.17	0.243
AAQoL Relationships	Pre	56.72	3.82		
	Post	2.73	4.09	0.67	0.504
	Follow up	3,97	4.09	0.97	0.331
AAQoL total score	Pre	49.36	2.64		
	Post	6.95	3.03	2.30	0.022*
	Follow up	8.24	3.03	2.72	0.007*

TABLE 4 | Simplified outputs from linear mixed-effects regressions of self-report measures examining change in ADHD-symptoms, everyday cognitive functioning and quality of life from baseline to post intervention and 6-month follow-up assessments. *ASRS, Adult ADHD Symptom Rating Scale; CFQ, Cognitive Failures Questionnaire; AAQoL, Adult ADHD Quality of Life inventory. P-values estimated using Satterthwaite's method. *p < 0.05 after application of control for false discovery rates.*

DISCUSSION

The main aim of the current study was to conduct an exploratory pilot testing of a neuropsychological model for examining the effects of GMT on inhibition, specifically, in a sample of adults with ADHD. The effects of GMT were studied immediately after completing the treatment and at a 6-month follow-up assessment. Due to the emphasis in GMT on strategies supporting the executive function of inhibition (Levine et al., 2000, 2011), we expected that measures of this, and not other aspects of executive functioning such as working memory, flexible control of processing speed or general problem solving, would show significant improvement. Indeed, we found support for this hypothesis in that the adults with ADHD demonstrated improved inhibitory control on selected neuropsychological measures of inhibition after completing GMT both at the post- and 6-month follow-up assessments, but not on tests of working memory.

Interestingly, at followup after 6 months, the results also showed improved problemsolving skills on the Hotel task and improvements on a measure of flexible control of processing speed. In addition to the improvements in inhibitory control following GMT, we found secondary positive effects after GMT in that the adults with ADHD reported improvements in everyday functioning. This was shown through self-reported improvements in ADHDsymptoms, everyday cognitive functioning and quality of life. Participants also reported improvements in aspects of executive functioning and emotion regulation, as can be seen in the **Supplementary Materials**.

In GMT, participants work specifically on improving strategies supporting goal-directed behavior by practicing intermittent stopping of ongoing behavior to monitor whether this behavior is in line with current goals (Levine et al., 2011; see also Cooper, 2010). Thus, GMT emphasizes inhibitory control training (i.e., “STOP!-and-think”).

The results in the current study supported our hypothesis that this specific function would improve following GMT compared to other neuropsychological measures of executive functions. Improvements in inhibition were evident both immediately following the intervention and 6 months later on the CWIT measure of interference control, a subtest requiring voluntary control over which stimuli are attended. Furthermore, after 6 months, improvements were also observed on the Tower test. This is a problem-solving test specifically requiring inhibitory control to be able to follow the rules and complete the tower as instructed (see Miyake et al., 2000; Young et al., 2007). The importance of strengthening inhibition is reflected in both theories of ADHD, suggesting that impaired inhibition is a predominant cause of the negative impact on everyday functioning associated with the disorder (e.g., Barkley, 1997), as well as in findings showing its importance for general functioning. Inhibition is central for the ability to pursue goaldirected behavior (Cooper, 2010), which is required in academic work and in occupational work settings (e.g., Halleland et al., 2015). It is also shown to be important for emotion regulation (see Shaw et al., 2014). Furthermore, there is research pointing to inhibitory control as an important aspect of psychological resilience (see Kalisch et al., 2015), which reduces the risk of developing adverse, psychological reactions despite exposure to stressful and potentially traumatic events.

Due to the importance of inhibitory control in regulating behavior, we expected that GMT would lead to improvements in the ability to handle the challenges of everyday life. Therefore, we expected positive secondary effects of GMT on self-reported everyday functioning. The results of the current study are in accordance with this expectation as the adults with ADHD reported improvements on self-reports of cognitive and executive functioning. In particular,

participants reported improvements on aspects of such functioning related to increased productivity and aspects of controlled emotion regulation. Further, positive effects of GMT were reported as a perceived reduction in the severity of ADHD symptoms after 6 months, and increased productivity with regards to school/work and everyday task achievement (AAQoL). Reports on the DERS questionnaire 6 months after completing GMT also showed that the participants experienced an enhanced ability to regulate emotional responses and were better able to use active strategies for helping them when they experienced negative emotions.

In line with our expectations, the adults with ADHD did not show changes in working memory after completing GMT. Interestingly, however, we found that after 6 months the adults with ADHD improved their general problem-solving skills as well as their flexible control of processing speed. Although we did not expect this, we believe that this change supports the interpretation of GMT leading to functional improvements. This is in contrast to the prior pilot study of an adapted version of GMT in adults with ADHD in which no change following the intervention was found on an everyday problem-solving task (In de Braek et al., 2017). The Hotel task is meant to be an analog of executive functioning in complex everyday situations (Shallice and Burgess, 1991; Manly et al., 2002), and requires that the participant devices a plan for performing the task whilst simultaneously monitoring his or her behavior and the time remaining. There are findings suggesting that the improvements on the Hotel task after completing GMT in the current study may be seen, at least in part, as a result of internalization of the exercises focusing on intermittent stopping (e.g., “STOP!-andthink”) by the participants. The periodic suspension of ongoing behavior to evaluate one’s overarching goal seems to increase goal achievement (Manly et al., 2002). In other patient samples, GMT has

also been shown to improve performance on the Hotel task and similar analogs of real-life task performance (e.g., Levine et al., 2000, 2007; Miotto et al., 2009; NovakovicAgopian et al., 2011; Stubberud et al., 2013; Tornås et al., 2016). Furthermore, in line with the findings from the current study, the majority of these studies have also shown improvements in self- or informant-reported evaluations of everyday functioning, which would be expected if participants had indeed internalized an efficient problem-solving strategy. Interestingly, in a study that showed no effect of GMT on an everyday problem-solving task, the participants did not report changes following GMT on measures of everyday cognitive functioning (Levine et al., 2011).

As the current study was a self-control case design, we cannot rule out that practice effects may have contributed to improved scores from pre- to post- and follow-up assessments. Important to note in this regard, is the fact that we hypothesized that inhibitory control would be improved, and found that neuropsychological test measures of this function, and not of working memory, improved after completing GMT. We believe that this supports the assumption that our primary results of enhanced inhibitory control are not due to pure practice effects. This interpretation is supported by results from available studies of practice effects. For instance, Calamia et al. (2012) found similar retest effect sizes for measures of working memory, processing speed and more general executive functions in their meta-analysis. Several meta-analyses have also shown that practice effects are most pronounced between the first and second administration of a test, with smaller increases for subsequent administrations (Scharfen et al., 2018a,b). This is important since we found strong effects 6 months after, and not just immediately after, completing GMT. The meta-analysis of Calamia et al. (2012) also showed that practice effects were substantially less pronounced

for clinical samples compared to healthy samples.

Although the findings in the current study need to be interpreted with caution, the results strongly support the notion that the participants with ADHD adopted the learned strategies and applied them in their everyday life 6 months after completing GMT. Furthermore, in line with the primary aim of the study, our findings support the use of neuropsychological outcome variables as effect measures of GMT in ADHD samples. Specifically, GMT in ADHD seems to address inhibitory control in particular more than executive functioning in general. Interestingly, newer revisions of the understanding of executive functions lean toward inhibitory control being the unitary component of executive functioning (Cooper, 2010; Miyake and Friedman, 2012). This may imply that the neuropsychological model for assessing effect of GMT in the current study can be applicable also for studies testing the effect of GMT in other clinical samples than ADHD. A critical point of treatment studies in ADHD is the question of whether the effects are generalized to the patients' everyday life. Cognitive remediation approaches have often been criticized for failing on this point in ADHD samples, examples include working memory training and neurofeedback (see Melby-Lervåg and Hulme, 2013; Cortese et al., 2016). In the current study, we found that the adults with ADHD also experienced improvement in their everyday life, lasting at least 6 months after completion of GMT. Future studies are, however, needed to test if these findings are replicated with a case-control design. Applying a case-control design would allow for control for spontaneous changes in how patients experience their life or changes associated with nonspecific effects (e.g., professional attention, group dynamics; McCambridge et al., 2012). Since the current study aimed to explore test-effects of GMT by assessing the patients with ADHD with a neuropsychological

test battery at three time points, resources for testing were prioritized above recruiting a bigger sample of patients. Due to potential participants being excluded, withdrawing due to scheduling conflicts and dropout, the final number of participants included was not in line with the original plans for the project and the power analysis conducted during this planning. As such, lower power in the statistical analyses may have contributed to negative results on effect measures that with a larger sample would appear as a positive effect of GMT. Future studies may therefore identify effects on measures which did not reach significance in the current study. Of note, we did control for multiple testing in our statistical analyses, and the effects of GMT on inhibitory control measures were still strong enough to reach significance. Also, of relevance, the baseline data showed that the dropout group was younger than the patients completing the GMT and the post-assessments, and also a tendency for the drop-out group to report higher symptom severity. In treatment studies of ADHD, there is often a problem with patients dropping out, which can result in a biased sample of patients completing the treatment. This can be handled with intention-to-treat analyses, however, this was not possible in the current study due to the self-control case design.

