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Attentional functioning in children with ADHD – predominantly hyperactive-impulsive type and children with ADHD – combined type

O. Tucha[1], **S. Walitza**[2], **L. Mecklinger**[1], **T.-A. Sontag**[1], **S. Kübber**[3], **M. Linder**[4], **K. W. Lange**[1]

[1] Department of Experimental Psychology, University of Regensburg, Regensburg, Germany
[2] Department of Child and Adolescent Psychiatry, University of Würzburg, Würzburg, Germany
[3] Practice of Child and Adolescent Psychiatry, Regensburg, Germany
[4] Department of Child and Adolescent Psychiatry, Disctrict Hospital of Regensburg, Regensburg, Germany

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Summary Although particular importance has been attributed to attention deficits in attention deficit hyperactivity disorder (ADHD), there is no consensus as to the exact nature of inattention in ADHD or which components of attention are affected. The present study was based on a neuropsychological model of attention and assessed various components of attention in 23 children with ADHD/predominantly hyperactive-impulsive type (ADHD-H), 32 children with ADHD/combined type (ADHD-C) and healthy children ($N_1 = 23$ and $N_2 = 32$). A computerized test battery consisting of reaction time tasks of low complexity was used for the assessment of attention (alertness task, vigilance task, divided attention task, visual scanning task, incompatibility task, test of crossmodal integration, flexibility task). In comparison to healthy participants, patient groups were impaired in measures of vigilance, divided attention, selective attention and flexibility but not in measures of alertness. Analysis of the test performance of patient groups revealed no differences between children with ADHD-H and children with ADHD-C. The results of the present study suggest that both children with ADHD-H and children with ADHD-C are seriously impaired in attentional functioning. Children with ADHD-H and children with ADHD-C produced comparable results in measures of attention.

Keywords: ADHD, divided attention, flexibility, selective attention, alertness

Introduction

Disturbances of attentional functioning have frequently been observed in children with attention deficit hyperactivity disorder (ADHD) when comparing the test performance of children with ADHD with that of healthy sex- and age-matched children. Disturbances of arousal, selective attention, distractibility, shifting and deficits of sustained attention, which are the most prominent disturbance of attention in ADHD, have been reported in a number of studies (Sroufe et al., 1973; Van der Meere and Sergeant, 1988; Trommer et al., 1988; Kupietz, 1990; Shue and Douglas, 1992; Grodzinsky and Diamond, 1992; Corkum and Siegel, 1993; Oommen et al., 1993; Losier et al., 1996; Jonkman et al., 1999; Borger et al., 1999; Perugini et al., 2000). Other studies, however, revealed no disturbances in the performance of children with ADHD in tests of selective attention, flexibility and divided attention (Prior et al., 1985; Seidman et al., 1997; Perugini et al., 2000; Oades, 2000). Unfortunately, only single aspects of attention were assessed in the above mentioned studies. Since attention is a multidimensional cognitive capacity (Zimmermann and Leclercq, 2002), these results need to be integrated. However, the results of available studies are difficult to bring together, since the samples examined in these studies vary concerning sample size, age and diagnostic criteria. Furthermore, the diagnostic procedures performed differed considerably in their requirements. While some tests involved working memory, others had a speed component or required access to previously learned knowledge or abilities, such as mathematical skills. Therefore, although much attention has been focused on inattention as a core symptom of ADHD (Aman and Turbott, 1986) there remains no consensus as to the precise nature of inattention in ADHD and which aspects of attention are most affected in this disorder.

Recent neuropsychological theories of attention include unitary concepts of attention within multidimensional

Correspondence: Prof. K. W. Lange, Department of Experimental Psychology, University of Regensburg, 93040 Regensburg, Germany
e-mail: klaus.lange@psychologie.uni-regensburg.de

models, with several distinct components or functions of attention (Sohlberg and Mateer, 1987; Mirsky et al., 1991; Cohen, 1993; Van Zomeren and Brouwer, 1994). These models are supported by both the results of experimental studies and the finding that different components of attention may selectively be affected by focal brain damage (Posner and Boies, 1971; Posner and Rafal, 1987; Cohen, 1993; Van Zomeren and Brouwer, 1994; Pashler, 1998). On the basis of the multi-component model of Posner and colleagues (Posner and Boies, 1971; Posner and Rafal, 1987) who included selective attention, arousal and vigilance as components of attention in their model, Van Zomeren and Brouwer (1994) delineated a theoretical framework of attentional functions. In their model, Van Zomeren and Brouwer (1994) further considered the distinction between aspects of selectivity and intensity made by Kahneman (1973) and the concept of a supervisory attentional control as devised by Shallice (1982). This new multi-component model includes the concepts of alertness – subdivided into tonic and phasic alertness, vigilance/sustained attention, selective attention, divided attention and strategy/flexibility (Van Zomeren and Brouwer, 1994). While tonic alertness refers to a relatively stable level of attention which changes slowly according to diurnal physiological variations of the organism, phasic alertness is the ability to enhance the activation level following a stimulus of high priority. The ability to sustain attention enables a subject to direct attention to one or more sources of information over a relatively long and unbroken period of time. Vigilance, as a type of sustained attention, is the ability to maintain attention over a prolonged period during which infrequent response-demanding events occur. Selective attention is defined as the ability to focus attention in the face of distracting or competing stimuli. Divided attention requires a simultaneous response to multiple tasks or multiple task demands. Flexibility refers to the ability to shift the focus of attention in order to control which information from competing sources will be selectively processed. While selective attention and divided attention are considered to be aspects of selectivity, alertness and vigilance/sustained attention are expressions of intensity (Van Zomeren and Brouwer, 1994).

