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Cognitive control in adults with attention-deficit/hyperactivity disorder

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ABSTRACT

The objective of the present study was to investigate the ability of adults with Attention-Deficit/Hyperactivity Disorder (ADHD) to direct their attention and exert cognitive control in a forced instruction dichotic listening (DL) task. The performance of 29 adults with ADHD was compared with 58 matched controls from the Bergen Dichotic Listening Database ($N>1500$). Participants in the Bergen DL task listen to and report from conflicting consonant–vowel combinations (two different syllables presented simultaneously, one to each ear). They are asked to report the syllable they hear (non-forced condition), or to focus and report either the right- or left-ear syllable (forced-right and forced-left condition). This procedure is presumed to tap distinct cognitive processes: perception (non-forced condition), orienting of attention (forced-right condition), and cognitive control (forced-left condition). Adults with ADHD did not show significant impairment in the conditions tapping perception and attention orientation, but were significantly impaired in their ability to report the left-ear syllable during the forced-left instruction condition, whereas the control group showed the expected left-ear advantage in this condition. This supports the hypothesis of a deficit in cognitive control in the ADHD group, presumably mediated by a deficit in a prefrontal neuronal circuitry. Our results may have implications for psychosocial adjustment for persons with ADHD in educational and work environments.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a disorder with three different clinical subtypes grouped according to their dominant symptoms; the inattentive, the hyperactive/impulsive, and the combined type (American Psychiatric Association, 2000). The estimated worldwide-pooled prevalence in children and adolescents with ADHD is 5.3% (Polanczyk et al., 2007). Although ADHD is primarily diagnosed in childhood the majority of children affected shows persistent symptoms which cause severe functional impairment into adulthood (Biederman and Faraone, 2005; Faraone et al., 2006). Typical symptoms that interfere with daily life are difficulties to maintain attention-span during longer periods of time or to keep attention focused despite distractions, problems in following instructions and to complete activities that demand cognitive focus.

Several causal models have been presented that attempt to explain the symptoms of ADHD (e.g. Sergeant et al., 2003; Nigg, 2006). Earlier models have stressed the dysfunction in a few core domains, such as problems with impaired executive functions (EF) and response inhibition (Pennington and Ozonoff, 1996; Barkley, 1997). ADHD is, however, likely to be a neuropsychologically heterogeneous disorder (Nigg and Casey, 2005; Willcutt et al., 2005; Doyle, 2006; Sonuga-Barke et al., 2010), reflected by the recently described multiple pathways models (Sergeant et al., 2003; Sonuga-Barke, 2005; Castellanos et al., 2006), which highlight other domains than merely EF as problematic, e.g. state regulation (Sanders, 1983; Sergeant, 2005) or delay aversion (Sonuga-Barke et al., 1992).

Deficits in EF or in cognitive control are, however, considered key impairments in ADHD in most of the existing models. Although not exclusive (Jurado and Rosselli, 2007), cognitive abilities often included into the concept of EF are working memory, response inhibition, set-shifting, planning and fluency (Pennington and Ozonoff, 1996; Sergeant et al., 2003). We will in the following use EF and cognitive control as synonym concepts, both defined by the ability to cope with disturbances and conflict situations, where bottom-up, automatic

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responses interfere with the given instructions requiring top-down control.

As recently suggested, dichotic listening (DL) to repeated presentations of consonant-vowel (CV) syllables may represent a way of studying orienting of attention and cognitive control processes (Hugdahl et al., 2009; Westerhausen et al., 2009; Arciuli et al., 2010; see also Carlsson et al., 1994, studying clinical samples). Confronted with two CV-syllables presented dichotically, i.e. one presented to the right and a different presented simultaneously to the left ear, participants more often correctly report the stimulus presented to the right compared with the left ear. Neuronal wiring of the auditory pathways and lateralization of speech sound processing to the left temporal lobe favor stimuli presented to the right ear, and this results in a right-ear advantage (REA) (Kimura, 1967). The REA may thus be regarded as a bottom-up automatic response tendency to presentations of CV-syllables that are reported by the participant.

Instructing the participants to attend to one ear and explicitly report only the syllable presented to that ear, however, will modulate the REA. Healthy participants, when asked to selectively report the right-ear stimulus (forced-right (FR) condition), show an increased REA as compared to the free report (non-forced (NF)) instruction condition. Conversely, when asked to focus attention on the left-ear stimulus (forced-left (FL) condition), the participants typically report more correct stimuli from the left ear, which results in a left-ear advantage (LEA) (Bryden et al., 1983; Hugdahl and Andersson, 1986). The FR and the FL condition may at the outset appear to reflect the same underlying attentional processes, but asking a participant to focus on and report only the right- or left-ear stimulus may create two different experimental conditions that rely on different cognitive functions (Hugdahl et al., 2009). The FR condition requires to focus attention on the stronger, or more salient stimulus (referred to as "orienting" by Posner and Rothbart, 2007), whereas the FL condition specifically requires the ability to resolve a conflict between the bottom-up stronger tendency to report the right-ear stimulus and the top-down instruction to report the weaker left-ear stimulus (Hugdahl et al., 2009). The ability to resolve a conflict is one of the most fundamental aspects of cognitive control (Miller and Cohen, 2001; Fan et al., 2005; Posner and Rothbart, 2007).

The DL task may thus explore three distinct aspects of perception and cognition: bottom-up perception in the NF condition, an orienting process with a synergic bottom-up and a top-down effect in the FR condition, and a cognitive control process with a conflicting top-down effect that needs to override the automatic response in the FL condition. Although the auditory stimuli are identical across all three instruction conditions, the different instructions in this paradigm may hypothetically allow to tease apart the processes of perception, orienting and cognitive control (Hugdahl et al., 2009). In fact, the single experimental manipulation that differentiates the FR and FL instruction conditions is one word within the instruction ("right" versus "left"), whereas all other parameters are kept identical between the two conditions. The NF instruction is in this context a baseline condition to against which to evaluate the effects in the FR and FL conditions.

