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Stopping and changing in adults with ADHD

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ABSTRACT

Background. A lack of inhibitory control has been suggested to be the core deficit in children with attention deficit hyperactivity disorder (ADHD). This means that a primary deficit in behavioral inhibition mediates a cascade of secondary deficits in other executive functions, such as arousal regulation. Clinical observations have revealed that with increasing age symptoms of hyperactivity and impulsivity decline at a higher rate than those of inattention. This might imply that a deficit in attention rather than a lack of inhibitory control is the major feature in adult ADHD.

Method. To study whether an attentional or inhibitory deficit predominates, the stop-signal task and the stop-change task were presented to 24 adults with ADHD combined subtype and 24 controls.

Results. Relative to controls, the stop-signal reaction time (SSRT) was significantly more prolonged than the go-stimulus reaction time (RT) in patients with ADHD. This disproportionate elongation of the SSRT was comparable across tasks, even though the stop-change task exerted more complex (or at least different) demands on the inhibitory system than the stop-signal task. ADHD patients had a higher proportion of choice errors, possibly reflecting more premature responses. Specifically in the stop-change task, patients had more variable choice responses and made more inappropriate change responses, which may also reflect enhanced impulsivity.

Conclusions. The results support a core deficit in behavioral inhibition in adults with ADHD. We further suggest that there is more evidence for a critical role of deficient inhibitory control in adults than in children with ADHD.

INTRODUCTION

Attention deficit hyperactivity disorder (ADHD) is a psychiatric disorder characterized by symptoms of inattention, hyperactivity and impulsivity (APA, 1994). Although traditionally considered a childhood disorder, it has become clear that approximately 30–66% of the patients do not outgrow their problems (Weiss *et al.* 1985; Mannuzza *et al.* 1991; Barkley *et al.* 2002; Pary *et al.* 2002). A lack of inhibitory control has been suggested to be the core deficit in children with ADHD: it mediates a wide variety of secondary problems in executive functions (Barkley, 1997; Quay, 1997). Some studies have confirmed a deficit in inhibition in adults with ADHD (Ross *et al.* 2000; Murphy *et al.* 2001; Rapport *et al.* 2001; Nigg *et al.* 2002). The 4-year follow-up study of Biederman *et al.* (2000), however, might be interpreted to imply a qualitatively different disorder in adults as opposed to children: symptoms of hyperactivity and impulsivity were found to decline at a higher rate and at an earlier age than symptoms of inattention. This suggests that, even in the combined subtype, inattention rather than disinhibition is the major feature of adult ADHD.

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The present study aims at determining whether inattention or disinhibition plays the leading part in clarifying performance deficits in adults with ADHD.

A task pre-eminently suitable to disentangle processes related to attention and inhibition is the stop-signal task. Subjects are presented with a primary choice reaction-time (RT) task. Occasionally and unpredictably, a tone is presented indicating that the planned response to the go-stimulus should be withheld. A related paradigm is the stop-change task, in which the tone additionally indicates that an alternative response should be generated. According to the Horse Race Model (Logan & Cowan, 1984; Logan, 1994), the probability of successful inhibitions depends on the relative finishing times of two sets of independently operating processes: the go-process and the stop-process. The latency of the stop-process can be estimated by assuming that it is a constant. Decrements in the go-process, i.e. increases in the mean RT, the variability of responding (SDRT), or the number of discrimination errors or missed responses (omissions), are generally inferred to reflect deficits in sustained attention (Corkum & Siegel, 1993; Castellanos & Tannock, 2002), whereas decrements in the stop-process, i.e. decreases in the probability of inhibition (Pi) or increases in stop-signal reaction time (SSRT), are inferred to reflect deficits in behavioral inhibition (Logan, 1994).