The current study indicates significant effects of GMT on inhibition among adults with ADHD. Furthermore, the current results provide support for the notion that GMT may also affect broad and important domains of functioning such as everyday cognition and productivity as well as emotion regulation. These results encourage further studies that include control conditions to examine GMT as an intervention for adults with ADHD, as replication would indicate that GMT represents an efficient and cost-effective treatment alternative.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the ethical approval states that anonymized data can only be made available for registered collaborators. Requests to access the datasets should be directed to DJ, Daniel.A.Jensen@uib.no.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Regional Committee for Medical and Health Research Ethics, West Norway. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LS was the project leader. DJ, LS, AL, AH, JS, and JH involved in conception and design, and approved the final version for publication. DJ collected the data. DJ and LS involved in analyses, interpretation, and writing of the manuscript. AH, AL, JS, and JH critically reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.659480/full#supplementary-material

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Goal management training improves executive control in adults with ADHD: an open trial employing attention network theory to examine effects on attention

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Abstract

Background: Adults with Attention-Deficit/Hyperactivity Disorder (ADHD) typically experience poorer attentional control. According to the attention network theory, attentional control relies on three interacting networks of alerting, orienting, and executive control. In ADHD, it is mainly the alerting and executive control networks that are suggested and found to be compromised.

Methods: In the current study, we investigated if a group-based metacognitive remediation program (Goal Management Training [GMT]) in adults with ADHD would enhance attentional control using an experimental measure of the attention network theory. We expected that GMT would specifically enhance the executive control and alerting networks.

Results: Data from post- and follow up-assessments of 21 adults (age: 39.05 [11.93]) with ADHD who had completed GMT were included. Linear mixed-effects modeling revealed significant improvements in the functioning of the executive control network for the majority of the participants, although a small subset of participants showed a negative development following the intervention. Results also showed an improvement in the orienting network at follow up, but no change in the alerting network.

Conclusion: The results may indicate that improvements in the functioning of the executive control network are central to the positive effects of GMT reported in disorders characterized by impaired attentional control. *Trial registration*: The study was retrospectively registered in the ISRCTN (Identifier: ISRCTN91988877) on the 18/01/2021.

Keywords: Attention deficit disorder with hyperactivity, Cognitive control, Executive function, Treatment, Cognitive rehabilitation

Introduction

Adults with Attention-Deficit/Hyperactivity Disorder (ADHD) struggle with elevated symptoms of inattention and/or hyperactivity/impulsivity in their everyday life [1].

Typically, this is reflected in a poorer ability to voluntarily focus their attention on the task at hand and maintain this attentional focus over time to aid goal-directed behavior [2–6]. As a result, they often experience academic [7–11]

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and occupational [9, 12–14] impairments. In ADHD, pharmacological treatment has been shown to reduce alterations in brain activity and structures in brain networks involved in attentional control [6]. However, pharmacological therapy has limited efficacy and not all individuals with ADHD tolerate such treatment [15]. Efforts have been made to investigate if it is possible to train attentional control and thereby enhance attention functions. Still, there is limited evidence for the effectiveness of non-pharmacological interventions for ADHD [15] including interventions focusing on attentional control [16]. The aim of the current study was therefore to investigate the effectiveness of a group-based metacognitive remediation program, Goal Management Training (GMT; [17, 18], in enhancing attentional control in adults with ADHD.

GMT is a group-based metacognitive remediation program aimed at reducing deficiencies of goal management, based on Duncan's [19] attentional control theory of goal neglect [17, 18]. The theory describes how goal management fails when an individual is unable to maintain task focus towards future goals due to being unable to cope with the competing demands of other salient stimuli or ongoing activities. The program, therefore, emphasizes teaching participants a five-stage strategy to increase goal attainment. The intervention builds on the assumption that participants, through practice, will be able to improve sustained attention via changes in the brain networks underlying this function and that this will allow for improved executive control [20]. Important components include the intermittent stopping of ongoing behavior ("STOP!-and-think") to orient towards relevant goals and to evaluate whether ongoing behavior is in line with these. The program also contains components of mindfulness training [21] meant to help participants develop the skills needed to maintain a focus on the present, as well as the active use of self-cueing to regulate alertness to maintain executive control [22]). These strategies and techniques are combined with the aim of improving awareness of attentional lapses to reduce the negative influence of poorer executive control. Thus, GMT can be said to target executive control and attention allocation [20].

GMT has been shown to have positive effects on measures of executive control and attention in several patient groups [23, 24]. However, to the best of our knowledge, only two earlier, small-scale pilot studies have investigated the effects of GMT in adults with ADHD [25, 26]. In de Braek et al. reported positive effects of GMT compared to psychoeducation with regards to clinician-rated, everyday cognitive functioning. However, they only included a general performance-based measure of problem solving, and no performance-based measures that specifically tap into executive control and attention allocation. Jensen et al., studying the same adult ADHD sample as in the current study, reported significant improvements on measures of executive control, such as on the Stroop test and the Tower test following GMT. However, these measures do not allow for differentiation between executive control and attention allocation of alertness and orienting attention [26]. Applying a systems-neuroscience approach for measuring effects of GMT would improve the understanding of which specific attention function(s) GMT improves in adults with ADHD.

The attention network theory [27–29] offers such a systems-neuroscience approach, defining three interacting networks of early-operating attention allocation of alerting and orienting, as well as executive control [27, 29–31]. The executive control network is involved in complex operations, such as detecting and resolving conflicts between stimuli, for instance in inhibiting salient stimuli to be able to attend to a task-based target stimulus. To facilitate executive control, the alerting network supports preparation for shifting from rest to task-based activity and to maintain effort over time (alertness). The orienting network, on the other hand, is involved in the selection of which stimuli to attend among multiple stimuli, such as the ability to quickly focus attention on task-based stimuli. ANT has not previously been applied in studies of GMT [23]. However, Berger and Posner [30] hypothesized that individuals with ADHD would show poorer functioning of the attention networks of executive control and alerting but not the orienting network. This has been supported in studies of children [32–36] and adults with ADHD [37], although there are also contradictory findings from studies of children [39–41].

So far, the use of the attention network theory to examine treatment effects in studies of adults with ADHD is limited. One study by Dotare et al. [42] reported positive effects of a computer-based cognitive remediation training program on executive control and not on the alerting or orienting networks. This is in line with findings showing that children without ADHD experienced positive effects of a tailored computer-based training program [43] specifically on the executive control network, and that children with the poorest attentional control at baseline were most likely to benefit from such interventions. These findings are also comparable to results from studies in which the attention network theory has been applied to test treatment effects in non-ADHD adult samples, such as effects of mindfulness training on attention. In mindfulness training, positive effects have been observed on executive control in addition to the orienting network, whereas positive effects on alerting have only been observed in experienced meditators/mindfulness practitioners [44, 45].

In the present study, we investigated the effects of GMT [17, 18, 46] on the three attention networks as described in the attention network theory [27], using the revised Attention Network Test (ANT-R; 47) in an open trial in which adults with ADHD participated. Since no prior study has tested the effects of GMT with ANT-R, we build on the theory of GMT and previous findings in ADHD samples using the original Attention Network Test [48] to develop the following hypotheses:

We expected (1) that adults with ADHD would show improvements in the executive control and alerting networks following GMT and not on the orienting network. (2) To find the most consistent change in the executive control network since goal achievement through efficient conflict detection is emphasized as a main mechanism in GMT [20]. In addition to the traditional focus on averaged group scores to measure effects of GMT, we also analyzed change scores for every participant to better understand individual differences in effects of GMT.

Methods

Participants

Participants in the current study were part of an exploratory investigation of GMT as an intervention for adults with ADHD recruited from local outpatient clinics in the municipality of Bergen, Norway (see 26 for further details). Inclusion criteria were an age > 18 years and a confirmed clinical diagnosis of ADHD. The participants had been diagnosed by a specialist (i.e., clinical psychologist or psychiatrist) outside of the project according to the current Norwegian guidelines [49] which employ diagnostic codes from the ICD-10 [50] but allow for the use of DSM-IV/5 criteria [1, 51] in the diagnostic assessment. These guidelines describe the necessity of assessing developmental history, current symptoms and effects on functioning across multiple domains, and an assessment of physical or psychiatric illnesses that may explain the symptoms. The guidelines recommend the use of the Diagnostic Interview for Adult ADHD, second edition (DIVA 2.0), the Mini International Neuropsychological Interview (M.I.N.I. Plus) and the Structured Clinical Interview II (SCID-II) for DSM-IV axis I and axis II disorders, respectively [52–54], in addition to self-report forms such as the Adult ADHD Self-report Scale (ASRS; [55]) and the Wender-Utah Rating scale (WURS; [56]). These guidelines also emphasize the need to collect collateral reports (e.g., the use of DIVA with parents/older siblings and/or long-term partner/spouse). Exact data on adherence to these guidelines was not available for inclusion in this study. Exclusion criteria in our study sample were a full-scale intelligence quotient below 80, a history of psychotic disorder, or other severe ongoing psychiatric disorders such as severe depression or acute suicidality, which would prohibit participation in the intervention study. In total, 34 participants volunteered for the study of whom 21 participants completed two or more assessment points and were included in the present study. Participants' age ranged from 21 to 62 years (M = 39.05, SD = 11.93, 57% males). A total of 13 of these 21 participants (61.9%) fulfilled the criteria for at least one other ongoing disorder according to the M.I.N.I. Plus [54]. Various anxiety disorders constituted the majority of these disorders

(Table 1). For further details on recruitment and clinical characterstics of the sample see Table 1 and Jensen et al. [26].