Since the model of Van Zomeren and Brouwer (1994) has proved its value in the clinical assessment of attentional functioning in patients with focal brain lesions (Van Zomeren and Brouwer, 1994), the aim of the present prospective study was to assess several components of attention, as suggested by this model, in a well-defined sample of children with ADHD and healthy children. On the basis of the results of the above studies, we hypothesized that children with different subtypes of ADHD would demonstrate disturbances of attention with regard to selectivity, intensity and flexibility. Furthermore, since results concerning cognitive functioning of subtypes of ADHD have been inconsistent, with evidence both for and against differences between ADHD subtypes (Carlson et al., 1986; Lahey et al., 1988; Barkley et al., 1990, 1992; Lockwood et al., 2001), we questioned whether subtypes of ADHD in children differ in regard to various components of attention. Assessment of attention components was performed using a computerized test battery for the assessment of attentional functions which allows for the examination of specific aspects of attention (Zimmermann and Fimm, 2002). Dependent variables and test requirements concerning previous knowledge were comparable across all test procedures used.

Methods

Participants

Fifty-seven children with ADHD according to the DSM-IV criteria participated in the present study. Children with ADHD were selected from the Department of Child and Adolescent Psychiatry of the District Hospital of Regensburg and from a local practice of child and adolescent psychiatry. Patients were selected according to age, diagnosis, intellectual functions (IQ) and willingness to participate in the study. Children with ADHD who were younger than 7 or older than 14 years of age, who had intelligence quotient (IQ) values below 85, who had uncorrected hearing or visual impairments or who had another Axis I diagnosis were excluded from the study.

Criterion C of the diagnostic features according to DSM-IV requires that some impairment from symptoms must be present in at least two settings (e.g. at home or at school/work). The symptoms typically worsen in situations requiring sustained attention or mental effort, e.g. while listening to classroom teachers or performing class assignments. The clinican should therefore gather information from multiple sources (parents, teachers) and inquire about the individual's behaviour in a variety of situations within each setting (DSM-IV-TR, 2005). The diagnosis of ADHD was therefore based on clinical assessment (DSM-IV), observations of children and interviews with parents and children, and both the Conners Teacher Rating Scale and the Conners Parent Rating Scale (Goyette et al., 1978). Interviews and assessment were performed by a team of experienced clinicians, including child psychiatrists and child psychologists. Thirty-two of the 57 children with ADHD met DSM-IV criteria for ADHD – combined type (ADHD-C), 23 children met criteria for ADHD – predominantly hyperactive-impulsive type (ADHD-H) and 2 children met criteria for ADHD – predominantly inattentive type (ADHD-I). Due to the small sample size the two children with ADHD-I were excluded from statistical analysis. Twenty-four children from the remaining sample of children with ADHD ($n = 55$) had never taken stimulants prior to the present examination; 31 have received the stimulant medication methylphenidate. None of the children were taking concurrent psychotropic medication at the time of the study (e.g. antidepressants). Children with ADHD who were being treated with stimulant medication remained medication free for at least 18 hours prior to participation in the study. All children with ADHD were therefore unmedicated at the time of assessment. Intellectual abilities (IQ) were measured using the Wechsler Intelligence Scale for Children (Wechsler, 1991) or the Kaufmann Assessment Battery for Children (Kaufmann and Kaufmann, 1983). Patient

Table 1. *Characteristics of healthy participants and patients with ADHD (means ± SEM)*

	CO-H	ADHD-H	CO-C	ADHD-C
n	23	23	32	32
Sex (female/male)	5/18	5/18	6/26	6/26
Handedness (left/right)	6/17	6/17	8/24	8/24
Age (in years)	11.35 ± 0.49	11.35 ± 0.49	11.00 ± 0.35	11.00 ± 0.35
Intellectual functions (IQ)[a]	–	99.70 ± 2.37	–	102.69 ± 2.29

Note. [a]Assessment using the Wechsler Intelligence Scale for Children (Wechsler, 1991) or the Kaufmann Assessment Battery for Children (Kaufmann and Kaufmann, 1983)

groups did not differ in age (Mann-Whitney-U: $Z = -0.44$, $p = 0.660$) or intellectual abilities (Mann-Whitney-U: $Z = -1.04$, $p = 0.298$).

Furthermore, two control groups containing a total of 55 healthy children who were matched to children with ADHD according to age, sex and handedness participated in the present study. Twenty-three of the healthy participants formed the control group (CO-H) for the patients with ADHD-H and 32 healthy participants formed the control group (CO-C) for the patients with ADHD-C. Healthy children were selected from a pool of subjects who voluntary participated in the neuropsychological assessment. Due to temporal constraints, the intellectual abilities (IQ) of healthy children were not assessed. Healthy participants responded to public announcements and received no reward for participating. None of them had any history of neurological or psychiatric disease or displayed signs of ADHD or learning disability. At the time of the study no healthy participant was taking medication known to affect the central nervous system. Characteristics of groups are summarized in Table 1. Prior to the start of the present study, all parents gave written consent and were informed of the aims and nature of the study.

Methods and procedure

All participants were tested with a computerized test battery which consisted of eight tasks measuring varying aspects of attention. The tests of attention used were developed and validated for the assessment of attentional deficits in children and adults with cerebral lesions (Zimmermann and Fimm, 1993, 2002). Test procedures were presented on a computer screen. Instructions were given orally. Participants were instructed to perform the computerized tasks as quickly as possible but to maintain a high level of accuracy. In order to familiarize the participants with the tasks, a brief sequence of practice trials preceded each test. Tests were performed only after participants had completed the practice trials without errors. Participants were assessed individually in a quiet room and the examiner was present during the entire assessment.