Oosterlaan *et al.* (1998) subjected eight studies in which the stop-signal task or the stop-change task was presented to children with ADHD to a meta-analysis. Children with ADHD were found to have a longer mean reaction time (MRT) and SSRT than normal controls. These findings might be indicative of a general slow mode of information processing caused by lapses in attention (Tannock, 1998; Sergeant *et al.* 1999; Kuntsi *et al.* 2001). The effect sizes (ES) (0·49 for RT and 0·64 for SSRT), however, suggest that the slowing was larger for the processing of the stop-signal. Overtoom *et al.* (2002) directly tested the relative slowing in a single sample of children performing the stop-signal task and found evidence for a disproportionate elongation of the SSRT relative to the RT. This favors an interpretation in terms of a specific lack of inhibitory control rather than in terms of inattention. Lijffijt *et al.* (in press) replicated this finding in a meta-analysis containing studies in which the stop-signal task or stop-change task was administered to children or adults with ADHD. Especially in children, however, the SSRT seemed only slightly more elongated than the RT in children. A regression analysis confirmed that the variable age explained a significant part of the variability across effect sizes reflecting group differences. It should be noted that in this meta-analysis the standard deviations of the difference scores (MRT − SSRT) were unknown for individual studies. Therefore, these standard deviations were estimated with the aid of an assumed correlation between MRT and SSRT, which was based on an arbitrary dataset obtained in 75 adults and 15 children.

Up until now, four studies have been published in which the stop-signal task was administered to adults with ADHD. The RT was either non-significantly shorter (Murphy, 2002; Aron *et al.* 2003; Ossmann & Mulligan, 2003) or longer (Epstein *et al.* 2001) in patients with ADHD as opposed to controls. An increase in SDRT was found by Epstein *et al.* (2001), but not replicated by Ossmann & Mulligan (2003). Aron *et al.* (2003) reported an increase in the percentage of discrimination errors, which was not found by Epstein *et al.* (2001). Finally, all studies, except for Epstein *et al.* (2001), found an elongation of the SSRT. Taken together, these results suggest a deficit in inhibition rather than in attention in adults with ADHD. First, the slowed processing of the stop-stimulus combined with the unimpaired processing speed of the go-stimulus suggests a specific response inhibition deficit. Second, the generally reported trend towards a faster RT to the go-stimulus might be indicative of an increase in the number of premature, impulsive responses. Third, the failure to replicate the group effect on SDRT, the variable showing the largest effect size when comparing children with ADHD to controls (Lijffijt *et al.* in press), contradicts a predominantly attentional deficit. The only finding in line with an attentional deficit in adults with ADHD is the increase in the percentage of discrimination errors reported by Aron *et al.* (2003), but this was not found by Epstein *et al.* (2001).

Before actually rejecting the attention-deficit hypothesis, a specific lack of inhibitory control in adults with ADHD should first be confirmed by demonstrating that the lengthening of the SSRT is significantly larger than the lengthening of the RT. Second, we compared the relative slowing in the stop-signal with that obtained in the stop-change task. The stop-change task has not been previously administered to adults with ADHD, but studies with healthy subjects have revealed that the stop-change task yields longer SSRTs. Logan & Burkell (1986) proposed that this elongation was either due to more complex inhibitory demands resulting in more competition for resources (see also Band & Van Boxtel, 1999) or to the 'grouping' of the internal and alternative response to the tone. Alternatively, De Jong *et al.* (1995) claimed that it reflects the predominant activation of a slow-acting central inhibition mechanism in the stop-change tasks and a fast-acting peripheral inhibition mechanism in the stop-signal task. While the present study does not attempt to settle this controversy, a specific inhibitory deficit in adults with ADHD might be particularly apparent in situations characterized by longer SSRTs.

METHOD

Subjects

Twenty-four out-patient adults diagnosed with ADHD combined subtype (mean age = 34·3, age range = 18–57 years; 12 males, 3 left-handed) were matched on age and gender with 24 normal controls (mean age = 34·9, age range = 18–57 years; 12 males, 1 left-handed). To ensure comparable IQ between groups, the vocabulary and block design subtest of the WAIS-III (Wechsler, 2000) was administered. Table 1 displays the mean age-scaled scores. All subjects completed translated versions of three questionnaires on ADHD symptoms: the BADDS (Brown, 1996), the CAARS (Conners *et al.* 1999), and the DSM-IV ADHD rating scale for current and past ADHD symptoms (DuPaul *et al.* 1998). Table 2 shows that patients with ADHD scored higher on measures related to both inattention and impulsivity than normal controls. All subjects signed an informed consent. The Ethics Committee of the University Medical Center Utrecht approved this study.

