Flanker Performance in Female College Students with ADHD – A Diffusion Model Analysis

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Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is characterized by poor adaptation to environmental demands that leads to various everyday life problems. The present study had four aims: (1) To compare performance in a flanker task in female college students with and without ADHD (*N* = 39) in a classical analyses of reaction time and error rate and studying the underlying processes using a diffusion model, (2) to compare the amount of focused attention, (3) to explore the adaptation of focused attention, and (4) to relate adaptation to psychological functioning. The study followed a 2-between (Group: ADHD vs. control) × 2-within (Flanker Conflict: incongruent vs. congruent) × 2-within (Conflict Frequency: 20% vs. 80%) design. Compared to a control group the ADHD group displayed prolonged response times accompanied by fewer errors in a flanker task. Results from diffusion model analyses revealed that members of the ADHD group showed deficits in nondecisional processes (i.e., higher nondecision time) and leaned more towards accuracy than participants without ADHD (i.e., setting higher boundaries). The ADHD group showed a more focused attention and less adaptation to the task conditions which is related to psychological functioning. Deficient nondecisional processes and poor adaptation are in line with theories of ADHD and presumably typical for the ADHD population, although this has not been shown using a diffusion model. However, we assume that the cautious strategy of trading speed of for accuracy is specific to the subgroup of female college students with ADHD and might be interpreted as a compensation mechanism.

Keywords: ADHD, neuropsychological function, flanker task, college students, females, diffusion model

Flanker Performance in Female College Students with ADHD – A Diffusion Model Analysis

Attention Deficit Hyperactivity Disorder (ADHD) is marked by developmentally inappropriate levels of hyperactivity, impulsivity, and inattention (Diagnostic and Statistical Manual of Mental Disorders, DSM-IV; American Psychiatric Association, APA 1994). Recent studies have revealed that (a) in 40-60% of children with ADHD the disorder continues into adulthood (Davidson 2008) and (b) the prevalence of ADHD in adulthood is estimated to be between 4-5% in the population (Kessler et al. 2006). ADHD in adulthood leads to several detrimental effects in everyday life, for instance, risky behavior (e.g., driving too quickly; Jerome, Segal, and Habinski 2006) and sensation seeking (e.g., participating in dangerous sports; Antrop, Roeyers, Van Oost, and Buysse 2000). Moreover, there are adverse effects on educational and occupational achievement as well as on social functioning in adults with ADHD (Biederman et al. 2006). Little is known about how these deficits in everyday life are related to deficits in neuropsychological functioning (Barkley and Fischer 2011).

ADHD has been characterized as a disorder of executive dysfunction with a core deficit in inhibition (Barkley 1997), thereby causing deficits in other higher order executive control processes such as working memory. On a group level differences between ADHD and control participants in executive function tasks have been replicated continuously (Willcutt, Doyle, Nigg, Faraone, and Pennington 2005). However, not every child with ADHD displays dysfunctional executive processes (Nigg, Willcutt, Doyle, and Sonuga-Barke 2005), while many children without ADHD, either with other psychiatric disorders or with no disorder at all, do (Willcutt et al., 2005). It has been suggested that the heterogeneity of ADHD cannot be accounted for by single process models, but dual or multiple path models are needed. Suggestions for factors accounting for ADHD have been delay aversion (Sonuga-Barke

2002), temporal processing that result in high intraindividual intertrial variability (Castellanos and Tannock 2002), deficits in working memory (Rapport et al. 2008), and a shortened delay gradient (Sagvolden, Johansen, Aase, and Russell 2005). Furthermore, it has been argued that fixed core deficits cannot account for the heterogeneity of ADHD but dynamic context dependent models like the delay aversion model (Sonuga-Barke 2002) or the state regulation model (Sergeant, Oosterlaan, and Van der Meere 1999) are needed (Sonuga-Barke, Wiersema, Van der Meere, and Roeyers 2010). These dynamic context dependent models assume that ADHD is not characterized by a fixed core deficit, as, for example, a general and stable deficit in inhibition that is displayed in every situation, but that the deficit is depending on the context. The deficit appears only under certain conditions, as, for example, slow and high, but not medium presentation rates (Sergeant 2005). Therefore, rather than having a fixed core deficit it appears that participants with ADHD show deficits in adapting to environmental demands, which only become apparent when they are presented with different environmental demands (i.e., experimental conditions).