In the *alertness tasks*, participants were asked to respond by pressing a button when a visual stimulus (a cross of about 1.2 by 1.8 cm) appeared on a computer screen. A total of 40 trials were undertaken. In the first 20 trials the stimulus appeared on the screen without prior warning (*tonic alertness task*), while during the second 20 trials, a warning tone preceded the appearance of the stimulus (*phasic alertness task*). The time span between the warning tone and the appearance of the stimulus was random (between 300 and 700 ms). Measures of tonic and phasic alertness were calculated on the basis of the reaction time of the participant (Zimmermann and Fimm, 1993, 2002). In addition, the variability of reaction time and the number of omission errors were measured.

In the *vigilance task*, a structure consisting of two rectangles (each about 2.0 by 2.0 cm) was presented in the center of the computer screen. One rectangle was situated on top of the other. These rectangles were alternately filled with a pattern (stimulus) for 500 ms with an interstimulus interval of 1000 ms. The duration of the test was 15 minutes. A total of 600 stimuli (changes of pattern location) were presented. The participants were requested to press the response button as quickly as possible when no change of the pattern location occurred. The target rate (i.e. no change of pattern location) was about one target stimulus per minute for a total of about 18 targets. The time intervals between target stimuli were irregular. Reaction time for correct responses, variability of reaction time, number of omission errors (lack of response to target stimuli) and the number of commission errors (responses to non-target stimuli) were calculated (Zimmermann and Fimm, 1993, 2002). The task measured vigilance by requiring the participant to remain alert and ready to react to infrequently occurring target stimuli over a relatively long and unbroken period of time.

The *divided attention task* required participants to concentrate simultaneously on a visual and an acoustic task presented by a computer. In the visual task, a series of matrices (of about 9.5 by 11.0 cm) was presented in the center of the computer screen. Each matrix, consisting of a regular array of sixteen dots and crosses (4×4), was displayed for 2000 ms. The participant was asked to press the response button as quickly as possible whenever the crosses formed the corners of a square (visual target). In the acoustic task, the participant was requested to listen to a continuous sequence of alternating high (2000 Hz) and low (1000 Hz) sounds and to press the response button as quickly as possible when irregularities of the sequence occurred (acoustic target). A total of 100 visual and 200 acoustic stimuli was presented including 17 visual and 16 acoustic targets. Reaction time for correct responses, variability of reaction time, number of omission errors (lack of response to target stimuli) and the number of commission errors (responses to non-target stimuli) were calculated as a measure of divided attention (Zimmermann and Fimm, 1993, 2002).

In the *visual scanning task* a series of 5×5 matrices (of about 8.8 by 8.8 cm) was presented in the center of the computer screen. Each matrix consisted of a regular pattern of 25 squares (each of about 1.2 by 1.2 cm) each of which had an opening on one side (top, bottom, left or right side). A square with an opening at the top was defined as a critical stimulus. The critical stimulus occurred only once in a matrix and was randomly distributed across the matrix. The participant was asked to press the left response button as quickly as possible whenever a matrix contained a critical stimulus (critical trials) or to press the right response button if the critical stimulus was not present (non-critical trials). A total of 50 trials were presented (25 critical trials and 25 non-critical trials). Reaction time for correct responses (critical trials), variability of reaction time, number of omission errors (lack of response to critical stimuli) and the number of commission errors (responses to non-critical stimuli) were calculated. This task assessed inhibition or impulsivity as a measure of selective attention (Zimmermann and Fimm, 1993, 2002).

In the *incompatibility task*, arrows (of a width of about 1.4 cm and a length of about 3.8 cm) pointing to the left or the right were presented briefly on the left or right side of a fixation point in the center of the computer screen. The participants were requested to press a response button as quickly as possible on the side indicated by the direction of the arrow, independent of the position of the arrow. If the position of the arrow and its orientation accorded (e.g. arrow on the left side of the fixation point pointing to the left side), the trial was classified as a compatible trial while trials in which presentation and orientation were not in accordance (e.g. arrow on the left side of the fixation point pointing to the right side) were classified as incompatible trials. A total of 57 trials were presented. The sequence of trials was random, with about half of the trials compatible and half incompatible. Reaction time, variability of reaction time and the number of commission errors were calculated, providing a measure of selective attention as the capacity to reject irrelevant information (Zimmermann and Fimm, 1993, 2002).

In the *test of crossmodal integration*, arrows (of a width of about 1.1 cm and a length of about 1.7 cm) directing up or down and high (790 Hz) or low sounds (530 Hz) were presented simultaneously. Each arrow was presented in the center of the computer screen for 1000 ms. Each sound was presented for 250 ms. The participant was asked to press a response button as quickly as possible when a given condition was met (e.g. simultaneous presentation of an arrow pointing up and a high-pitched sound). A total of 40 trials were presented (18 targets and 22 non-targets). Reaction time for correct responses, variability of reaction time, number of omission errors (lack of response to target stimuli) and the number of commission errors (responses to non-target stimuli) were calculated. The task measured selective attention as the capacity to integrate sensory information of different modalities (Mesulam, 1981; Zimmermann and Fimm, 1993, 2002).

The *flexibility task* required the participant to place each hand on a separate response button while viewing a computer screen, on which a letter and a digit number (of about 12 by 16 mm) were displayed simultaneously. The distance between the letter and the digit number was 5 cm. The participant was instructed to respond by alternately pressing the button that was on the same side of the screen as the letter, and then pressing the button that was on the same side of the screen as the number. After each response, a new letter and number appeared, randomly assigned to either side of the screen. A total of 100 trials were presented. Reaction time, variability of reaction time and the number of commission errors were calculated, providing a measure of flexibility (Zimmermann and Fimm, 1993, 2002).