Table 1 Descriptive statistics of the sample and included variables

		M	*SD*
	***n* (%)**		
Number of males	12 (57.1)		
Number of females	9 (42.9)		
Receiving stimulant medication	10 (47.6)		
Age	21	39.2	11.4
IQ	21	120.1	10.1
Comorbidities			
No other disorder	8 (38.1)		
Major depressive disorder	2 (9.5)		
Anxiety disorder	11 (52.4)		
Other disorders	7 (33.3)		
ASRS			
Pre	21	44.4	8.8
Post	20	41.2	9.1
Follow up	20	39.3	11.2
ANT-r measures	21		
Flanker conflict			
Pre		175.4	160.7
Post		155.1	147.0
Follow up		150.0	143.6
Alerting			
Pre		41.9	175.5
Post		34.7	157.9
Follow up		35.0	144.6
Validity			
Pre		93.0	176.0
Post		104.4	162.6
Follow up		112.2	155.1

Receiving medication = number and percentage of participants receiving medication for ADHD at baseline, IQ = full-scale IQ estimate from the Wechsler Abbreviated Scale of Intelligence, Comorbidities = ongoing diagnoses according to M.I.N.I. PLUS, Anxiety disorder = Panic disorder, Agoraphobia, Social phobia Antisocial personality disorder, or Generalized anxiety disorder, Other disorder = Sum score Body dysmorphic disorder and PMS dysphoric disorder, ASRS = from the Adult ADHD Self-report Scale, ANT-*r* measures = calculated effects in milliseconds

Procedure

Diagnostic assessment of comorbid disorders, selfreports of, among others, ADHD symptoms, and assessments with a neuropsychological test battery and electrocardiogram (ECG) were conducted at the neuropsychological outpatient clinic at the University of Bergen. As participants had an existing ADHD-diagnosis, only self-reports of current symptoms where collected. For further details see Jensen et al. [26]. Participants completed the ANT-R in a soundproof room approximately midway through the assessment and immediately following a break at all three time points.

GMT was administered in nine two-hour group sessions in groups of four to eight participants led by a clinical psychologist (six years of studies at the university level) and a co-therapist who was either a clinical psychologist or a clinical psychology student with clinical experience (i.e., students who had completed at least four

and a half of the six years of study and had experience from clinical work as psychologists under supervision). Guidance from a clinical psychologist with extensive experience with GMT was also available. Due to various holidays the duration of the intervention varied between nine and 11 weeks. Participants were asked to complete daily homework assignments between sessions and their experiences with these were discussed in the following session. Participants had to complete a minimum of six out of nine sessions to be included in the post- and follow up-assessments.

Assessments were conducted within three weeks before the first session of the GMT-intervention and within two weeks after the last session. Follow up-assessments were conducted six months after completion of the intervention (± two weeks).

Measurements

Attention network test—revised

The ANT-R, developed by Fan et al. [47], is a revision of the original Attention Network Test [48], introducing new elements that allow for the investigation of interactions between the three constituent attentional networks. In the ANT-R the presentation of the flanker condition is presented at one of two locations on a computer screen and these locations can be either congruent or incongruent. Furthermore, the ANT-R includes three cue conditions: no cue, double cue (alerting cues) and spatial cue (orienting cues). In the current study we included the reaction time scores for alerting, orienting and executive control (see Table 2).

Table 2 Descriptive information about the ANT-r scores

During performance of the ANT-R, the participants are seated in front of a computer. They are instructed to attend to a fixation crosshair at the center of the screen

Attention networks	Variable score	Measures	Operational score calculation
Alerting	Alerting	Tonic[a] and phasic arousal (temporal cues)	(RT no cue-condition)—(RT double cue-condition)
Orienting	Validity	Endogenous[a] and exogenous attention engagement (spatial cues)	(RT invalid cue-condition)—(RT valid cue-condition)
Executive control	Flanker conflict	Conflict processing[b] (congruent and incongruent conditions)	(RT flanker incongruent)—(RT flanker congruent)

RT.Reaction time. [a]Lower scores indicate an effect of the endogenous, self-regulated system on alertness and orienting. [b] Lower scores indicate more efficient conflict processing. Table adapted from Sørensen et al. [57]

and informed that a set of five arrows will appear inside one of two boxes which are placed to the left and right of this crosshair. Their task is to indicate the direction of the center arrow as quickly and accurately as possible by pressing the left mouse key with their right index finger if the arrow is facing left, and the right mouse key with their right middle finger if the arrow is facing right. The flanker condition is defined as congruent if the center arrow is facing in the same direction as the surrounding flanker arrows and incongruent if the direction of the flanker arrows is opposite of the direction of the target arrow (e.g., center arrow facing right, flanker arrows facing left). Each trial consists of the presentation of the flanker arrows for 500 ms. This is preceded by the presentation of the varying cue conditions for 100 ms, followed by a cue-target interval of either 0, 400 or 800 ms. During the 100 ms in which the cue is presented the participants receive either no cue, a valid (i.e., the box surrounding the location where the flanker will appear flashes) or invalid (i.e., the box surrounding the location where the flanker will *not* appear flashes) spatial cue, or a temporal cue (both boxes flash). The trials are separated by a fixation period lasting between 2000 and 12,000 ms. Before beginning the task, participants completed a practice round where they were given step-by-step instructions pertaining to the cue and target conditions as well as 32 practice trials demonstrating the task in the same way as during the actual ANT-R procedure. In total (excluding the practice trials), the ANT-R consist of four blocks, each containing 72 trials (see 47 for further details). The task was performed on a desktop PC, using E-Prime™ software (Psychology Software Tools, Pittsburgh, PA).

Adult ADHD self-report scale

The ASRS [55] is an 18-item scale where participants are instructed to evaluate the presence and frequency of ADHD-symptoms over the past six months on a Likert scale ranging from never (0) to very often [4]. The scale showed acceptable internal consistency with a Cronbach's α of 0.87. In the present study, this scale was used to describe the symptom severity of the included sample of adults with ADHD at pre-, post- and follow-up sessions.

Mini international neuropsychiatric interview plus

The M.I.N.I. Plus [54] was administered to assess participants for eligibility for participation as well as to assess the presence of other psychiatric disorders. The interview was administered by an experienced clinical psychologist or by a clinical psychology student with clinical experience—who was supervised by an experienced clinical psychologist.

Wechsler abbreviated scale of intelligence

Participants completed two subtests from the Wechsler Abbreviated Scale of Intelligence (Matrix reasoning and Vocabulary; [58]) to obtain an estimate of their intelligence quotient.

Statistical analyses

All statistical analyses were conducted using R version 4.0.2 [59] and packages *lme4*, *lmerTest*, *ggplot2, tidyverse* and *SIMR* [60–64]. Linear mixed-effect modeling was used to examine changes in ANT-R scores within individuals over time. Separate models were built for the three dependent variables alerting, orienting and executive control. The baseline models included a random intercept and slope nested within participants. Random intercept and slope for the effects of session were then examined to investigate if this led to improved fit. The covariates of age, sex, IQ and medication use due to ADHD were included as fixed effects and backwards tested. Model fit was assessed by likelihood-ratio tests and covariates were retained if such tests indicated a significant improvement in model fit (See Additional file 1: Table S1). After inclusion of covariates the moderating effects of each predictor on the change in ANT-R measures were examined by adding the interaction between each of these

predictors and assessment number to the model. Effect size estimates were calculated using the procedure described by Westfall et al. [65], resulting in estimates approximating Cohen's *d* [66]. Post-hoc power analyses were conducted on the final models using Monte Carlo simulations as implemented in SIMR. Lastly, results were inspected visually to examine individual patterns of change on the ANT-R score(s) that were shown to be enhanced following GMT. The clinical characteristics of participants showing a negative effect of GMT on ANT-R were further analyzed by inspecting their ASRS scores, medication status, IQ, and comorbid disorders (see Fig. 1).

Results

Data preparation

Reaction time data from trials with correct answers were used in the analyses. These were inspected and responses below 100 ms were removed ($N = 1$). Visual inspection indicated that the reaction times (RTs) were not normally distributed. RTs were therefore transformed using an inverse gaussian transformation followed by a multiplication of -1000 as described by Baayen and Milin [67] to approximate a normal distribution. These transformed RTs were then used to calculate measures for the flanker conflict, alerting, and validity effects in line with the descriptions of Fan et al. [47]. After calculation of these measures the data were once again inspected for outliers. For the flanker conflict two extreme trials out of a total of 8167 were removed to ascertain a normal distribution of the data. For the alerting and validity effects extreme values resulted in the removal of eight out of 2771 and one out of 2740 trials, respectively. Furthermore, continuous covariates were centered using grand mean centering. Table 1 shows an overview of the baseline characteristics of the sample as well as information about ANT-R effects and changes in ASRS-scores.