Adaptation to Environmental Demands

Adaptive behavior means optimally fitting the internal state (e.g., arousal, motivation) to environmental demands. This implies neither stable nor flexible behavior but two different aspects: (a) a change in behavior when environmental demands are changed, but (b) stable behavior when environmental demands stay the same. Examining the first aspect, dynamic context dependent models of ADHD assume that individuals with ADHD have problems in adapting their internal state to task demands and therefore show good performance only under specific conditions. The cognitive-energetic model, for instance, predicts best performance under a medium level of activation (Sergeant 2005). The level of activation is often manipulated by event rate as, for instance, with a interstimulus interval of either one, four, or eight seconds (Van der Meere 2002). Children with ADHD show the same performance as children without ADHD under a medium event rate, but comparatively worse performance under a slow or fast event rate (Van der Meere 2002). The delay aversion model (Sonuga-Barke 2002) predicts best performance when incentives are not delayed (Sonuga-Barke et al. 2010). Both models have in common that they predict good performance in only one condition for participants with ADHD whereas participants without ADHD can adapt to environmental demands and show good performance in different kinds of conditions. However, few studies have explored such adaptation to task demands (Mulder et al. 2010; Van Meel, Heslenfeld, Oosterlaan, and Sergeant 2007). Interestingly, poor adaptation to task conditions is a better predictor of ADHD symptoms than response time and accuracy in a perceptual decision-making paradigm (Mulder et al. 2010).

Research examining the second aspect of adaptive behavior - stable behavior when environmental demands stay the same – also found ADHD-related deficits. Specifically, participants with ADHD not only shown deficits in adapting to task demands but they also show a higher variability in response (Castellanos et al. 2005) when task demands are stable. The high variability is related to deficits in temporal processing. This high variability might be caused by an interference of activation associated with rest (i.e., default mode) into the active state (Sonuga-Barke and Castellanos 2007). To summarize, previous findings suggest that participants with ADHD show difficulties in (a) adapting to changing task demands and (b) high response variability when task demands are stable, thus, deficits in both aspects of adaptive behavior.

Adaptation of Focused Attention to Conflict

Adaptation of the focus of attention plays a crucial role in conflict tasks, such as the Stroop (MacLeod 1991), the Eriksen flanker (Eriksen 1995), or the Simon task (Lu and Proctor 1995). Thus, in tasks where relevant (i.e., target) and irrelevant stimuli (i.e., distractor) are presented simultaneously. A distractor stimulus feature can be associated with the same response as the target stimulus (i.e., congruent trial) or with a different response than the target stimulus feature (i.e., incongruent trials). During congruent trials, less focused attention leads to a good performance because the distractor elicits the same response as the target. In contrast, during incongruent trials, highly focused attention leads to a good performance since the distractor elicits a different response. The performance decrement on incongruent trials is assumed to arise, at least in part, from distractor-elicited response activation, that is, from conflict between the responses activated by the target and the distractor stimulus feature (Coles, Gratton, Bashore, Eriksen, and Donchin 1985). Reaction time (RT) and error rates (ER) are usually increased on incongruent as compared to the congruent trials, thereby demonstrating that selection is incomplete. The performance difference between congruent and incongruent trials (henceforth referred to as *congruency effect*) can be taken as a measure of focused attention. Hereby, a high congruency effect (i.e., large difference between performance in congruent and incongruent trials) would imply a less focused attention. A small congruency effect would imply a more focused attention, and therefore less interference from the distractor in incongruent trials but also less benefit from the distractor in congruent trials.

Congruency effects have frequently been found to be larger in children with ADHD than in children without ADHD (e.g., Johnson et al. 2008; Mullane, Corkum, Klein, and McLaughlin 2009), suggesting generally impaired interference control and reduced focused attention. Imaging studies suggest that the anterior cingulate cortex (ACC) acts as the conflict detection device, signaling the degree of current conflict to dorsolateral prefrontal areas, in which the adjustment of attentional weights takes place (Botvinick, Cohen, and Carter 2004). Interestingly, an fMRI study failed to find increased neural activation in the cognitive division of the ACC in adults with ADHD when administering blocks of incongruent trials of a Stroop task variant (Bush et al. 1999). Taken together, these findings suggest impaired conflict adaptions in adults with ADHD due to a lack of activation in the ACC.