Data analysis

Due to the small sample sizes of groups, statistical analysis was performed using nonparametric tests. While comparisons between patient and control groups were performed using Wilcoxon tests, Mann-Whitney-U tests were performed to compare the test results of patients with ADHD-H with the results of patients with ADHD-C. For statistical analysis an alpha level of 0.05 was applied. The tests of significance were not corrected for multiple testing because the present investigation is a pilot study attempting to differentiate between subgroups of ADHD on the basis of a neuropsychological model of attention. All statistical analyses were carried out using the Statistical Package for Social Sciences 11.5 for Windows. Furthermore, effect sizes for group differences and effect sizes for differences between paired observations were computed (Cohen, 1988). While the significance criterion represents the standard measure for analysing whether a phenomenon exists, the effect size refers to the magnitude or the importance of effects (Pedhazur and Pedhazur Schmelkin, 1991). Following Cohen's (1988) guidelines for interpreting effect sizes, negligible effects ($d < 0.20$), small effects ($d = 0.20$), medium effects ($d = 0.50$) and large effects ($d = 0.8$) were distinguished (Bezeau and Graves, 2001; Zakzanis, 2001).

Results

Comparisons between patient groups and control groups

Alertness

Comparison between patient groups and control groups using Wilcoxon tests revealed no significant differences with regard to reaction time (ADHD-H vs. CO-H: $Z = -0.18$, $p = 0.855$; ADHD-C vs. CO-C: $Z = -1.38$, $p = 0.166$), variability of reaction time (ADHD-H vs. CO-H: $Z = -1.55$, $p = 0.121$; ADHD-C vs. CO-C: $Z = -1.48$, $p = 0.140$) or number of omission errors (ADHD-H vs. CO-H: $Z = -0.58$, $p = 0.564$; ADHD-C vs. CO-C: $Z = -0.58$, $p = 0.564$) in the tonic alertness task (Table 2). Furthermore, patient groups did not differ from control groups in reaction time (ADHD-H vs. CO-H: $Z = -0.49$, $p = 0.626$; ADHD-C vs. CO-C: $Z = -1.08$, $p = 0.282$), variability of reaction time (ADHD-H vs. CO-H: $Z = -1.76$, $p = 0.078$; ADHD-C vs. CO-C: $Z = -1.65$, $p = 0.100$) or number of omission errors (ADHD-H vs. CO-H: $Z = 0.00$, $p = 1.000$; ADHD-C vs. CO-C: $Z = -0.58$, $p = 0.564$) in the phasic alertness task. The analysis of effect sizes revealed small to negligible differences concerning reaction time and the number of omission errors in both the tonic and the phasic alertness task (Table 3). While small effects sizes were observed between the patient and control groups in the variability of reaction time in the tonic alertness task, medium to large effects were found with regard to variability of reaction time in the phasic alertness task. Both patient groups displayed a higher variability than the control groups.

Vigilance

Significant differences between patient groups and healthy participants were observed in the number of omission errors (ADHD-H vs. CO-H: $Z = -3.35$, $p = 0.001$; ADHD-C vs. CO-C: $Z = -3.80$, $p < 0.001$) and commission errors (ADHD-H vs. CO-H: $Z = -2.63$, $p = 0.009$; ADHD-C vs. CO-C: $Z = -3.98$, $p < 0.001$) indicating a higher error rate in children with ADHD. Furthermore, in comparison to healthy participants, patients with ADHD-C showed an increased variability of reaction time (ADHD-C vs. CO-C: $Z = -2.37$, $p = 0.018$). No differences were found between the ADHD-C group and the CO-C group in reaction time (ADHD-C vs. CO-C: $Z = -1.37$, $p = 0.170$). Patients with ADHD-H did not differ from their healthy counterparts either in reaction time (ADHD-H vs. CO-H: $Z = -1.29$, $p = 0.198$) or in variability of reaction time (ADHD-H vs. CO-H: $Z = -1.49$, $p = 0.136$). The analysis of effect sizes revealed medium to large effects with the exception of a small effect between the ADHD-H and CO-H group in the variability of reaction time.

Divided attention

In the divided attention task patient groups made significantly more omission errors (ADHD-H vs. CO-H: $Z = -2.49$, $p = 0.013$; ADHD-C vs. CO-C: $Z = -3.46$, $p = 0.001$) and displayed a higher variability of reaction time (ADHD-H vs. CO-H: $Z = -2.37$, $p = 0.018$; ADHD-C vs. CO-C: $Z = -2.34$, $p = 0.019$) than healthy participants. While patients with ADHD-C showed an increased reaction time in comparison to their healthy counterparts (ADHD-C vs.

Table 2. *Test performance of healthy participants and patients with ADHD (means ± SEM)*