Recruitment and selection

Controls were recruited through advertisements in local newspapers and received €90 for participation. Controls were excluded if currently suspected of ADHD, diagnosed with a developmental disorder in childhood (e.g. ADHD, ODD, CD, autism), reporting an ADHD diagnosis among relatives, or treated by a health-care professional. Four controls were currently suspected of ADHD, and one reported to have a son with ADHD.

Table 1. *Mean age-scaled scores and standard deviations (in parentheses) on the vocabulary and block design subtests of the WAIS-III (Wechsler, 2000), displayed separately for each group. The significance levels on the right reveal that groups did not differ in estimated IQ*

WAIS-III subtest	ADHD	Controls	Level of significance
Vocabulary	10·25 (3·60)	11·13 (3·22)	$F(1, 46) = 0{\cdot}79$, $p = 0{\cdot}38$
Block design	10·04 (2·97)	10·50 (3·89)	$F(1, 46) = 0{\cdot}21$, $p = 0{\cdot}65$

Patients were recruited when first seeking clinical help and did not yet use psycho-stimulant medication. Co-morbid disorders were assessed with the computerized CIDI lifetime version 2.1 for DSM-IV diagnoses [Robins *et al.* 1988; World Health Organisation (WHO), 1997] supplemented with the clinical judgement of an experienced physician. Patients with co-morbid disorders were excluded if the severity was such that the co-morbid disorder was required to be treated first or that abstinence from previously prescribed medication was advised against. Co-morbid Axis-I disorders included current depression ($n = 2$, both dysthymic), lifetime depression ($n = 13$), current anxiety disorders ($n = 8$), bipolar disorder ($n = 1$, lifetime), and tic disorder ($n = 1$, lifetime). Two subjects discontinued use of an SSRI prior to participation.

With regard to both groups, subjects who suffered from clinically unstable conditions, such as suicidal behaviors, psychosis, mania, and physical aggression, and subjects who reported organic brain disorder, epilepsy, past concussions, or a loss of consciousness due to head injury were excluded. Prior to participation, the use of psychoactive medication (at least six times the half-life concerned), drugs (at least 3 weeks), alcohol (at least 24 hours), nicotine, caffeine and cacao (last three for at least 12 hours) was prohibited. All subjects claimed to

Table 2. *Mean scores and standard deviations (in parentheses) concerning the translated versions (in Dutch) of three self-report questionnaires: the DSM-IV ADHD rating scale (DuPaul et al. 1998), the BADDS (Brown, 1996), and the CAARS (Conners et al. 1999), displayed separately for controls and adults with ADHD. The significance levels on the right reveal that patients with ADHD scored higher on symptoms of inattention as well as impulsivity than controls*

	ADHD	Controls	Level of significance
DSM-IV rating scale			
Attention deficit in childhood	6·58 (2·72)	0·25 (0·61)	$F(1, 46) = 124{\cdot}16$, $p = 0{\cdot}00$
Hyperactivity/Impulsivity in childhood	5·88 (2·86)	0·88 (1·78)	$F(1, 46) = 52{\cdot}82$, $p = 0{\cdot}00$
Attention deficit in the last 6 months	6·21 (2·99)	0·33 (0·64)	$F(1, 46) = 88{\cdot}50$, $p = 0{\cdot}00$
Hyperactivity/Impulsivity in the last 6 months	6·13 (2·13)	0·46 (0·93)	$F(1, 46) = 142{\cdot}28$, $p = 0{\cdot}00$
BADDS			
Total score	70·58 (22·74)	24·46 (14·61)	$F(1, 46) = 69{\cdot}87$, $p = 0{\cdot}00$
CAARS			
ADHD Index	21·96 (6·37)	6·25 (4·11)	$F(1, 46) = 103{\cdot}07$, $p = 0{\cdot}00$

have normal hearing and normal or corrected-to-normal vision.