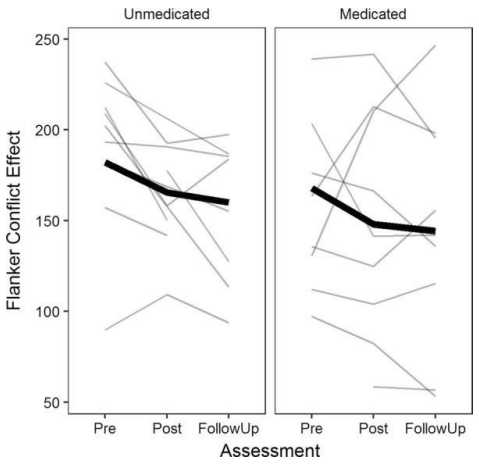

Fig. 1 Individual- and group values for the flanker conflict effect (in milliseconds) at each of the three assessments. The bold line depicts changes in group mean across the three assessments, while the regular lines show the development for individual participants

Linear mixed-effect models

In line with our hypotheses we investigated the changes in the executive control, alerting, and orienting networks. We expected reductions in the flanker conflict and alerting effects across the assessments. Furthermore, we investigated the orienting effect to assess whether participants showed an improvement in the use of spatial cueing.

Executive control

Following the model fitting approach described under statistical analyses, the final linear-mixed effect model included a random slope and intercept for each individual participant as an effect of assessment-session. Furthermore, the model included fixed effects for session, age and medication status as well as interaction terms for the effects of age by session and medication status by session (AIC 1743.2, see Additional file 1: Table S1 for further information). Monte Carlo simulations based on 1000 repetitions using the final model and an α of 0.05 indicated a power of 78.70% (95% CI: *LL* = 75.03, *UL* = 81.20) for the predictor session.

The results showed a significant fixed effect of assessment-session with reductions in the flanker conflicteffect from baseline to post- and follow up-assessments. The most substantial change occurred between baseline- and post-assessments with a small and non-significant increase from post- to follow up-assessment (β = -0.003, *SD* = 0.021, 95% CI = − 0.044 – 0.037, δt = − 0.011, p = 0.9). The results also showed a significant random effect of assessment-session. Furthermore, results showed negative relationships between the use of medication and the flanker conflict-effect and between age and the flanker conflict effect (See Table 3). The strength of the prediction of the observed values at each

assessment-session is visualized in the Additional file 2 : Fig. S1.

Alerting

Results indicated no significant change from baseline to the post- and follow-up assessments ($p > 0.25$), and the model fit was not significantly improved by adding the covariates (all p- values > 0.85 compared to the model which only included the fixed effects of session and random effect of participants), as such the original model without covariates was used. For further details see Table 4). Monte Carlo simulations based on 1000 repetitions using the final model and an α of 0.05 indicated a power of 17.90% (95% CI: *LL* = 15.57, *UL* = 20.42) for the predictor session.

Orienting

There was no significant change from baseline to postassessment, but a significant effect on the orienting effect from baseline to follow-up, after controlling for the random variance within individual participants ($p < 0.01$. This was also reflected in a significant change between the post and follow up-assessments ($\beta = 0.040$, $SD = 0.015$, 95% CI = 0.012 – 0.069, $\delta t = 0.203$, $p < 0.01$). For further details see Table 5. Monte Carlo simulations based on 1000 repetitions using the final model and an α of 0.05 indicated a power of 45.00% (95% CI: *LL* = 41.89, *UL* = 48.14) for the predictor session.

Table 3 Summary of a linear mixed-effects model of the Flanker Conflict-effect

Parameter	Fixed effects					Random effects		
						By Subject		
	β	SE	95% CI *LL*	*t* *UL*	*p*	δt		*SD*
Intercept	.458	.030	.399	.518	15.045	< .001***		.122
								Session
Post-assessment	− .066	.020	− .105	− .026	− 3.286	<.01*	− 0.21	.053
Follow up-assessment	− .069	.027	− .122	− .015	− 2.515	<.05*	− 0.22	.078
Age	− .006	.002	− .011	− .002	− 2.672	<.05*	− 0.02	
Medication status	− .072	.030	− .130	− .014	− 2.423	<.05*	− 0.23	
Post-assessment*Age.002	.002	001	.000	.004	1.700	.11	0.01	
Follow up-assessment*Age	.003	.002	.000	.007	2.040	.06	0.01	
Post-assessment*Medication status	.042	.029	− .014	.099	1.470	.16	0.14	
Follow up-assessment*Medication status	.053	.039	− .023	.129	1.374	.18	0.17	

Age = Age in years centered using grand mean centering, Medication status = Factor describing whether or not participants use ADHD-medication, 95% confidence intervals approximated using the Wald method. *** = $p < .001$, ** = $p < .01$, * = $p < .05$

Table 4 Summary of components in a mixed-effects model of the Alerting-effect

Parameter	Fixed effects						Random effects	
						By Subject		
	β	SE	95% CI		*t*	*p*	δt	*SD*
			LL	*UL*				
Intercept	.091	.013	.066	.117	6.494	< .001***		.033
							Session	
Post-assessment		− .015 .015		− .044	.015	− 0.960	*ns*	*− 0.05*
Follow up-assessment		− .001 .016		− .032	.029	− 0.076	*ns*	*− 0.00*

95% confidence intervals approximated using the Wald method. *** = *p* <.001

Table 5 Summary of components in a mixed-effects model of the orienting-effect

Parameter	Fixed effects					Random effects	
						By Subject	
	β	SE	95% CI	*t*	*p*	δt	SD
			LL	*UL*			
Intercept	.231	.026	.179	.282	8.791	*< .001****	Session .112
Post-assessment	.026	.020	- .013	.065	1.293	*ns*	*0.08*
Follow up-assessment	.063	.028	.007	.119	2.211	*< .01****	0.20

95% confidence intervals approximated using the Wald method. *** = *p* <.001, * = *p* <.05

Visual inspection of individual changes of flanker scores from pre- to follow-up assessments

As can be seen in Fig. 1, the majority of participants showed a decrease in the flanker conflict-effect from baseline to the post-assessment. However, there were relatively large individual differences in change scores (*Range* = [− 98.6 – 79.7 ms]) and a total of four participants showed increases in the flanker conflicteffect from baseline to post-assessment (*Range* = [2.6 – 79.7 ms]). Similarly, five participants showed an increase in the flanker conflict-effect from baseline to follow up-assessment (*Range* = [3.3 – 116.1 ms]). Three of these participants showed an increase from baseline at both timepoints. An inspection showed that all three were men, that two out of the three were older than the average of the sample (51 and 52 years, the third was 33 years), and that the first two had an IQ below the average level of the sample (93 and 103, the third had an IQ of 131). The first two of these participants used medication for ADHD, whereas the last participant did not use such medication. ASRS-scores at baseline were close to the average of the sample (46, 43 and 45, respectively) and increased in parallel with increases in flanker conflict effects for the first two participants at post-assessment (46 to 47 and 43 to 48, respectively) but were greatly reduced for the last participant (45 to 28) despite an increase in the flanker conflict effect. At follow-up all three participants reported changes in ASRS-scores in the same direction as the direction of the flanker conflicteffect relative to post-assessment scores (i.e., the first participant reported an increase [47 to 50], while the last two participants reported reductions [48 to 40, 28 to 26]). The first participant reported ongoing anxiety disorders (panic- and social anxiety disorder) and body dysmorphic disorder, whereas the other two screened positive for antisocial personality disorder.

Discussion

In the current open trial, we investigated the effects of GMT on executive control and attention allocation as defined by the attention network theory (29) in adults with

ADHD. The results supported our expectation that improvements would be found in the executive control network following GMT. However, against our á priori expectation we found no significant changes following GMT on the alerting scores but rather a change in orienting attention scores. The positive change in executive control was detectable immediately after the intervention ended, whereas the change in orienting attention appeared on the follow-up assessment six months later.

The current findings showing improvements in executive control following GMT are in line with previous studies showing that this network is malleable to improvement after non-pharmacological interventions in adults with [42] and without ADHD [45]. The findings are also in accordance with earlier investigations of GMT for other disorders showing a reduction in errors on various neuropsychological measures which include an aspect of response ambiguity [24, 46]. This finding may therefore indicate that changes in goalmanagement following GMT in adults with ADHD are related to an enhanced ability to handle and detect competing stimuli and thought processes. As such, the current results complement the previous study by Jensen et al. [26] showing specific effects of GMT on executive control in adults with ADHD. Using the ANT-R allowed us to provide support for the notion that this effect on executive control was not driven by improved attention allocation, but a specific effect on conflict detection itself. This demonstrates the advantage of applying experimental paradigms to assess effects of treatment by allowing for investigations of potential mechanisms of change. Another advantage is that the attention network theory is based on a defined neuroscience model of the brain. This may provide indications regarding which brain mechanisms are involved in for instance improvement of executive control following GMT [23, 25, 26]. The executive control network has been shown to rely on frontal brain regions in several fMRI studies [68–70]. Among the regions involved in the executive control network are the anterior cingulate cortex (ACC) and

insula, regions that are also part of the salience network and involved in conflict monitoring and upregulation of cognitive control in response to uncertainty or error [71, 72]. In accordance with the assumptions underlying GMT, a possible explanation would therefore be that GMT acts through changes in brain networks involved in executive control and orienting/alertness [20]. Importantly, activation in the ACC and insula has been shown to differentiate between individuals with ADHD and non-ADHD controls during performance of cognitive inhibition tasks [73]. Improvements in the connectivity of the ACC has also been shown to be associated with symptom remittance among adolescents with ADHD [74]. As findings from studies of various populations, including ADHD, indicate that both short-term mindfulness interventions [75–78] and cognitive rehabilitation interventions [79, 80] may improve the functional connectivity of the ACC and/or insula, this may also be a possible mechanism involved in our findings. Future studies may delineate the importance of these components for functional changes following GMT.