	CO-H	ADHD-H	CO-C	ADHD-C
Tonic alertness				
Reaction time (in ms)	289.85 ± 57.41	291.98 ± 64.18	289.41 ± 41.34	307.53 ± 65.84
Variability of reaction time (in ms)	50.79 ± 46.20	60.58 ± 56.44	50.90 ± 40.65	63.52 ± 35.66
Number of omission errors	0.04 ± 0.04	0.09 ± 0.06	0.03 ± 0.03	0.063 ± 0.04
Phasic alertness				
Reaction time (in ms)	276.15 ± 50.92	278.54 ± 55.08	270.42 ± 51.73	280.20 ± 64.69
Variability of reaction time (in ms)	55.68 ± 24.37	85.00 ± 63.25	59.94 ± 33.80	77.92 ± 49.47
Number of omission errors	0.04 ± 0.04	0.04 ± 0.04	0.03 ± 0.03	0.06 ± 0.04
Vigilance				
Reaction time (in ms)	740.02 ± 91.67	823.48 ± 238.22	783.50 ± 110.29	838.16 ± 154.59
Variability of reaction time (in ms)	148.19 ± 72.00	188.22 ± 77.09	169.12 ± 52.29	214.08 ± 82.98[b]
Number of omission errors	2.65 ± 3.32	8.52 ± 4.86[a]	3.19 ± 4.45	8.38 ± 4.13[b]
Number of commission errors	2.43 ± 2.17	14.04 ± 29.37[a]	2.28 ± 2.47	12.31 ± 19.03[b]
Divided attention				
Reaction time (in ms)	760.28 ± 131.72	790.22 ± 181.88	750.30 ± 79.80	801.97 ± 135.40[b]
Variability of reaction time (in ms)	236.07 ± 82.11	307.98 ± 101.25[a]	249.07 ± 78.60	296.02 ± 106.27[b]
Number of omission errors	3.00 ± 3.71	6.96 ± 6.53[a]	2.28 ± 2.41	4.78 ± 3.42[b]
Number of commission errors	1.35 ± 1.53	2.52 ± 3.04	1.38 ± 3.19	2.31 ± 4.38
Inhibition				
Reaction time (in ms)	3303.26 ± 1537.33	4262.40 ± 2299.42	3339.64 ± 1096.75	3546.31 ± 1614.47
Variability of reaction time (in ms)	1697.32 ± 872.86	2357.39 ± 1266.39[a]	1818.38 ± 765.98	2009.11 ± 1262.11
Number of omission errors	1.78 ± 1.93	5.57 ± 6.40[a]	2.38 ± 2.81	3.53 ± 2.96[b]
Number of commission errors	0.35 ± 0.57	1.35 ± 2.39[a]	0.63 ± 0.83	0.88 ± 1.10
Focused attention				
Reaction time (in ms)	531.43 ± 159.92	540.15 ± 137.77	499.64 ± 107.27	530.64 ± 133.69
Variability of reaction time (in ms)	119.00 ± 69.02	181.36 ± 116.34[a]	103.76 ± 38.94	145.33 ± 81.90[b]
Number of commission errors	3.87 ± 3.08	9.96 ± 9.73[a]	3.19 ± 2.83	6.78 ± 6.93[b]
Integration of sensory information				
Reaction time (in ms)	480.41 ± 87.49	518.78 ± 117.70	480.67 ± 79.18	548.77 ± 145.00[b]
Variability of reaction time (in ms)	110.86 ± 59.78	187.64 ± 86.18[a]	113.90 ± 57.95	193.30 ± 116.45[b]
Number of omission errors	0.17 ± 0.49	1.57 ± 2.19[a]	0.31 ± 0.82	0.88 ± 1.18[b]
Number of commission errors	1.91 ± 2.59	3.17 ± 2.52[a]	1.13 ± 1.07	3.31 ± 3.75[b]
Flexibility				
Reaction time (in ms)	986.39 ± 419.87	1050.88 ± 292.06	893.61 ± 252.53	1031.94 ± 368.89[b]
Variability of reaction time (in ms)	330.99 ± 208.41	435.79 ± 226.44	266.89 ± 140.71	414.06 ± 236.72[b]
Number of commission errors	3.52 ± 3.49	9.68 ± 10.20[a]	4.34 ± 3.69	7.78 ± 7.21[b]

Note. [a]$p < 0.05$ compared with the CO-H group; [b]$p < 0.05$ compared with the CO-C group

CO-C: $Z = -2.18$, $p = 0.029$), patients with ADHD-H did not differ from their control group in reaction time (ADHD-H vs. CO-H: $Z = -0.30$, $p = 0.761$). The number of commission errors was also comparable in patient and control groups (ADHD-H vs. CO-H: $Z = -1.54$, $p = 0.123$; ADHD-C vs. CO-C: $Z = -1.03$, $p = 0.302$). The analysis of effect sizes revealed large effects between both patient groups and control groups concerning the number of omission errors. The differences between patient groups and healthy participants in the variability of reaction time were of large to medium size. Furthermore, the difference between the ADHD-C group and the CO-C group in reaction time represented a large effect. The effect between the ADHD-H group and the CO-H group in the number of commission errors was medium. The remaining effect sizes were small.

Inhibition

Comparison between patient groups and control groups showed significant differences in the number of omission errors (ADHD-H vs. CO-H: $Z = -2.63$, $p = 0.008$; ADHD-C vs. CO-C: $Z = -2.07$, $p = 0.039$) indicating an impairment of inhibition in patient groups. While patients with ADHD-C did not differ from healthy participants in reaction time, (ADHD-C vs. CO-C: $Z = -0.65$, $p = 0.513$), variability of reaction time (ADHD-C vs. CO-C: $Z = -0.26$, $p = 0.793$) or number of commission errors (ADHD-C vs. CO-C:

Table 3. *Effect sizes for group differences*

	ADHD-H vs. CO-H	ADHD-C vs. CO-C	ADHD-H vs. ADHD-C
Tonic alertness			
Reaction time	0.05	0.46	0.24
Variability of reaction time	0.26	0.27	0.06
Number of omission errors	0.19	0.16	0.11
Phasic alertness			
Reaction time	0.05	0.23	0.03
Variability of reaction time	1.28	0.62	0.12
Number of omission errors	0.00	0.16	0.09
Vigilance			
Reaction time	0.98	0.51	0.07
Variability of reaction time	0.48	0.91	0.32
Number of omission errors	1.60	1.09	0.03
Number of commission errors	5.08	5.07	0.07
Divided attention			
Reaction time	0.23	0.83	0.07
Variability of reaction time	0.93	0.70	0.12
Number of omission errors	1.20	1.34	0.42
Number of commission errors	0.70	0.34	0.06
Inhibition			
Reaction time	0.63	0.20	0.36
Variability of reaction time	0.89	0.27	0.28
Number of omission errors	2.24	0.43	0.41
Number of commission errors	2.11	0.30	0.25
Focused attention			
Reaction time	0.06	0.37	0.07
Variability of reaction time	0.95	1.32	0.36
Number of commission errors	2.62	1.37	0.38
Integration of sensory information			
Reaction time	0.51	0.94	0.23
Variability of reaction time	1.47	1.48	0.06
Number of omission errors	2.95	0.66	0.39
Number of commission errors	0.51	2.04	0.04
Flexibility			
Reaction time in ms	0.19	0.70	0.06
Variability of reaction time	0.60	1.19	0.09
Number of commission errors	1.82	0.96	0.22