The conflict monitoring theory (Botvinick, Braver, Barch, Carter, and Cohen 2001; Botvinick et al. 2004) further states that the degree of focused attention is adapted to the experienced utility of the distractor stimulus information. That means conflict between incompatible responses, as occurring on incongruent trials, is countered by enhancement of focused attention, that is, increased attentional weight given to the target stimulus dimension and decreased attentional weight given to the distractor stimulus dimension reducing the congruency effect on future occasions (i.e., *conflict adaptation effect*). Consistent with these assumptions, the flanker congruency effect is reduced when the proportion of incongruent trials is increased (Gratton, Coles, and Donchin 1992; Wendt and Luna-Rodriguez 2009; Wendt, Luna-Rodriguez, and Jacobsen, 2012). This effect has mostly been studied to examine underlying processes in human conflict processing in general. However, the difference between congruency effects in blocks of high and low conflict is also an intraindividual measure of adaptation of focused attention to conflict and can be compared between different groups of participants. A high conflict adaptation effect (i.e., large difference between the congruency effects in blocks of high and low conflict occurrence) would imply that the participant showed adaptive behavior.

Exploring Underlying Processes

Performances in two-choice selective attention or conflict tasks is commonly described in terms of two dependent variables: accuracy (i.e., ER) and speed (i.e., RT). In classical analysis these two variables are evaluated separately precluding the investigation of the (unobservable) latent processes that contribute to both variables. The Ratcliff diffusion model (Ratcliff 1978) is a mathematical model for binary RT tasks that allows for the statistical separation of different latent processes contributing to the decision in a given trial (i.e., RT and ER; Wagenmakers 2009). These latent processes include the amount of information uptake per time and a speed-accuracy tradeoff (e.g., potential compensation mechanisms). According to the model during two-choice decisions information accumulates in a noisy (i.e., random walk) process until a decision boundary (i.e., threshold) is reached and the response is initiated (see Figure 1).

The model separates decisional from non-decisional processes. The first parameter $t0$, the nondecision time, is a measure of all processes other than decision processes that contribute to a given response (i.e., the time prior to information accumulation) and is an estimate of preparatory and encoding processes preceding the decisional phase and motor processes of the response system. With a longer nondecision time the decision process is initiated later, leading to longer RT if everything else is equal. The second parameter a, the response boundary, is a measure of response caution or speed-accuracy tradeoff (i.e., the distance between decision boundaries). With a larger response boundary, it takes longer for the decision process to reach its threshold, which decreases the probability of an erroneous response (i.e., everything else being equal fewer errors but longer RTs). The third parameter v, the drift rate, is a measure of the amount of information uptake or information accumulation per time unit (i.e., the slope of the diffusion process). With a larger drift rate, more information is gathered in the same amount of time and the decision threshold can be reached more quickly (i.e., everything else being equal a faster response). A further benefit of diffusion modeling is that all trials are used for analysis (i.e., including RTs of error trials)[1].

In the ADHD literature it has been assumed that performance deficits in children with ADHD are caused by heightened impulsivity (Barkley 1997) leading to preferences of speed over accuracy, which would be represented in a lower decision boundary. However, others have assumed that performance deficits in children with ADHD occur due to basic processing difficulties in arousal/encoding and activation/motor organization (Sergeant 2005), which would be represented in the nondecision time. Another assumption is that it is actually a lower drift rate causing the response variability in ADHD (Huang-Pollock, Karalunas, Tam, and Moore 2012) and that this might be caused by difficulties in allocating effort to the processing (memory search and decision) or an intrusion of the default mode interfering with the information processing (Sonuga-Barke and Castellanos 2007).