Diagnostic procedure in ADHD group

An experienced physician and nurse made the DSM-IV diagnosis of childhood-onset and current ADHD. To be diagnosed with ADHD, subjects must have (1) met 6 out of 9 DSM-IV criteria of inattention and hyperactivity/impulsivity for a diagnosis of ADHD in childhood and at least 5 of 9 criteria in adulthood (Murphy & Barkley, 1996; Biederman *et al.* 2000), (2) described persistent ADHD symptoms from childhood to adulthood, and (3) experienced a moderate to severe level of impairment attributed to the ADHD symptoms. Current and childhood ADHD symptoms were evaluated with a semi-structured diagnostic interview for ADHD and co-morbid disorders, the SGIK (Kooij, 2002). Other childhood disruptive disorders were assessed with a translated version of the structured diagnostic interview for retrospective diagnosis of ADHD and other disruptive disorders, the sections DIS-L/N/O/P of the DIS-IV (Robins *et al.* 1981, 1995). To support the retrospective evaluation, school reports were examined. When possible, parents and partners were interviewed and asked to complete the three questionnaires described earlier in the 'Subjects' section.

Tasks and procedures

On arrival in the laboratory, subjects were familiarized with the procedure. The use of drugs (amphetamine, barbiturates, benzodiazepines, cocaine, morphine and THC) was tested with a urinal drug detection device (Instant-View Drug Screen, Rapid Detect; Horizon Medical Technologies, Morgantown, WV, USA) and the use of alcohol was tested with a breath device (Alcotest, Dräger Medical, Lübeck, Germany). Subjects were seated in a sound-attenuating cabin at a distance of 100 cm from a computer screen. The stop-signal task and the stop-change task were presented while electrical brain activity (EEG) was measured. The EEG data is discussed elsewhere.

Each trial started with a white '+' symbol, which was presented for 500 ms against a gray background in the middle of the computer screen. This warning stimulus was replaced by a square-wave, black-on-white grating ($5{\cdot}71^\circ \times 5{\cdot}71^\circ$) with a high [4·8 cycles per degree (cpd)] or a low (0·6 cpd) spatial frequency, appearing with equal probability. After 750 ms, the gray background replaced the grating for 1000–1250 ms. Subjects were instructed to press a button with the right index finger when a high spatial frequency grating was presented and to press a button with the left index finger when a low spatial frequency grating was presented. The mapping of the response hand reversed after half of the blocks. Unpredictably, on 40% of the trials, a tone (1000 Hz, 80 dB, 400 ms) was presented binaurally through earplugs. In the stop-signal task, this tone indicated that the planned response to the grating should be withheld. In the stop-change task, the tone additionally indicated that an alternative response should be executed: subjects needed to push a foot pedal with both feet simultaneously (De Jong *et al.* 1995). The delay between the grating and the tone (SOA) was adjusted with a tracking algorithm to yield a performance of approximately 50 % corrected successful inhibitions (Pic) (De Jong *et al.* 1995). To increase the unpredictability of the stop-tone, the actual delay between grating and stop-tone was jittered in a range of 240 ms surrounding the calculated SOA (Pliszka *et al.* 2000).

The sequence of task presentation (i.e. stop-signal task first or stop-change task first) and the mapping of the response hand (i.e. right hand to high spatial frequencies first or to low spatial frequencies first) were balanced across subjects. Subjects received a practice block in which no tones were presented and a practice block that consisted of the stop-signal task. In the stop-change task, the use of the foot pedal was trained in an additional practice block (Schachar *et al.* 1995; Oosterlaan & Sergeant, 1998). Prior to the reversal of the response hand, a practice block without tones was presented. For each task, four experimental blocks were presented that contained 126 trials: 76 trials without a tone and 50 trials with a tone. Within each block the sequence of trials was pseudo-randomized with the restriction of a maximum of three successive stop-trials or change-trials.