$Z = -1.02$, $p = 0.307$), patients with ADHD-H displayed an increased variability of reaction time (ADHD-H vs. CO-H: $Z = -2.25$, $p = 0.024$) and an increased number of commission errors (ADHD-H vs. CO-H: $Z = -2.17$, $p = 0.030$) when compared to their healthy counterparts. Patients with ADHD-H did not differ significantly from healthy participants regarding reaction time (ADHD-H vs. CO-H: $Z = -1.49$, $p = 0.136$). While the differences between patients with ADHD-C and healthy participants were of small size, primarily large effects were found between the ADHD-H and the CO-H group.

Focused attention

In the incompatibility task, patient groups displayed an increased variability of reaction time (ADHD-H vs. CO-H: $Z = -2.31$, $p = 0.021$; ADHD-C vs. CO-C: $Z = -2.79$, $p = 0.005$) and significantly more commission errors than healthy participants (ADHD-H vs. CO-H: $Z = -3.57$, $p < 0.001$; ADHD-C vs. CO-C: $Z = -2.39$, $p = 0.017$). Patient groups did not differ from control groups in the reaction time (ADHD-H vs. CO-H: $Z = -0.70$, $p = 0.484$; ADHD-C vs. CO-C: $Z = -0.89$, $p = 0.374$). The analysis of effect sizes revealed that the significant differences between patient and control groups were of large size. The differences in reaction time were negligible or small effects.

Integration of sensory information

Significant differences between patient groups and healthy participants were observed in the number of omission errors (ADHD-H vs. CO-H: $Z = -2.85$, $p = 0.004$; ADHD-C vs. CO-C: $Z = -2.37$, $p = 0.018$) and commission errors (ADHD-H vs. CO-H: $Z = -1.96$, $p = 0.050$; ADHD-C vs. CO-C: $Z = -3.03$, $p = 0.002$) indicating an impairment in task accuracy in children with ADHD. Furthermore, in comparison to healthy participants, patients with ADHD displayed an increased variability of reaction time (ADHD-H vs. CO-H: $Z = -3.13$, $p = 0.002$; ADHD-C vs. CO-C: $Z = -3.20$, $p = 0.001$). The analysis of reaction time showed a significant difference between patients with ADHD-C and healthy participants (ADHD-C vs. CO-C: $Z = -2.49$, $p = 0.013$) indicating an increased reaction time of patients with ADHD-C. Patients with ADHD-H did not differ from their healthy counterparts in reaction time (ADHD-H vs. CO-HI: $Z = -1.25$, $p = 0.212$). The differences between patient groups and control groups represented medium or large effects.

Flexibility

Comparison between patient groups and control groups revealed significant differences in the number of commission errors with poorer test performance of children with ADHD (ADHD-H vs. CO-H: $Z = -2.58$, $p = 0.010$; ADHD-C vs. CO-C: $Z = -2.43$, $p = 0.015$). While patients with ADHD-C displayed an increased reaction time (ADHD-C vs. CO-C: $Z = -2.11$, $p = 0.035$) and an increased variability of reaction time(ADHD-C vs. CO-C: $Z = -3.03$, $p = 0.002$) compared to the healthy children, patients with ADHD-H did not differ from healthy participants in reaction time (ADHD-H vs. CO-H: $Z = -0.89$, $p = 0.372$) or variability of reaction time (ADHD-H vs. CO-H: $Z = -1.48$, $p = 0.140$). With the exception of a negligible effect between the ADHD-H and CO-H group concerning reaction time, medium to large effects were found.

Comparisons between ADHD subgroups

Comparison between patient groups using Mann-Whitney-U tests revealed no significant differences in any of the test measures of attention used in the present study. Patients with ADHD-H did not differ from patients with ADHD-C in regard to tonic alertness (reaction time: $Z = -1.27$, $p = 0.204$; variability of reaction time: $Z = -1.28$, $p = 0.198$; number of omission errors: $Z = -0.34$, $p = 0.733$), phasic alertness (reaction time: $Z = -0.05$, $p = 0.959$; variability of reaction time: $Z = -0.08$, $p = 0.939$; number of omission errors: $Z = -0.30$, $p = 0.761$), vigilance (reaction time: $Z = -0.57$, $p = 0.569$; variability of reaction time: $Z = -1.02$, $p = 0.307$; number of omission errors: $Z = -0.10$, $p = 0.918$; number of commission errors: $Z = -0.55$, $p = 0.584$), divided attention (reaction time: $Z = -0.66$, $p = 0.511$; variability of reaction time: $Z = -0.46$, $p = 0.645$; number of omission errors: $Z = -0.93$, $p = 0.354$; number of commission errors: $Z = -1.26$, $p = 0.207$), inhibition (reaction time: $Z = -1.09$, $p = 0.275$; variability of reaction time: $Z = -1.23$, $p = 0.219$; number of omission errors: $Z = -0.53$, $p = 0.553$; number of commission errors: $Z = -0.02$, $p = 0.985$), focused attention (reaction time: $Z = -0.21$, $p = 0.831$; variability of reaction time: $Z = -1.02$, $p = 0.306$; number of commission errors: $Z = -1.75$, $p = 0.081$), capacity to integrate sensory information (reaction time: $Z = -0.76$, $p = 0.448$; variability of reaction time: $Z = -0.22$, $p = 0.824$; number of omission errors: $Z = -1.09$, $p = 0.274$; number of commission errors: $Z = -0.65$, $p = 0.517$) and flexibility (reaction time: $Z = -0.51$, $p = 0.610$; variability of reaction time: $Z = -0.55$, $p = 0.585$; number of commission errors: $Z = -0.57$, $p = 0.566$). In addition, the analysis of effect sizes revealed only negligible or small differences between patient groups (Table 3).