Studies using the diffusion model to answer the question of which underlying processes are impaired in ADHD so far found differential effects on the boundary separation parameter in reaction to task demands and effects on the drift rate. In a study by Mulder and colleagues (2010), participants worked on a perceptual decision-making paradigm. The ADHD group showed less adaptation to task demands by demonstrating lower decision thresholds than control participants in accuracy sessions but higher decision thresholds in speed sessions. There were no group differences or interaction effects for the drift rate or nondecision time (Mulder et al. 2010). In contrast, in their review of studies using the continuous performance test in ADHD, Huang-Pollock et al. (2012) computed diffusion model parameters and found lower drift rates in the ADHD groups. Lower drift rates were also found by Karalunas, Huang-Pollock, and Nigg (2012) when analyzing RTs from a forced-choice RT paradigm. Both studies did not find differences in nondecision time or boundary separation, but assumed that differences in boundary separation might be more prominent for tasks that require two choice decisions or have a higher percentage of targets (Huang-Pollock et al. 2012). In sum, studies using a diffusion model analysis to explore underlying processes of two-choice tasks in ADHD are promising but rare. However, it might be helpful to study underlying processes especially in subgroups of the ADHD population which have revealed inconsistent results in the domain of neuropsychological functioning.

Female College Students with ADHD

Girls with ADHD who manage to graduate from high school and gain admittance to postsecondary institutions represent a subpopulation of individuals with ADHD that is understudied (Nelson and Gregg 2012; Weyandt and DuPaul 2008). College students with ADHD consistently show academic and psychological difficulties (Weyandt and DuPaul 2008). A handful of studies have compared the psychological functioning of college students with and without ADHD. In a study using the Symptom Checklist-90-Revised (SCL-90-R; Derogatis 1986) college students with ADHD reported significantly higher ratings than controls on somatization, obsessive compulsive disorder, interpersonal sensitivity, depression, anxiety, hostility, paranoid ideation, and psychoticism (Richards, Rosen, and Ramirez 1999). Students with ADHD also reported greater psychological distress than comparison students on the Global Severity Index of the Brief Symptom Inventory (BSI; Derogatis 1993; Weyandt, Rice, Linterman, Mitzlaff, and Emert 1998). Results with regard to performance in neuropsychological tasks are mixed. Preliminary studies suggest that college students with ADHD perform similar to control participants on intelligence tests and the findings are heterogeneous with respect to performance on specific neuropsychological tests (Weyandt and DuPaul 2008).

College students with ADHD have most likely experienced more academic success than those adults with ADHD who do not attend college, and their pursuit of postsecondary education may lead to a stronger belief in their abilities (Nelson and Gregg 2012). Additionally, college students with ADHD may have a less severe form of the disorder than those with ADHD who do not attend college (Nelson and Gregg 2012). It has been suggested that college students with ADHD are likely to have (a) higher ability levels, (b) greater academic success during primary and secondary school, and (c) better compensatory skills than individuals with ADHD from the general population (Frazier, Youngstrom, Glutting, and Watkins 2007). Thus, it is possible that college students with ADHD compensated for their deficits by investment of more time or effort, utilization of latent skills, or acquisition of new skills. Therefore, it might be that deficits are disguised by compensatory strategies (Adler 2004; Frazier et al. 2007).

Present Study

In the present study, female college students with and without ADHD performed a flanker task in which they judged the parity of a central digit flanked by two different digits by pressing a left or right key. On congruent trials the central and flanking digits had the same parity (e.g., 848). On incongruent trials the parity of the flanking digits diverged from the parity of the central digit (e.g., 343). Furthermore, the frequency of flanker conflict was manipulated so that in one half of the experiment there was infrequent flanker conflict (20%) and in the other half there was frequent flanker conflict (80%). The digit flanker task we used has been shown to be an efficient means of assessing adaptation to conflict (Lehle and Hübner 2008). Compared with other widely used versions of the flanker task it has the advantage that it involves a comparably large stimulus set, thereby strongly reducing trial-to-trial stimulus repetitions.

Furthermore, participants were asked to fill out a questionnaire regarding their psychological functioning to assess impairment in everyday life. A meta-analysis showed that college students with ADHD are impaired in academic and psychological functioning (Weyandt and DuPaul 2008). Academic achievement is not tested with standardized measures in Germany (as, for example, the Grade Point Average) and therefore it is difficult to compare between students studying different subjects. Therefore, we chose to focus on psychological functioning, measured with the BSI (Franke 2000), as a domain in which impairment has been repeatedly shown in college students (Weyandt and DuPaul 2008). We aimed to explore how neuropsychological functioning of female college students with ADHD is related to psychological functioning.