The adults with ADHD did not show the expected improvement in alertness after GMT. Rather, and in contrast to our expectations, they showed significant changes in results on the measure of the orienting network at follow up. Interestingly, these findings are in accordance with previous studies of mindfulness training showing effects on executive control and orienting after shorter periods of training [44, 45]. It is important to note that the attention networks are believed both to interact and to operate independently from each other. This is in line with the view emphasizing the importance of also studying supportive processes such as attention allocation in order to improve the understanding of conflict detection [81]. For instance, there may be an overlap of functioning between the orienting attention of ANT-R when defined by validity of cues and executive control since they rely on some of the same brain regions (i.e., ACC and insula; 47). This was supported in a study by Trautwein et al. [70] in that invalidly cued targets

induced activation in the ACC and insula. We have also found in a previous study that the interaction between early updating of stimuli (e.g., orienting attention) and conflict detection (e.g., executive control) associated with higher flexibility of the autonomous nervous system (i.e., heart rate variability; 82). Similarly, being alert to *when* stimuli appear on the screen may also affect an alertness to *where* the same stimuli appear (see 28). An improvement in the orienting attention and/or the executive control network may therefore reflect higher alertness following GMT despite this not being overtly observed through higher alerting scores following GMT.

In addition to the traditional focus on treatment effects on a group level, it is of clinical relevance to look at individual change scores to investigate if some participants may have a negative effect of GMT. Our sample was too small to statistically test differences between the three men who, on visual inspection of the flanker conflict score (i.e., executive control network score), appeared to have a negative effect by being less efficient on both assessments after GMT compared to baseline. However, by looking at other variables/scores of clinical interest from the assessments of these three male participants, we observed that with the exception of sex and that two out of three had a comorbid antisocial personality disorder (according to the M.I.N.I. Plus), there did not appear to be any specific variable included in our study in which these participants systematically differed from the rest of the sample and that could explain the differential effect of GMT on ANT-R. However, of interest, their negative change on the flanker conflict score for the most part mirrored changes in ADHD symptom reports on ASRS after GMT. It is challenging to delineate if this negative development was due to lack of effect of GMT or if something else occurred in these participants' lives that prevented them from engaging in the remediation practices of GMT. Few studies show such individual effect scores of GMT or of other types of treatment. This can be an important way to improve the understanding of which participants experience both positive and negative

effects, and thereby improve individually targeted treatment in patient groups.

Strengths, limitations, and future directions

We believe that the current results support the use of attention network theory and the ANT-R in future studies of interventions for ADHD and in investigations of GMT, and that such studies may provide important insights into potential mechanisms involved in reducing symptoms and impairments associated with the disorder being studied. Furthermore, the recruitment of a clinically-based sample of adults with ADHD probably increased the transferability of the results to patients with ADHD seeking treatment in the health care system. Also, the description of individual trajectories and the attempts to characterize individual differences in effects of the intervention can be an inspiration for adapting the same approach in future treatment studies.

There are several limitations to the current study. First of all, due to the lack of a control group, practice effects cannot be ruled out. We do, however, believe that the differential effects on the separate networks and the differing timing of effects speak against such an interpretation. Investigations of practice effects in Flanker-tasks also seem to indicate that these are relatively small and quite equal between congruent and incongruent trials [83, 84]. Secondly, the sample size was small and power analyses only indicate that the model investigating executive control achieved statistical power close to what is satisfactory. The sample size also did not allow for statistical power to perform between-group analyses to explore the influence of factors such as medication status and ADHD-subtype. Earlier findings indicate that these factors may influence RTs on the ANT-R (e.g., [42]) and we found an indication in the current study of a negative relationship between medication use and the flanker effect. Related to this, the fact that analyses were limited to participants who completed two or more assessments may have influenced the finding. As the current sample consisted of adults with ADHD that were mainly recruited from local outpatient clinics, many of

the participants also had comorbid disorders, mainly anxiety disorders. It is therefore possible that the current results may also reflect effects not directly related to ADHD but to concurrent anxiety disorders or other comorbid conditions. Finally, the current sample attained above average estimates of full scale-IQ. As such, it is possible that the reported results and/or the attained effect of the intervention may not be generalizable to samples with lower intelligence.

We argue that the current results indicate that there is reason to believe that GMT may be an advantageous intervention for adults with ADHD and that this should be evaluated in a larger randomized trial. Furthermore, we believe that inclusion of brain imaging techniques in such a trial could clarify the current results and inform the validity of the possible explanations discussed above.

Conclusion

The current open trial found an improvement in one aspect of attention, namely executive control, following GMT in a sample of adults with ADHD. Our finding thus suggests that GMT may be an efficient intervention for ADHD and further, that improvements in executive control may be a potential mechanism of change for adults with ADHD using this training procedure. A possible brain-correlated mechanism explaining this improvement may be enhanced functioning or connectivity in the ACC and/or insula following the intervention. Future randomized controlled studies of GMT are encouraged to include the ANT-R in combination with brain imaging techniques such as fMRI to increase the neurobiological understanding of effects of GMT in ADHD and other patient groups.

Abbreviations

ACC:: Anterior cingulate cortex; ADHD:: Attention-deficit/hyperactivity disorder; ANT:: Attention network test; ANT-R:: Attention network test-revised; ASRS:: Adult ADHD self-report scale; DSM-IV:: Diagnostic and statistical manual of mental disorders, 4th edition; DSM-5: : Diagnostic and statistical manual of mental disorders, 5th edition; ECG: : Electrocardiogram; GMT: : Goal management training; ICD-10: : International classification of diseases; M.I.N.I. Plus: : Mini international neuropsychiatric interview plus; RT: : Reaction time.

Supplementary Information

The online version contains supplementary material available at https:// doi. org/ 10. 1186/ s40359- 022- 00902-9.

Additional file 1: Table S1: Summary of linear mixed-effects model comparisons for the Flanker Conflict-Effect.

Additional file 2: Fig. S1: A graphical illustration of observed vs predicted flanker conflict effects for each individual participant

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Author contributions
DAJ: Literature search, figures, study design, data collection, data analysis, data interpretation, writing. AJL, JS, AH, JH: Literature search, data interpretation, study design. LS: Literature search, study design, data collection, data interpretation, writing, supervision. All authors have read and approved by the final manuscript.

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Availability of data and materials
The datasets generated and analyzed during the current study are not publicly available due to limitations in the ethical approval for the study but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All participants gave informed consent, and the study was carried out in line with the Declaration of Helsinki. Ethical approval was granted by the Regional Ethics Committee of Norway (Regional Etisk Komite Vest: Study number 2015/2325).

Consent for publication
Not applicable.

Competing interests

DAJ, AJL, JS, AH, JH and LS declare that the research has been conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. JH declares that he has received speaker honoraria from Lilly, Shire, HB Pharma, Medice, Takeda and Biocodex.

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	Løberg, Tor, Dr. philos.	Neuropsychological assessment in alcohol dependence.
1985	Hellesnes, Tore, Dr. philos.	Læring og problemløsning. En studie av den perseptuelle analysens betydning for verbal læring.
	Håland, Wenche, Dr. philos.	Psykoterapi: relasjon, utviklingsprosess og effekt.
1986	Hagtvet, Knut A., Dr. philos.	The construct of test anxiety: Conceptual and methodological issues.
	Jellestad, Finn K., Dr. philos.	Effects of neuron specific amygdala lesions on fear-motivated behavior in rats.
1987	Aarø, Leif E., Dr. philos.	Health behaviour and sosioeconomic Status. A survey among the adult population in Norway.
	Underlid, Kjell, Dr. philos.	Arbeidsløyse i psykososialt perspektiv.
	Laberg, Jon C., Dr. philos.	Expectancy and classical conditioning in alcoholics' craving.
	Vollmer, Fred, Dr. philos.	Essays on explanation in psychology.

	Ellertsen, Bjørn, Dr. philos.	Migraine and tension headache: Psychophysiology, personality and therapy.
1988	Kaufmann, Astrid, Dr. philos.	Antisosial atferd hos ungdom. En studie av psykologiske determinanter.
	Mykletun, Reidar J., Dr. philos.	Teacher stress: personality, work-load and health.
	Havik, Odd E., Dr. philos.	After the myocardial infarction: A medical and psychological study with special emphasis on perceived illness.
1989	Bråten, Stein, Dr. philos.	Menneskedyaden. En teoretisk tese om sinnets dialogiske natur med informasjons- og utviklingspsykologiske implikasjoner sammenholdt med utvalgte spedbarnsstudier.
	Wold, Bente, Dr. psychol.	Lifestyles and physical activity. A theoretical and empirical analysis of socialization among children and adolescents.
1990	Flaten, Magne A., Dr. psychol.	The role of habituation and learning in reflex modification.
1991	Alsaker, Françoise D., Dr. philos.	Global negative self-evaluations in early adolescence.
	Kraft, Pål, Dr. philos.	AIDS prevention in Norway. Empirical studies on diffusion of knowledge, public opinion, and sexual behaviour.
	Endresen, Inger M., Dr. philos.	Psychoimmuniological stress markers in working life.
	Faleide, Asbjørn O., Dr. philos.	Asthma and allergy in childhood. Psychosocial and psychotherapeutic problems.
1992	Dalen, Knut, Dr. philos.	Hemispheric asymmetry and the Dual-Task Paradigm: An experimental approach.
	Bø, Inge B., Dr. philos.	Ungdoms sosiale økologi. En undersøkelse av 14-16 åringers sosiale nettverk.
	Nivison, Mary E., Dr. philos.	The relationship between noise as an experimental and environmental stressor, physiological changes and psychological factors.
	Torgersen, Anne M., Dr. philos.	Genetic and environmental influence on temperamental behaviour. A longitudinal study of twins from infancy to adolescence.
1993	Larsen, Svein, Dr. philos.	Cultural background and problem drinking.
	Nordhus, Inger Hilde, Dr. philos.	Family caregiving. A community psychological study with special emphasis on clinical interventions.
	Thuen, Frode, Dr. psychol.	Accident-related behaviour among children and young adolescents: Prediction and prevention.