Data analysis

Performance measures were calculated separately for each subject, each block, and each stimulus category. RTs and SDRTs were computed out of a response window of 150–1250 ms post-stimulus. Other attention-related measures consisted of the percentage of incorrect responses, the percentage of omissions, as well as RTs and standard deviations to the alternative response in the stop-change task. The percentage of errors was calculated separately for the total error score (incorrect hand responses in the stop-signal task and incorrect hand responses in addition to incorrect foot responses in the stop-change task), for incorrect hand responses only (in both tasks), and for incorrect foot presses only (in the stop-change task). These percentages were calculated by dividing the number of incorrect responses by the number of incorrect responses + the number of correct responses (thus without the number of omissions). The percentage of omissions was calculated by dividing the number of omissions by the number of go-trials. Inhibition-related measures consisted of the Pi, the SOA, and the SSRT. The Pi was corrected (Pic) for the estimated number of omissions on stop-trials (Tannock *et al.* 1989). The SSRT was estimated as described in Logan *et al.* (1994).

These dependent measures were subjected to repeated-measures ANOVA with the between-factor group (ADHD *versus* control) and the within-factor task (stop-signal *versus* stop-change). To investigate the possible disproportionate lengthening of the SSRT, the within-factor measure (SSRT *versus* RT) was added. All effects were analyzed using F tests with a critical α-level of 0·05. To enable a comparison of the results from different studies, effect sizes are reported in the discussion. These effect sizes were calculated by subtracting the mean of the control group from the mean of the ADHD group, which was then divided by the standard deviation that was pooled over diagnostic groups (Lipsey & Wilson, 2001). Thus, positive values reflect higher scores in the ADHD group, and negative values reflect lower scores in the ADHD group than in the control group.

RESULTS

Table 3 displays performance data. Group effects were tested for each task separately provided that the omnibus interaction between group and task effects was significant.

Effects of group

The group × measure effect [$F(1, 46) = 4{\cdot}15$, $p < 0{\cdot}05$] reflected that SSRTs were elongated in adults with ADHD [$F(1, 46) = 10{\cdot}43$, $p < 0{\cdot}01$], whereas RTs did not differ across groups. This effect is illustrated in Fig. 1. To further support the finding that slowing was particularly related to the processing of the tone, we performed a *post-hoc* ANCOVA in which SSRT and RT were pooled over tasks. The group effect on SSRT [$F(1, 46) = 10{\cdot}43$, $p < 0{\cdot}01$] remained after correcting for effects of RT [$F(1, 46) = 11{\cdot}18$, $p < 0{\cdot}01$]. SOAs were significantly shorter in patients with ADHD than in controls [$F(1, 46) = 4{\cdot}79$, $p < 0{\cdot}05$]. The percentage of total errors

Table 3. *Performance data obtained from the stop-signal task and the stop-change task. Mean values and standard deviations (in parentheses) are displayed for controls and adults with ADHD. Dependent measures concerning Go-trials and Stop-trials are presented separately*

	Stop-signal task		Stop-change task	
	ADHD	Controls	ADHD	Controls
Go				
MRT	467·89 (87·59)	463·34 (68·75)	504·76 (104·79)	488·45 (90·61)
SD	112·39 (27·40)	105·04 (24·91)	129·57 (35·59)	110·78 (29·89)
P_error_tot	3·43 (2·70)	2·12 (2·16)	7·41 (4·68)	4·00 (2·27)
P_error_hand	—	—	3·45 (3·38)	1·84 (1·42)
P_error_foot	—	—	4·29 (2·92)	2·25 (1·55)
P_omis	2·63 (3·05)	1·22 (1·18)	2·89 (4·87)	1·36 (1·90)
MRT_alternative	—	—	645·90 (157·26)	692·40 (157·53)
SD_alternative	—	—	123·69 (41·24)	120·41 (47·28)
Stop				
SSRT	237·26 (87·18)	185·24 (38·93)	307·78 (87·85)	246·25 (68·48)
Pi	42·76 (10·58)	46·42 (6·48)	40·46 (3·30)	42·57 (11·35)
Pic	42·16 (10·49)	46·14 (6·52)	39·89 (13·03)	42·23 (11·31)
SOA	230·26 (78·10)	267·57 (58·43)	211·97 (63·62)	248·28 (66·94)

MRT, mean reaction time to go-stimulus; SDRT, standard deviation of reaction times to go-stimulus; P_omis, percentage of omissions; P_error_tot, percentage of total incorrect responses; P_error_hand, percentage of incorrect hand responses only; P_error_foot, percentage of incorrect foot responses in stop-change task only; MRT_alternative, mean reaction time of foot response; SD_alternative, standard deviation of reaction times of foot response; SSRT, stop-signal reaction time; Pi, probability of successful inhibitions; Pic, Pi corrected for estimated number of omissions on stop-trials; SOA, delay between go-stimulus and stop-stimulus.