Our study had four aims. First, to compare the RTs and ERs of female college students with and without ADHD and furthermore to explore estimates of diffusion model parameters (nondecision time, boundary separation, and drift rate) and hence, describe the underlying processes splitting up the observable behavior of RT and ER into nondecisional processes, speed-accuracy tradeoff, and information uptake. Second, to explore differences in the amount of focused attention in female college students with and without ADHD. Third, to compare adaptation to conflict in female college students with and without ADHD. Finally, we wanted to explore how adaptation is related to psychological functioning.

Our aims were defined by four research questions:

1. Do female college students with ADHD differ from female college students without ADHD in RT, ER, non-decision time, boundary separation, and drift rate?
2. Do female college students with ADHD show less or more focused attention compared to female college students without ADHD?
3. Do female college students with ADHD show less adaptation to a conflict manipulation (infrequent versus frequent conflict) compared to female college students without ADHD?
4. Is the adaptation of focused attention related to psychological functioning?

Based on the literature we hypothesized that students with ADHD would show slower RTs and higher ERs. Regarding the parameters of the diffusion model we predicted higher non-decision time, higher boundary separation, and lower drift rates. Previous research also suggests reduced focused attention in participants with ADHD compared to participants without ADHD. Furthermore, we expected to find less conflict adaptation in students with ADHD compared to students without ADHD regarding RT, ER, and one or more parameters of the diffusion model. Finally, we expected poor adaptation measured through a reduced congruency effect (i.e., smaller differences between congruency and incongruent trials) or a reduced conflict adaptation effect (i.e., smaller differences between congruency effects in blocks with frequent incongruent trials and blocks with infrequent incongruent trials) to be related to psychological impairment. Importantly, all participants in both the ADHD and the control group were given a professional ADHD diagnostic evaluation (i.e., clinical interviews, neuropsychological tasks, questionnaires to the participants and their significant others).

Method

Design

The study followed a 2-between (Group: ADHD vs. control) × 2-within (Flanker Conflict: incongruent vs. congruent) × 2-within (Conflict Frequency: 20% vs. 80%) design. Dependent variables were RT, ER, nondecision time $t0$, boundary separation a, and drift rate v.

Participants

Demographic data of our sample is displayed in Table 1. Fifteen female college students (*M* age = 30.20 years, *SD* = 5.93) were diagnosed with ADHD as their primary disorder by the fourth author, a head neurologist and psychiatrist of a neurological outpatient practice with over 20 years of experience in diagnosing ADHD. Patients admitted themselves to the practice. They were informed about the possibility to participate in the experimental session if they were female, college students, and currently in the diagnostic procedure for receiving an ADHD diagnosis ($n = 9$) or had received a diagnosis of ADHD in the neurological outpatient practice ($n = 6$). Only three participants received their diagnosis before the age of 25 and none before the age of 20. The participants were enrolled in diverse study subjects (e.g., psychology, educational science, medicine, law, communication design, fashion design), Exclusion criteria were medication with methylphenidate (MPH) or atomoxetin at the time of the experiment. None of our participants had any history of medication with atomoxetin. Altogether, five participants with ADHD received psychostimulant medication of MPH. They were asked to discontinue medication 48 hours before the start of the experiment. Therefore, no participant was excluded due to medication at the time of the experiment. Participants received no other forms of treatment (i.e., cognitive behavioral therapy).

The 24 comparison female students (*M* age = 22.58 years, *SD* = 2.53) without ADHD were recruited from an educational psychology lecture and courses at the University of Hamburg and studied psychology (*n* = 16), educational science (*n* = 7), and American studies (*n* = 1). They underwent the same diagnostic procedures as the participants with ADHD. Exclusion criteria were any psychiatric disorders and the intake of any medication. With regard to ethnic background, all of the participating females were Caucasian. We assessed the socioeconomic status by asking questions about the marital status, highest educational level, and income of students (see Table 1). Female college students with ADHD were older compared to female college students without ADHD, they were more often divorced, worked more frequently in part time jobs, had more children, and a higher income.