	Solheim, Ragnar, Dr. philos.	Spesifikke lærevansker. Diskrepanskriteriet anvendt i seleksjonsmetodikk.
	Johnsen, Bjørn Helge, Dr. psychol.	Brain assymetry and facial emotional expressions: Conditioning experiments.
1994	Tønnessen, Finn E., Dr. philos.	The etiology of Dyslexia.
	Kvale, Gerd, Dr. psychol.	Psychological factors in anticipatory nausea and vomiting in cancer chemotherapy.
	Asbjørnsen, Arve E., Dr. psychol.	Structural and dynamic factors in dichotic listening: An interactional model.
	Bru, Edvin, Dr. philos.	The role of psychological factors in neck, shoulder and low back pain among female hospitale staff.
	Braathen, Eli T., Dr. psychol.	Prediction of exellence and discontinuation in different types of sport: The significance of motivation and EMG.
	Johannessen, Birte F., Dr. philos.	Det flytende kjønnet. Om lederskap, politikk og identitet.
1995	Sam, David L., Dr. psychol.	Acculturation of young immigrants in Norway: A psychological and socio-cultural adaptation.
	Bjaalid, Inger-Kristin, Dr. philos.	Component processes in word recognition.
	Martinsen, Øyvind, Dr. philos.	Cognitive style and insight.
	Nordby, Helge, Dr. philos.	Processing of auditory deviant events: Mismatch negativity of event-related brain potentials.
	Raaheim, Arild, Dr. philos.	Health perception and health behaviour, theoretical considerations, empirical studies, and practical implications.
	Seltzer, Wencke J., Dr. philos.	Studies of Psychocultural Approach to Families in Therapy.
	Brun, Wibecke, Dr. philos.	Subjective conceptions of uncertainty and risk.
	Aas, Henrik N., Dr. psychol.	Alcohol expectancies and socialization: Adolescents learning to drink.
	Bjørkly, Stål, Dr. psychol.	Diagnosis and prediction of intra-institutional aggressive behaviour in psychotic patients
1996	Anderssen, Norman, Dr. psychol.	Physical activity of young people in a health perspective: Stability, change and social influences.
	Sandal, Gro Mjeldheim, Dr. psychol.	Coping in extreme environments: The role of personality.
	Strumse, Einar, Dr. philos.	The psychology of aesthetics: explaining visual preferences for agrarian landscapes in Western Norway.

	Hestad, Knut, Dr. philos.	Neuropsychological deficits in HIV-1 infection.
	Lugoe, L.Wycliffe, Dr. philos.	Prediction of Tanzanian students' HIV risk and preventive behaviours
	Sandvik, B. Gunnhild, Dr. philos.	Fra distriktsjordmor til institusjonsjordmor. Fremveksten av en profesjon og en profesjonsutdanning
	Lie, Gro Therese, Dr. psychol.	The disease that dares not speak its name: Studies on factors of importance for coping with HIV/AIDS in Northern Tanzania
	Øygard, Lisbet, Dr. philos.	Health behaviors among young adults. A psychological and sociological approach
	Stormark, Kjell Morten, Dr. psychol.	Emotional modulation of selective attention: Experimental and clinical evidence.
	Einarsen, Ståle, Dr. psychol.	Bullying and harassment at work: epidemiological and psychosocial aspects.
1997	Knivsberg, Ann-Mari, Dr. philos.	Behavioural abnormalities and childhood psychopathology: Urinary peptide patterns as a potential tool in diagnosis and remediation.
	Eide, Arne H., Dr. philos.	Adolescent drug use in Zimbabwe. Cultural orientation in a global-local perspective and use of psychoactive substances among secondary school students.
	Sørensen, Marit, Dr. philos.	The psychology of initiating and maintaining exercise and diet behaviour.
	Skjæveland, Oddvar, Dr. psychol.	Relationships between spatial-physical neighborhood attributes and social relations among neighbors.
	Zewdie, Teka, Dr. philos.	Mother-child relational patterns in Ethiopia. Issues of developmental theories and intervention programs.
	Wilhelmsen, Britt Unni, Dr. philos.	Development and evaluation of two educational programmes designed to prevent alcohol use among adolescents.
	Manger, Terje, Dr. philos.	Gender differences in mathematical achievement among Norwegian elementary school students.
1998 V	Lindstrøm, Torill Christine, Dr. philos.	«Good Grief»: Adapting to Bereavement.
	Skogstad, Anders, Dr. philos.	Effects of leadership behaviour on job satisfaction, health and efficiency.
	Haldorsen, Ellen M. Håland, Dr. psychol.	Return to work in low back pain patients.
	Besemer, Susan P., Dr. philos.	Creative Product Analysis: The Search for a Valid Model for Understanding Creativity in Products.

H	Winje, Dagfinn, Dr. psychol.	Psychological adjustment after severe trauma. A longitudinal study of adults' and children's posttraumatic reactions and coping after the bus accident in Måbødalen, Norway 1988.
	Vosburg, Suzanne K., Dr. philos.	The effects of mood on creative problem solving.
	Eriksen, Hege R., Dr. philos.	Stress and coping: Does it really matter for subjective health complaints?
	Jakobsen, Reidar, Dr. psychol.	Empiriske studier av kunnskap og holdninger om hiv/aids og den normative seksuelle utvikling i ungdomsårene.
1999 V	Mikkelsen, Aslaug, Dr. philos.	Effects of learning opportunities and learning climate on occupational health.
	Samdal, Oddrun, Dr. philos.	The school environment as a risk or resource for students' health-related behaviours and subjective well-being.
	Friestad, Christine, Dr. philos.	Social psychological approaches to smoking.
	Ekeland, Tor-Johan, Dr. philos.	Meining som medisin. Ein analyse av placebofenomenet og implikasjoner for terapi og terapeutiske teoriar.
H	Saban, Sara, Dr. psychol.	Brain Asymmetry and Attention: Classical Conditioning Experiments.
	Carlsten, Carl Thomas, Dr. philos.	God lesing – God læring. En aksjonsrettet studie av undervisning i fagtekstlesing.
	Dundas, Ingrid, Dr. psychol.	Functional and dysfunctional closeness. Family interaction and children's adjustment.
	Engen, Liv, Dr. philos.	Kartlegging av leseferdighet på småskoletrinnet og vurdering av faktorer som kan være av betydning for optimal leseutvikling.
2000 V	Hovland, Ole Johan, Dr. philos.	Transforming a self-preserving "alarm" reaction into a self-defeating emotional response: Toward an integrative approach to anxiety as a human phenomenon.
	Lillejord, Sølvi, Dr. philos.	Handlingsrasjonalitet og spesialundervisning. En analyse av aktørperspektiver.
	Sandell, Ove, Dr. philos.	Den varme kunnskapen.
	Oftedal, Marit Petersen, Dr. philos.	Diagnostisering av ordavkodingsvansker: En prosessanalytisk tilnærmingsmåte.
H	Sandbak, Tone, Dr. psychol.	Alcohol consumption and preference in the rat: The significance of individual differences and relationships to stress pathology
	Eid, Jarle, Dr. psychol.	Early predictors of PTSD symptom reporting; The significance of contextual and individual factors.

2001 V	Skinstad, Anne Helene, Dr. philos.	Substance dependence and borderline personality disorders.
	Binder, Per-Einar, Dr. psychol.	Individet og den meningsbærende andre. En teoretisk undersøkelse av de mellommenneskelige forutsetningene for psykisk liv og utvikling med utgangspunkt i Donald Winnicotts teori.
	Roald, Ingvild K., Dr. philos.	Building of concepts. A study of Physics concepts of Norwegian deaf students.
H	Fekadu, Zelalem W., Dr. philos.	Predicting contraceptive use and intention among a sample of adolescent girls. An application of the theory of planned behaviour in Ethiopian context.
	Melesse, Fantu, Dr. philos.	The more intelligent and sensitive child (MISC) mediational intervention in an Ethiopian context: An evaluation study.
	Råheim, Målfrid, Dr. philos.	Kvinners kroppserfaring og livssammenheng. En fenomenologisk – hermeneutisk studie av friske kvinner og kvinner med kroniske muskelsmerter.
	Engelsen, Birthe Kari, Dr. psychol.	Measurement of the eating problem construct.
	Lau, Bjørn, Dr. philos.	Weight and eating concerns in adolescence.
2002 V	Ihlebæk, Camilla, Dr. philos.	Epidemiological studies of subjective health complaints.
	Rosén, Gunnar O. R., Dr. philos.	The phantom limb experience. Models for understanding and treatment of pain with hypnosis.
	Høines, Marit Johnsen, Dr. philos.	Fleksible språkrom. Matematikklæring som tekstutvikling.
	Anthun, Roald Andor, Dr. philos.	School psychology service quality. Consumer appraisal, quality dimensions, and collaborative improvement potential
	Pallesen, Ståle, Dr. psychol.	Insomnia in the elderly. Epidemiology, psychological characteristics and treatment.
	Midthassel, Unni Vere, Dr. philos.	Teacher involvement in school development activity. A study of teachers in Norwegian compulsory schools
	Kallestad, Jan Helge, Dr. philos.	Teachers, schools and implementation of the Olweus Bullying Prevention Program.
H	Ofte, Sonja Helgesen, Dr. psychol.	Right-left discrimination in adults and children.
	Netland, Marit, Dr. psychol.	Exposure to political violence. The need to estimate our estimations.
	Diseth, Åge, Dr. psychol.	Approaches to learning: Validity and prediction of academic performance.