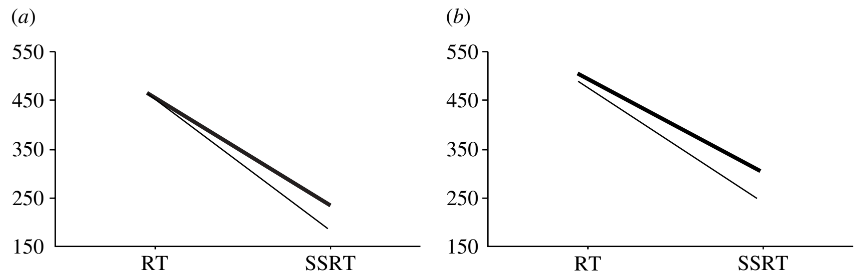

FIG. 1. The disproportionate elongation of the stop-signal reaction time (SSRT) as opposed to the reaction time (RT) in adults with ADHD (▬) relative to controls (—) is displayed for the stop-signal task (*a*) and stop-change task (*b*) separately. The effect of group × measure (SSRT *versus* RT) did not interact with task.

[$F(1, 46) = 9{\cdot}45$, $p < 0{\cdot}01$], incorrect hand responses [$F(1, 46) = 4{\cdot}95$, $p < 0{\cdot}05$], and incorrect foot responses [$F(1, 46) = 9{\cdot}13$, $p < 0{\cdot}01$] were larger in patients with ADHD, and the percentage of omissions tended to be larger [$F(1, 46) = 3{\cdot}51$, $p = 0{\cdot}067$]. RTs and standard deviations in response to the go-stimulus or the alternative foot response in the stop-change task did not differentiate groups.

Effects of task

The task × measure effect [$F(1, 46) = 7{\cdot}33$, $p < 0{\cdot}01$] indicated that the increase in SSRT in the stop-change task relative to the stop-signal task [$F(1, 46) = 31{\cdot}00$, $p < 0{\cdot}01$] was larger than the corresponding increase in RT [$F(1, 46) = 12{\cdot}73$, $p < 0{\cdot}01$]. Relative to the stop-signal task, the stop-change task tended to yield a shorter SOA [$F(1, 46) = 3{\cdot}79$, $p = 0{\cdot}058$], and lower Pi and Pic [$F(1, 46) = 3{\cdot}06$, $p = 0{\cdot}087$ and $F(1, 46) = 3{\cdot}08$, $p = 0{\cdot}086$ respectively]. The SDRT [$F(1, 46) = 17{\cdot}72$, $p < 0{\cdot}01$] and the percentage of total errors [$F(1, 46) = 38{\cdot}01$, $p < 0{\cdot}01$] were larger in the stop-change task.

Interaction of group and task effects

Importantly, an interaction of group × task × measure was not found (see Fig. 1). Interactions of group × task were found for SDRT [$F = (1, 46) = 4{\cdot}41$, $p < 0{\cdot}05$] and the total percentage of errors [$F(1, 46) = 4{\cdot}91$, $p < 0{\cdot}05$]. The increase in SDRT in the stop-change task was significant in the ADHD group [$F(1, 23)=15{\cdot}58$, $p<0{\cdot}01$], but not in the control group [$F(1, 23)=3{\cdot}08$, $p=0{\cdot}093$]. As for incorrect responses, the increase in the stop-change task was larger in the ADHD group [$F(1, 23)=23{\cdot}87$, $p<0{\cdot}01$] than in the control group [$F(1, 23)=14{\cdot}75$, $p<0{\cdot}01$]. The effect of task as well as the interaction with group was no longer significant when analyzed for the percentage of incorrect hand responses only.

DISCUSSION

To disentangle attention and inhibition, the stop-signal task and the stop-change task were presented to 24 ADHD patients diagnosed with the combined subtype and to 24 controls. The results suggest that a lack of inhibitory control rather than a deficit in attention underlies the deteriorated task performance in adults with ADHD.