Discussion

In the present study, attentional functioning of children with clinically diagnosed ADHD-H or ADHD-C was examined. Attentional functioning was assessed from a multicomponential perspective using several test procedures measuring different aspects of attention. The findings revealed that, compared to control groups of healthy sex-, handedness- and age-matched participants, both patient groups were markedly impaired in vigilance, divided attention, selective attention and flexibility. These impairments comprise aspects of both intensity and selectivity of attention (Kahneman, 1973; Van Zomeren and Brouwer, 1994). In comparison to healthy participants, only tonic and phasic alertness were not impaired in patients with ADHD-H or ADHD-C. The results of former studies assessing aspects of alertness or arousal in children with ADHD are inconsistent. While some authors have reported increased reaction times and an enhanced variability of reaction time in children with ADHD in tasks measuring tonic and/or phasic alertness when compared to test performances of healthy participants (Cohen and Douglas, 1972; Barkley, 1977; Van der Meere et al., 1992; Oommen et al., 1993), other authors have found no differences in these measures (Sroufe et al., 1973). In the ADHD patients of the present study, an age appropriate level of alertness, which can be defined as a generalized state of receptiveness to stimulation and preparedness to respond (Posner and Rafal, 1987; Van Zomeren and Brouwer, 1994), and which may therefore represent a fundamental requirement for optimal mental efficiency (Lezak, 1995) was found. Furthermore, an increase in reaction time due to a general slowing or motor impairment in children with ADHD could be excluded since no differences in reaction time were found to exist between the patient and control groups in either of the alertness tasks. In comparison to healthy participants, patients with ADHD-C showed an increased reaction time in measures of vigilance, divided attention, crossmodal integration and flexibility, as indicated by significant differences and/or medium to large effect sizes. The presence of medium or large effect sizes between children with ADHD-H and healthy participants with regard to reaction time in the vigilance task, the crossmodal integration test and the visual scanning task suggests that children with ADHD-H suffer from impairments in processing.

In addition, in comparison to the test performance of healthy participants, the variability of reaction time was found to be significantly increased in both patient groups in several components of attention including divided attention and selective attention. An increase in within-subject variability of reaction time in children with ADHD had previously been observed in measures of alertness (Cohen and Douglas, 1972; Sroufe et al., 1973), vigilance or sustained attention (Seidel and Joschko, 1990; Borger et al., 1999) and selective attention (Van der Meere and Sergeant, 1988; Borger and Van der Meere, 2000). The variability of reaction time is a measure of the fluctuation in a participant's efficiency in processing during the course of a continuous task (Van Zomeren and Brouwer, 1994). The more the variability of reaction time is increased the severer the impairment in test performance. Post hoc inspection of individual test performances of children with ADHD gave no indication that the variability increases with task duration. The inspection rather showed that the increases in reaction time in children with ADHD are relatively homogenous over the course of the task with few sudden increases. These increases were not found to be concentrated in the latter part of individual attention tests. Fatigue or boredom in children with ADHD will not therefore explain the impairments found in variability of reaction time. The kind of variability displayed by children with ADHD is more likely to be due to lapses of attention, which may be the consequence of heightened distractibility, deficient self-regulation of motivation and/or impaired perseverence. These features have commonly been found in children with ADHD (Solanto et al., 1997; Barkley, 1998). The impairment seen in children in the present study were not so severe as to necessitate the discontinuation of the neuropsychological assessment of any of the participants. Neither did any participant refuse to continue with the assessment of attentional functions during the course of the examination. Studies examining distractibility of children with ADHD by assessing the effects of external and irrelevant stimulation on attention have yielded conflicting results. While some studies found that external stimulation impairs attentional functioning in children with ADHD (Worland et al., 1973; Rosenthal and Allen, 1980; Barkley et al., 1997), other examinations observed no effects of external stimulation (Fischer et al., 1990, 1993). Further studies, however, have reported paradoxically beneficial effects of external stimulation on attention performance of children with ADHD (Zentall et al., 1985).

As well as an increase in reaction time and variability of reaction time in several test procedures, patients with ADHD-H or ADHD-C displayed significant impairments of accuracy in all tests performed except the alertness tasks. Previous studies have demonstrated that measures of task accuracy are more discriminative in the differentiation of children with ADHD from healthy participants than measures of reaction time or processing speed (Sergeant et al., 1979; Hopkins et al., 1979; Homatidis and Konstantareas, 1981; Barkley, 1998). A deficit in inhibiting behaviour in patients with ADHD has frequently been described (Barkley, 1998). Disinhibition or impulsivity as a core characteristic of the disease reflects a general deficiency of control in modulating behaviour in response to situational demands. Barkley (1994, 1997) suggested that children with ADHD suffer from difficulties in various aspects of response inhibition including the inhibition of prepotent responses, the stopping of an ongoing response and the inhibition of interference. In neuropsychological assessment, deficient inhibition of impulsive reactions becomes apparent in a pattern of rapid but often inaccurate responding to tasks (Sergeant and Van der Meere, 1989). In the present study, the inaccurate responding to task demands in children with ADHD is reflected in an increased number of both omission and commission errors. While omission errors are considered a measure of inattention, commission errors are a measure of impulsivity (Trommer et al., 1991; Matier-Sharma et al., 1995). Since children with ADHD did not react faster than healthy children but displayed an increased rate of both omission errors and commission errors, the present results may suggest that the performance of children with ADHD-H or ADHD-C in tasks measuring different components of attentional functioning was adversely affected by both inattentive and impulsive behaviour. The impairments in accuracy cannot be attributed solely to the lapses of attention as observed in patient groups, since lapses of attention typically lead to an increased number of omission errors but not to an increased number of commission errors (Leclercq, 2002).