During the past decade, researchers have started to explore the specific neuropsychological deficits in adults with ADHD (Hervey et al., 2004; Boonstra et al., 2005), whereas prior research has focused mainly on children and adolescents. Profiles generated in samples of children with ADHD are not consistently overlapping with those stemming from adults (Doyle, 2006). In comparison to children with ADHD, adults have had the opportunity to develop different cognitive strategies to cope with cognitive conflicts and response inhibition. We expected that applying a new paradigm with rigorous experimental control could reveal new aspects of cognitive deficits in ADHD. The objective of the present study was thus to investigate the performance in the forced instruction DL tasks in adults with ADHD. We predicted that individuals with ADHD compared with sex- and handedness-matched controls would show impaired cognitive control during FL condition.

2. Methods

2.1. Participants

The sample consisted of 29 participants with ADHD, 15 men and 14 women. The patients were recruited from the Norwegian ADHD-project in Bergen, and further details of the procedure for recruitment are accessible in other publications (Johansson et al., 2008; Halleland et al., 2009; Halmoy et al., 2009). Exclusion criteria were current serious psychiatric disturbance or substance abuse, epilepsy or other neurological or physical disease that significantly impair neurocognitive function, a lifetime history of developmental delay, premature birth before 34 weeks of gestational age, or an IQ below 70, as measured by the Wechsler Abbreviated Scale of Intelligence (WASI). Audiometry was performed for the frequencies 500, 1000, 2000, and 3000 Hz prior to the DL task. We excluded participants with hearing deficits (more than 35 dB hearing loss) on one of the ears in any of the above mentioned frequencies, and individuals that had more than 10 dB differences in hearing between the two ears in two or more frequencies. Applying these criteria, five out of 34 individuals originally recruited from the Norwegian ADHD-project, were not eligible for the present study. All patients had been diagnosed according to ICD-10 or DSM-IV criteria for hyperkinetic disorder/ADHD by a psychiatrist or psychologist before the inclusion in the project. One of the participants had received a diagnosis of bipolar disorder several years ago, but that diagnosis was not confirmed as prior or present diagnosis during the clinical diagnostic interview.

An experienced psychiatrist (M.D.) used the ADHD module of the K-SADS (Kaufman et al., 1997) adjusted to adults to validate the diagnoses and determine the subtype of ADHD. Current ADHD symptoms were determined with the Adult ADHD Self-Report Scale (ASRS-18) (Kessler et al., 2005). The profile of symptoms reported in childhood determined the ADHD-subtype, resulting in 19 participants with a combined type, seven with an inattentive type, and three with a hyperactive/impulsive type.

The mean age in the ADHD group was 32.9 years (S.D. = 7.1, age range 21–48 years), and mean IQ was 110.6 (S.D. = 14.3, IQ range 78–128). Sixteen patients were medicated with stimulants or atomoxetine. Patients were instructed to withhold medication 48 h prior to testing, and nine did this, whereas two continued their ordinary medication and five reduced the dosage during the last 48 h prior to the examination. Thirteen of the patients had not used stimulants or atomoxetine during the past 6 months. Handedness was determined by the hand the participant preferred to draw and write with. Using this definition, 23 of the patients were right-handed, and six were left-handed.

Participants in the control group were selected from the Bergen Dichotic Listening Database, which consists of data from more than 1500 healthy participants, and which all have been tested using the same version of the DL test as used in the present study (described below; see also Hugdahl, 2003). Controls were randomly selected after matching for gender and handedness. Two controls were selected for each participant with ADHD, resulting in 58 controls, 30 men and 28 women, with 46 participants being right-handed and 12 left-handed. The database consists of controls in the following categories of age: <8 years, 9 years, 10–15 years, 16–30 years, 31–49 years, 50–70 years, and controls in corresponding age groups to the participants with ADHD, were selected. Exact age in years and IQ measures were not available for the control group.

2.2. The Dichotic Listening paradigm

The Bergen Dichotic Listening paradigm (Hugdahl, 2003) consists of consonant-vowel (CV) stimuli/ba/,/da/,/ga/,/pa/,/ta/, and/ka/with dichotic stimuli pairs originating from 30 possible (heteronym) combinations of two different stimuli (e.g.,/ba/–/da/,/ba/-/ga/). Homonym pairs, such as/ba/–/ba/, were not presented in the present study. The syllables were read by a male voice in Norwegian with constant intonation and intensity. Each CV syllable lasted between 400 and 450 ms, and the interstimulus interval between two consecutive presentations was about 4 s. Participants were shown the six syllables printed on a piece of paper before the test. Stimulus presentation was performed using headphones, and the stimulus administration and response collection were controlled using E-Prime (Psychology Software Tools Inc., Pittsburgh, PA, USA).

The 30 dichotic CV-pairs were presented three times with three different randomizations, one for each attention instruction condition, thus giving a total of 90 presentations. In the first condition, the NF condition, the participants were instructed to report the syllable they heard best without any specific instruction concerning the focus of attention. In the two remaining conditions the participants were instructed to focus attention on and report the syllable heard either in the right ear, the FR condition, or in the left ear, the FL condition. The NF condition was always presented first, whereas the FR and FL conditions alternated (counterbalanced across participants), being presented second or third.

The numbers of correct reports from left and right ear, respectively, were scored with a maximum score of 30 for each ear and condition (NF, FR, FL). The experimenter scored the response on-line on the same PC that controlled the stimulus presentations.