	Bjuland, Raymond, Dr. philos.	Problem solving in geometry. Reasoning processes of student teachers working in small groups: A dialogical approach.
2003 V	Arefjord, Kjersti, Dr. psychol.	After the myocardial infarction – the wives' view. Short- and long-term adjustment in wives of myocardial infarction patients.
	Ingjaldsson, Jón Þorvaldur, Dr. psychol.	Unconscious Processes and Vagal Activity in Alcohol Dependency.
	Holden, Børge, Dr. philos.	Følger av atferdsanalytiske forklaringer for atferdsanalysens tilnærming til utforming av behandling.
	Holsen, Ingrid, Dr. philos.	Depressed mood from adolescence to 'emerging adulthood'. Course and longitudinal influences of body image and parent-adolescent relationship.
	Hammar, Åsa Karin, Dr. psychol.	Major depression and cognitive dysfunction- An experimental study of the cognitive effort hypothesis.
	Sprugevica, Ieva, Dr. philos.	The impact of enabling skills on early reading acquisition.
	Gabrielsen, Egil, Dr. philos.	LESE FOR LIVET. Lesekompetansen i den norske voksenbefolkningen sett i lys av visjonen om en enhetsskole.
H	Hansen, Anita Lill, Dr. psychol.	The influence of heart rate variability in the regulation of attentional and memory processes.
	Dyregrov, Kari, Dr. philos.	The loss of child by suicide, SIDS, and accidents: Consequences, needs and provisions of help.
2004 V	Torsheim, Torbjørn, Dr. psychol.	Student role strain and subjective health complaints: Individual, contextual, and longitudinal perspectives.
	Haugland, Bente Storm Mowatt Dr. psychol.	Parental alcohol abuse. Family functioning and child adjustment.
	Milde, Anne Marita, Dr. psychol.	Ulcerative colitis and the role of stress. Animal studies of psychobiological factors in relationship to experimentally induced colitis.
	Stornes, Tor, Dr. philos.	Socio-moral behaviour in sport. An investigation of perceptions of sportspersonship in handball related to important factors of socio-moral influence.
	Mæhle, Magne, Dr. philos.	Re-inventing the child in family therapy: An investigation of the relevance and applicability of theory and research in child development for family therapy involving children.
	Kobbeltvedt, Therese, Dr. psychol.	Risk and feelings: A field approach.
2004 H	Thomsen, Tormod, Dr. psychol.	Localization of attention in the brain.
	Løberg, Else-Marie, Dr. psychol.	Functional laterality and attention modulation in schizophrenia: Effects of clinical variables.

	Kyrkjebø, Jane Mikkelsen, Dr. philos.	Learning to improve: Integrating continuous quality improvement learning into nursing education.
	Laumann, Karin, Dr. psychol.	Restorative and stress-reducing effects of natural environments: Experiencal, behavioural and cardiovascular indices.
	Holgersen, Helge, PhD	Mellom oss - Essay i relasjonell psykoanalyse.
2005 V	Hetland, Hilde, Dr. psychol.	Leading to the extraordinary? Antecedents and outcomes of transformational leadership.
	Iversen, Anette Christine, Dr. philos.	Social differences in health behaviour: the motivational role of perceived control and coping.
2005 H	Mathisen, Gro Ellen, PhD	Climates for creativity and innovation: Definitions, measurement, predictors and consequences.
	Sævi, Tone, Dr. philos.	Seeing disability pedagogically – The lived experience of disability in the pedagogical encounter.
	Wiium, Nora, PhD	Intrapersonal factors, family and school norms: combined and interactive influence on adolescent smoking behaviour.
	Kanagaratnam, Pushpa, PhD	Subjective and objective correlates of Posttraumatic Stress in immigrants/refugees exposed to political violence.
	Larsen, Torill M. B. , PhD	Evaluating principals` and teachers` implementation of Second Step. A case study of four Norwegian primary schools.
	Bancila, Delia, PhD	Psychosocial stress and distress among Romanian adolescents and adults.
2006 V	Hillestad, Torgeir Martin, Dr. philos.	Normalitet og avvik. Forutsetninger for et objektivt psykopatologisk avviksbegrep. En psykologisk, sosial, erkjennelsesteoretisk og teorihistorisk framstilling.
	Nordanger, Dag Øystein, Dr. psychol.	Psychosocial discourses and responses to political violence in post-war Tigray, Ethiopia.
	Rimol, Lars Morten, PhD	Behavioral and fMRI studies of auditory laterality and speech sound processing.
	Krumsvik, Rune Johan, Dr. philos.	ICT in the school. ICT-initiated school development in lower secondary school.
	Norman, Elisabeth, Dr. psychol.	Gut feelings and unconscious thought: An exploration of fringe consiousness in implicit cognition.
	Israel, K Pravin, Dr. psychol.	Parent involvement in the mental health care of children and adolescents. Emperical studies from clinical care setting.

	Glasø, Lars, PhD	Affects and emotional regulation in leader-subordinate relationships.
	Knutsen, Ketil, Dr. philos.	HISTORIER UNGDOM LEVER – En studie av hvordan ungdommer bruker historie for å gjøre livet meningsfullt.
	Matthiesen, Stig Berge, PhD	Bullying at work. Antecedents and outcomes.
2006 H	Gramstad, Arne, PhD	Neuropsychological assessment of cognitive and emotional functioning in patients with epilepsy.
	Bendixen, Mons, PhD	Antisocial behaviour in early adolescence: Methodological and substantive issues.
	Mrumbi, Khalifa Maulid, PhD	Parental illness and loss to HIV/AIDS as experienced by AIDS orphans aged between 12-17 years from Temeke District, Dar es Salaam, Tanzania: A study of the children's psychosocial health and coping responses.
	Hetland, Jørn, Dr. psychol.	The nature of subjective health complaints in adolescence: Dimensionality, stability, and psychosocial predictors
	Kakoko, Deodatus Conatus Vitalis, PhD	Voluntary HIV counselling and testing service uptake among primary school teachers in Mwanza, Tanzania: assessment of socio-demographic, psychosocial and socio-cognitive aspects
	Mykletun, Arnstein, Dr. psychol.	Mortality and work-related disability as long-term consequences of anxiety and depression: Historical cohort designs based on the HUNT-2 study
	Sivertsen, Børge, PhD	Insomnia in older adults. Consequences, assessment and treatment.
2007 V	Singhammer, John, Dr. philos.	Social conditions from before birth to early adulthood – the influence on health and health behaviour
	Janvin, Carmen Ani Cristea, PhD	Cognitive impairment in patients with Parkinson's disease: profiles and implications for prognosis
	Braarud, Hanne Cecilie, Dr.psychol.	Infant regulation of distress: A longitudinal study of transactions between mothers and infants
	Tveito, Torill Helene, PhD	Sick Leave and Subjective Health Complaints
	Magnussen, Liv Heide, PhD	Returning disability pensioners with back pain to work
	Thuen, Elin Marie, Dr.philos.	Learning environment, students' coping styles and emotional and behavioural problems. A study of Norwegian secondary school students.
	Solberg, Ole Asbjørn, PhD	Peacekeeping warriors – A longitudinal study of Norwegian peacekeepers in Kosovo
2007 H	Søreide, Gunn Elisabeth, Dr.philos.	Narrative construction of teacher identity