As for inhibition-related measures, adults with ADHD were found to have a longer SSRT than controls (ES = 0·96). The tracking algorithm generated a shorter SOA in patients with ADHD to compensate for the longer SSRT: the earlier the stop-signal is presented after appearance of the go-stimulus, the higher the chance that the elongated stop-process wins the race against the go-process (Logan & Cowan, 1984; Logan, 1994). As a consequence, no group effect on the probability of successful inhibitions (Pi/Pic) was found. The finding of a longer SSRT is in line with previous results obtained when administering the stop-signal task to adults with ADHD (Murphy, 2002; Aron *et al.* 2003; Ossmann & Mulligan, 2003) as well as to children with ADHD (Oosterlaan *et al.* 1998; Lijffijt *et al.* in press). Epstein *et al.* (2001) did not find a significant group difference in SSRT, but since their effect size (ES = 0·60) was comparable to the effect size of Ossmann & Mulligan (2003) (ES = 0·70), this might have been caused by a lack of power.

The slowed processing of the stop-stimulus is in itself not informative with regard to the primacy of disinhibition in adults with ADHD, since it could equally well reflect an impairment of attention to the tone. Therefore, the slowed processing of the stop-stimulus was studied in relation to the processing speed of the go-stimulus (RT). A significant group effect on RT (ES = 0·13) was not found. This corresponds to previous results obtained in adults with ADHD (Epstein *et al.* 2001; Murphy, 2002; Aron *et al.* 2003; Ossmann & Mulligan, 2003), but contrasts with the longer RTs found in children with ADHD (Oosterlaan *et al.* 1998; Lijffijt *et al.* in press). Statistical analysis indicated that the slowing in SSRT was significantly larger than the (non-significant) slowing in RT (ES = −0·90). This finding was confirmed by a *post-hoc* ANCOVA that revealed a group effect on SSRT after correction for effects of RT. It is, therefore, concluded that a specific lack of inhibitory control rather than a deficit in attention underlies ADHD in adults. A core deficit in inhibition even seems to stand out more clearly in adults than it does in children: although the disproportionate elongation of the SSRT as opposed to the RT was found to be significant in an individual study with ADHD children (Overtoom *et al.* 2002), a meta-analysis suggested that, especially in children, the additional elongation in SSRT was only minor (Lijffijt *et al.* in press). Furthermore, an increase in SDRT, which has been claimed to reflect temporal lapses in attention and (Castellanos & Tannock, 2002) to be particularly suitable to discriminate children with and without ADHD (Lijffijt *et al.* in press), was not found in the present study. The central role for deficient inhibitory rather than attentional processes in adults with ADHD is supported by the recent findings of Wodushek & Neumann (2003), who assessed non-clinical adults with high or low symptom levels of ADHD and found that the SSRT accounts for a greater proportion of the variance of ADHD symptoms than any other cognitive variable.

The presentation of the stop-change task to adults with ADHD has no precedent in the literature. In line with findings obtained from healthy adults (Logan & Burkell, 1986; De Jong *et al.* 1995), both the SSRT and RT were found to be longer in the stop-change task than in the stop-signal task. Again, the tracking algorithm generated a (trend towards a) shorter SOA to compensate for this increase in SSRT. The present study confirms that the stop-signal and the stop-change task specifically differ in inhibitory demands: the increase in SSRT in the stop-change task was disproportionately larger than the corresponding increase in RT. In spite of that, a significant interaction of group × task was not found, i.e. the inhibitory performance of ADHD patients as opposed to controls was not additionally impaired when the demands on the inhibition mechanism increased or at least changed (see Introduction). The alternative foot response itself was not disturbed in adults with ADHD, although previously, in children with ADHD, the change RT has been found to be longer, and the change SDRT has been found to be larger than in controls (Schachar *et al.* 1995; Schachar & Tannock, 1995; Oosterlaan & Sergeant, 1998).