The finding of the present study that both patients with ADHD-H and patients with ADHD-C may suffer from inattention and impulsivity is of some importance. Since former studies assessing attentional functions in children with ADHD concentrated on only single aspects of attention, the attention deficit in children with ADHD could not be viewed in its entirety. The present study, which is based on a neuropsychological model of attention, demonstrated that patients with ADHD-H or ADHD-C were seriously impaired in a considerable number of attentional processes including vigilance, divided attention, flexibility and aspects of selective attention such as measures of focused attention, inhibition and integration of sensory information. These findings indicate that children with ADHD are not differentially impaired in attentional processes but rather suffer from a more global disturbance of attention. Therefore, studying the course of attention deficits in children with ADHD or examining the effectiveness of psychological or pharmacological treatments of ADHD requires the consideration of multiple components of attention. This should be the aim of future studies, since attentional disturbances may seriously affect the daily life of children with ADHD by contributing to academic failure and social disturbances in peer relationships (Hoza and Pelham, 1993; Barkley, 1998).

In the present study, children with ADHD-H did not differ to any significant degree from children with ADHD-C in attention functions. In addition, the analysis of effect sizes revealed only small or negligible differences. These findings support the results of a number of former examinations which found few or no differences between subtypes of attention deficit disorder (ADD) with or without hyperactivity or ADHD in a variety of areas including academic achievement and cognitive abilities (Maurer and Stewart, 1980; Rubinstein and Brown, 1984; Carlson et al., 1986; Barkley, 1998). In a review of neuropsychological studies, Goodyear and Hynd (1992) concluded that assessment using neuropsychological test measures provided only limited support for differentiating subtypes of ADD. The similarly results of the neuropsychological tests of attention used in the present study do not substantiate the assumption of a differentiation of two subtypes of ADHD. There are however a number of studies reporting differences between subtypes of ADD or ADHD in various measures of functioning (King and Young, 1982; Berry et al., 1985; Sergeant and Scholten, 1985; Lahey et al., 1988; Barkley et al., 1990; Barkley et al., 1992; Barkley, 1998). In a more recent study, Lockwood et al. (2001) attempted to differentiate subtypes of ADHD on the basis of several neuropsychological measures associated with attentional functioning. According to the model of attention devised by Cohen (1993), these authors examined in a retrospective study aspects of sensory and response selection, capacity/focus and sustained attention in children with ADHD-I or ADHD-C. While patient groups did not differ in the capacity/focus and sustained attention components, differences between patient groups were observed concerning sensory and response selection. According to 16 measures of attention, children with ADHD-I could be distinguished from children with ADHD-C with an accuracy of 80%. The contradictions in the findings of previous studies and the present results regarding group differences of ADHD subtypes can be partly explained by methodological differences between the studies such as inclusion and exclusion criteria. For example, in a variety of clinical studies, participants with psychiatric comorbidity or participants receiving pharmacological treatment were included. Furthermore, studies differed in regard to the selection of test measures. For instance, Lockwood et al. (2001) performed tests for the assessment of attentional functioning in children with ADHD-I or ADHD-C such as the copy administration of the Complex Figure Test (Rey, 1941; Osterrieth, 1944) or verbal fluency tests (Benton et al., 1994). These tests were not designed for the diagnosis of attention deficits. Additional research is therefore necessary to address the methodological problems of the available literature and to clarify possible differences of attentional functioning in subtypes of ADHD children. In this respect, a sample of children with ADHD-I should be considered in future research. Furthermore, the aim of future studies could be to examine whether neuropsychological assessment of multiple components of attention is of clinical diagnostic utility in the differentiation of children with ADHD and children suffering from other psychiatric disorders.

The present results must be viewed in the context of some limitations. First, temporal constraints prevented the measurement of IQ in healthy children. Although a comparison of children groups regarding IQ could not be performed, the selection of healthy children on the basis of on-grade-level academic performance may provide a reasonable indication that these children were functioning within the average range of intelligence. The individual IQ values of ADHD children were at least within the normal range, with a mean of about 101 so that the effect of intelligence is minimized. Furthermore, in an unpublished study on the relationship between attention and demographic variables, we found only weak correlations between IQ and the tests used in the present study. A second limitation of the study is that no statistical corrections (e.g. Bonferroni correction) required by multiple comparisons within the study were performed. This strategy increases the likelihood of type I error. However, the significant differences of the present study are largely consistent with effect sizes. With the exception of the difference between the ADHD-C and the CO-C group in the number of omission errors in the visual scanning task, all differences found to be significant were at least of medium size. According to Cohen (1988), more than 80% of significant differences were of large size. A final limitation is that laboratory measures were performed in the present study. Since laboratory measures are usually designed to prove theoretical predictions under strict control of situational variables, concerns regarding their ecological validity have been raised (Barkley, 1991). However, laboratory measures appear not to be susceptible to different types of informant bias such as the attribution to ADHD symptomatology of behavioural disturbances that are neither typical nor specific for ADHD (Schachar et al., 1986; Abikoff et al., 1993). In addition, some characteristics of ADHD may only occur in certain situations and may not therefore be seen by all raters, parents, teachers or other observers (Marks et al., 1999; Riccio et al., 2001). The extent of any behavioural disturbance may also depend on the situation in which the child finds itself.

With these limitations in mind, the results of the present study suggest that, in comparison with healthy children, children with ADHD-H or ADHD-C without psychiatric comorbidity are seriously disturbed in a number of functions of attention, in particular aspects of intensity and selectivity of attention. No differences in measures of attention were observed between children with ADHD-H and children with ADHD-C. This indicates that children with these subtypes of ADHD suffer from the same attention deficit.

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