	Svensen, Erling, PhD	WORK & HEALTH. Cognitive Activation Theory of Stress applied in an organisational setting.
	Øverland, Simon Nygaard, PhD	Mental health and impairment in disability benefits. Studies applying linkages between health surveys and administrative registries.
	Eichele, Tom, PhD	Electrophysiological and Hemodynamic Correlates of Expectancy in Target Processing
	Børhaug, Kjetil, Dr.philos.	Oppseding til demokrati. Ein studie av politisk oppseding i norsk skule.
	Eikeland, Thorleif, Dr.philos.	Om å vokse opp på barnehjem og på sykehus. En undersøkelse av barnehjemsbarns opplevelser på barnehjem sammenholdt med sanatoriebarns beskrivelse av langvarige sykehusopphold – og et forsøk på forklaring.
	Wadel, Carl Cato, Dr.philos.	Medarbeidersamhandling og medarbeiderledelse i en lagbasert organisasjon
	Vinje, Hege Forbech, PhD	Thriving despite adversity: Job engagement and self-care among community nurses
	Noort, Maurits van den, PhD	Working memory capacity and foreign language acquisition
2008 V	Breivik, Kyrre, Dr.psychol.	The Adjustment of Children and Adolescents in Different Post-Divorce Family Structures. A Norwegian Study of Risks and Mechanisms.
	Johnsen, Grethe E., PhD	Memory impairment in patients with posttraumatic stress disorder
	Sætrevik, Bjørn, PhD	Cognitive Control in Auditory Processing
	Carvalhosa, Susana Fonseca, PhD	Prevention of bullying in schools: an ecological model
2008 H	Brønnick, Kolbjørn Selvåg	Attentional dysfunction in dementia associated with Parkinson's disease.
	Posserud, Maj-Britt Rocio	Epidemiology of autism spectrum disorders
	Haug, Ellen	Multilevel correlates of physical activity in the school setting
	Skjerve, Arvid	Assessing mild dementia – a study of brief cognitive tests.
	Kjønniksen, Lise	The association between adolescent experiences in physical activity and leisure time physical activity in adulthood: a ten year longitudinal study
	Gundersen, Hilde	The effects of alcohol and expectancy on brain function

	Omvik, Siri	Insomnia – a night and day problem
2009 V	Molde, Helge	Pathological gambling: prevalence, mechanisms and treatment outcome.
	Foss, Else	Den omsorgsfulle væremåte. En studie av voksnes væremåte i forhold til barn i barnehagen.
	Westrheim, Kariane	Education in a Political Context: A study of Konwledge Processes and Learning Sites in the PKK.
	Wehling, Eike	Cognitive and olfactory changes in aging
	Wangberg, Silje C.	Internet based interventions to support health behaviours: The role of self-efficacy.
	Nielsen, Morten B.	Methodological issues in research on workplace bullying. Operationalisations, measurements and samples.
	Sandu, Anca Larisa	MRI measures of brain volume and cortical complexity in clinical groups and during development.
	Guribye, Eugene	Refugees and mental health interventions
	Sørensen, Lin	Emotional problems in inattentive children – effects on cognitive control functions.
	Tjomsland, Hege E.	Health promotion with teachers. Evaluation of the Norwegian Network of Health Promoting Schools: Quantitative and qualitative analyses of predisposing, reinforcing and enabling conditions related to teacher participation and program sustainability.
	Helleve, Ingrid	Productive interactions in ICT supported communities of learners
2009 H	Skorpen, Aina Øye, Christine	Dagliglivet i en psykiatrisk institusjon: En analyse av miljøterapeutiske praksiser
	Andreassen, Cecilie Schou	WORKAHOLISM – Antecedents and Outcomes
	Stang, Ingun	Being in the same boat: An empowerment intervention in breast cancer self-help groups
	Sequeira, Sarah Dorothee Dos Santos	The effects of background noise on asymmetrical speech perception
	Kleiven, Jo, dr.philos.	The Lillehammer scales: Measuring common motives for vacation and leisure behavior
	Jónsdóttir, Guðrún	Dubito ergo sum? Ni jenter møter naturfaglig kunnskap.
	Hove, Oddbjørn	Mental health disorders in adults with intellectual disabilities - Methods of assessment and prevalence of mental health disorders and problem behaviour
	Wageningen, Heidi Karin van	The role of glutamate on brain function

	Bjørkvik, Jofrid	God nok? Selvaktelse og interpersonlig fungering hos pasienter innen psykisk helsevern: Forholdet til diagnoser, symptomer og behandlingsutbytte
	Andersson, Martin	A study of attention control in children and elderly using a forced-attention dichotic listening paradigm
	Almås, Aslaug Grov	Teachers in the Digital Network Society: Visions and Realities. A study of teachers' experiences with the use of ICT in teaching and learning.
	Ulvik, Marit	Lærerutdanning som danning? Tre stemmer i diskusjonen
2010 V	Skår, Randi	Læringsprosesser i sykepleieres profesjonsutøvelse. En studie av sykepleieres læringserfaringer.
	Roald, Knut	Kvalitetsvurdering som organisasjonslæring mellom skole og skoleeigar
	Lunde, Linn-Heidi	Chronic pain in older adults. Consequences, assessment and treatment.
	Danielsen, Anne Grete	Perceived psychosocial support, students' self-reported academic initiative and perceived life satisfaction
	Hysing, Mari	Mental health in children with chronic illness
	Olsen, Olav Kjellevold	Are good leaders moral leaders? The relationship between effective military operational leadership and morals
	Riese, Hanne	Friendship and learning. Entrepreneurship education through mini-enterprises.
	Holthe, Asle	Evaluating the implementation of the Norwegian guidelines for healthy school meals: A case study involving three secondary schools
H	Hauge, Lars Johan	Environmental antecedents of workplace bullying: A multi-design approach
	Bjørkelo, Brita	Whistleblowing at work: Antecedents and consequences
	Reme, Silje Endresen	Common Complaints – Common Cure? Psychiatric comorbidity and predictors of treatment outcome in low back pain and irritable bowel syndrome
	Helland, Wenche Andersen	Communication difficulties in children identified with psychiatric problems
	Beneventi, Harald	Neuronal correlates of working memory in dyslexia
	Thygesen, Elin	Subjective health and coping in care-dependent old persons living at home

	Aanes, Mette Marthinussen	Poor social relationships as a threat to belongingness needs. Interpersonal stress and subjective health complaints: Mediating and moderating factors.
	Anker, Morten Gustav	Client directed outcome informed couple therapy
	Bull, Torill	Combining employment and child care: The subjective well-being of single women in Scandinavia and in Southern Europe
	Viig, Nina Grieg	Tilrettelegging for læreres deltakelse i helsefremmende arbeid. En kvalitativ og kvantitativ analyse av sammenhengen mellom organisatoriske forhold og læreres deltakelse i utvikling og implementering av Europeisk Nettverk av Helsefremmende Skoler i Norge
	Wolff, Katharina	To know or not to know? Attitudes towards receiving genetic information among patients and the general public.
	Ogden, Terje, dr.philos.	Familiebasert behandling av alvorlige atferdsproblemer blant barn og ungdom. Evaluering og implementering av evidensbaserte behandlingsprogrammer i Norge.
	Solberg, Mona Elin	Self-reported bullying and victimisation at school: Prevalence, overlap and psychosocial adjustment.
2011 V	Bye, Hege Høivik	Self-presentation in job interviews. Individual and cultural differences in applicant self-presentation during job interviews and hiring managers' evaluation
	Notelaers, Guy	Workplace bullying. A risk control perspective.
	Moltu, Christian	Being a therapist in difficult therapeutic impasses. A hermeneutic phenomenological analysis of skilled psychotherapists' experiences, needs, and strategies in difficult therapies ending well.
	Myrseth, Helga	Pathological Gambling - Treatment and Personality Factors
	Schanche, Elisabeth	From self-criticism to self-compassion. An empirical investigation of hypothesized change prosesses in the Affect Phobia Treatment Model of short-term dynamic psychotherapy for patients with Cluster C personality disorders.
	Våpenstad, Eystein Victor, dr.philos.	Det tempererte nærvær. En teoretisk undersøkelse av psykoterapautens subjektivitet i psykoanalyse og psykoanalytisk psykoterapi.
	Haukebø, Kristin	Cognitive, behavioral and neural correlates of dental and intra-oral injection phobia. Results from one treatment and one fMRI study of randomized, controlled design.
	Harris, Anette	Adaptation and health in extreme and isolated environments. From 78°N to 75°S.

	Bjørknes, Ragnhild	Parent Management Training-Oregon Model: intervention effects on maternal practice and child behavior in ethnic minority families
	Mamen, Asgeir	Aspects of using physical training in patients with substance dependence and additional mental distress
	Espevik, Roar	Expert teams: Do shared mental models of team members make a difference
	Haara, Frode Olav	Unveiling teachers' reasons for choosing practical activities in mathematics teaching
2011 H	Hauge, Hans Abraham	How can employee empowerment be made conducive to both employee health and organisation performance? An empirical investigation of a tailor-made approach to organisation learning in a municipal public service organisation.
	Melkevik, Ole Rogstad	Screen-based sedentary behaviours: pastimes for the poor, inactive and overweight? A cross-national survey of children and adolescents in 39 countries.
	Vøllestad, Jon	Mindfulness-based treatment for anxiety disorders. A quantitative review of the evidence, results from a randomized controlled trial, and a qualitative exploration of patient experiences.
	Tolo, Astrid	Hvordan blir lærerkompetanse konstruert? En kvalitativ studie av PPU-studenters kunnskapsutvikling.
	Saus, Evelyn-Rose	Training effectiveness: Situation awareness training in simulators
	Nordgreen, Tine	Internet-based self-help for social anxiety disorder and panic disorder. Factors associated with effect and use of self-help.
	Munkvold, Linda Helen	Oppositional Defiant Disorder: Informant discrepancies, gender differences, co-occuring mental health problems and neurocognitive function.
	Christiansen, Øivin	Når barn plasseres utenfor hjemmet: beslutninger, forløp og relasjoner. Under barnevernets (ved)tak.
	Brunborg, Geir Scott	Conditionability and Reinforcement Sensitivity in Gambling Behaviour
	Hystad, Sigurd William	Measuring Psychological Resiliency: Validation of an Adapted Norwegian Hardiness Scale
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