The stop-change task not only exerted higher (or different) demands on the inhibitory system, but also on presumed measures of attention: it evoked larger standard deviations and a higher percentage of total errors. These effects interacted with group. Regarding SDRT, the interaction indicated that the ADHD group, in contrast to the control group, displayed an increase in the variability of responding to the go-stimulus in the stop-change task as opposed to the stop-signal task. The interaction effect on the percentage of total errors could be completely attributed to an increase in the percentage of incorrect foot responses in the stop-change task. Particularly patients with ADHD generated incorrect foot responses when hand responses were required. These effects suggest that interference from the alternative response option on the go-process was larger in the ADHD group than in the control group and that correct responses to the go-stimulus were more variable in speed, because patients with ADHD had more trouble inhibiting the tendency to generate the alternative response as was indicated by the increased number of incorrect foot responses. Thus, although increases in SDRT and in the percentage of errors are usually explained in terms of lapses in attention (Castellanos & Tannock, 2002), these effects are more plausibly explained in terms of disinhibition in the present study. This form of impulsivity (tendency to generate the additional response option) would not have become visible had only the stop-signal task been presented. Alternatively, since the stop-change task involves response re-engagement besides inhibition, these effects could reflect a deficit in task-set maintenance. Task-set switching deficits have previously been demonstrated in children with ADHD (Cepeda *et al.* 2000; Kramer *et al.* 2001).

Finally, as reported by Aron *et al.* (2003) adults with ADHD were found to make more discrimination errors than controls. An increased error rate not accompanied by an increase in RT (previous studies even reported a trend towards a shorter RT in patients with ADHD) might be indicative of a speed-accuracy trade-off (Luce, 1986) favoring fast, impulsive responses. Thus, again an increase in the percentage of discrimination errors, which is usually taken as evidence of inattention, is most likely to be related to a deficit in inhibition in the present context. The only finding that probably reflects a deficit in attention in the present study is the increase in the percentage of omissions. As described in the Results section, however, this effect did not reach significance.

Taken together, the results suggest that although a minor deficit in attention might be present in adults (they tended to make more omission errors than controls), disinhibition primarily underlies the deteriorated stopping and changing performance in adults with ADHD. Findings of a deficient inhibitory control in adults with ADHD have previously been reported (Ross *et al.* 2000; Murphy *et al.* 2001; Rapport *et al.* 2001; Nigg *et al.* 2002). Since a core deficit in inhibition has been hypothesized to underlie ADHD in children (Barkley, 1997; Quay, 1997), these results might be taken to suggest that ADHD reflects the same disorder in adults as it does in children (Faraone *et al.* 2000; McLean *et al.* 2004). However, response inhibition deficits seem to be more pronounced in adults than in children with ADHD (see also Lijffijt *et al.* in press), which is in contrast with previous clinical observations revealing that symptoms of hyperactivity and impulsivity decline at a higher rate and at an earlier age than symptoms of inattention do (Biederman *et al.* 2000). This inconsistency might reflect conceptualization differences between experimental and clinical research: response inhibition as measured in the present study is not likely to be directly related to the wide variety of well-documented everyday life dysfunctions in ADHD. It might, however, serve as an index for a more fundamental cognitive deficit (e.g. a more general sort of inhibitory problem), which is important for (certain forms) of attention too (e.g. interference control) (Knight *et al.* 1999). As a final point, two other limitations of the present study are noted. First, since at least 75% of adults with ADHD suffer from co-morbid disorders (Biederman *et al.* 1993; Kooij *et al.* 2001; Pary *et al.* 2002), we decided not to exclude subjects with additional symptoms of other DSM-IV disorders as long as their severity was moderate. Future research should focus on isolating symptoms related to ADHD, but, on the other hand, a sample completely free from co-morbid disorders might not be representative of the majority of adults with ADHD either. Second, we selected patients diagnosed with the combined subtype. The primarily hyperactive-impulsive subtype may be the precursor to this more common combined subtype (Hart *et al.* 1995). Patients starting off with the inattentive subtype may differ on behavioral as well as cognitive measures from this group (Lahey & Carlson, 1991; Goodyear *et al.* 1992). Future research should determine whether adult patients diagnosed with the inattentive subtype are also predominantly disturbed in inhibition or rather have a core deficit in attention.

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DECLARATION OF INTEREST

None.

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