Informed consent was obtained from all participants after stressing that (a) all participants would remain anonymous and data would be kept strictly confidential, (b) participants were free to withdraw their consent at any time with no unfavorable consequences, and (c) all data would be processed electronically. Participants received reimbursement (€5-8) for their travel expenses, and were offered a written report about the results of the study in general. The study was approved by the local research ethics committee and is compliant with the World Medical Association's Helsinki Declaration.

Diagnostic Procedure

Participants with ADHD. The results of the diagnostic procedure are displayed in Table 2. Participants with ADHD came to the neurological outpatient practice because they assumed they had ADHD and underwent the standard diagnostic procedure (separate from the experimental session) in three 20-40 min appointments, each on a separate day. The first appointment with the head neurologist and psychiatrist in the neurological outpatient practice consisted of a general gathering of information and a clinical interview exploring the criteria of the International Classification of Diseases (ICD-10; World Health Organization 2009) and DSM-IV for ADHD (APA 1994, SKID; Wittchen, Zaudig, and Fydrich 1997).

At the second appointment, participants underwent a battery of neuropsychological tests sensitive for ADHD. The tests were administered in the outpatient practice by a trained research assistant. All participants completed the digit span forward and backward test from the German version of the Wechsler Adult Intelligence Scale (WAIS; Aster, Neubauer, and Horn 2006), the Trail-Making-Test (TMT) forms A and B (Lewis and Rennick 1979), the d2 test (Brickenkamp 2002), and two subtests from the test battery for attentional performance (visual scanning and Go/NoGo; TAP 2.0; Zimmermann and Fimm 2006). The digit span forward and backward tests are measures of verbal working memory. In the digit span forward task a sequence of digits of increasing length has to be recalled in the same order (i.e., recall), whereas in the digit span backward test a sequence of digits of increasing length has to be recalled in the reversed order (i.e., thus requiring further manipulation of working memory content). We presented participants with sequences from three to eight digits (forward) and two to seven digits (backward), scoring 0 for a failed and 1 for a successful recall (Aster, Neubauer, and Horn 2006). The Trail-Making-Test (TMT) is a neuropsychological test of visual attention and shifting (i.e., task switching or shifting). The task requires participants to connect targets (i.e., “1”, “2”, “3”, “4”, …) in Version A and to connect alternately numbers and letters (i.e., “1”, “A”, “2”, “B”, “3”, “C”, “4”, “D”, …). Participants are instructed to finish the test as quickly and accurately as possible. The dependent variable in this test is the time taken to complete all items. The d2 is a psychological paper-pencil test of attention consisting of letters as stimuli (i.e., “d”, “p”). These letters are accompanied by one to four dashes arranged either individually or in pairs above or below the letters. Participants are required to cross out d’s with two dashes as quickly and accurately as possible. The Go/NoGo and visual scanning subtests from the computerized test of attentional performance (TAP) measure inhibition abilities (i.e., Go/NoGo) and sustained attention (i.e., visual scanning). Dependent variables are RT and ER. Furthermore, each participant and one significant other person (boyfriends in most cases) were asked to complete the dysexecutive questionnaire (DEX; Wilson, Alderman, Burgess, Emslie, and Evans 1996), a questionnaire on experienced deficits in attention (FEDA; Zimmermann, Messner, Poser, and Sedelmeier 1991), and a questionnaire used for screening psychological disorders of the DSM-IV (SKID; Wittchen et al. 1997).

At the third appointment, the head neurologist reviewed primary school reports of the participants with ADHD to ensure the occurrence of the symptoms before the age of seven and participants also brought – if available – information on psychiatric examinations in childhood. Furthermore, he used a semi-structured interview to exclude disorders other than ADHD which could account for symptoms (SKID). According to SKID cutoffs five participants in the ADHD group exhibited the following comorbid disorders: dyslexia ($n = 2$), dyscalculia ($n = 1$), personality disorders and anxiety ($n = 2$). On average, participants were 29.00 years old ($SD = 6.24$) at the time of their ADHD diagnosis. Thus, all participants had received their diagnosis during adulthood and within the last year before their participation in the study. During the diagnostic procedure participants were asked if they were interested in participating in the experimental session. Two participants were excluded from the analyses after participating in the diagnostic procedure and the experimental session because they received no diagnosis of ADHD. We asked participants for their permission to use their neuropsychological data in the study right after the diagnostic session. All of the nine participants in the ADHD group that were still in an ongoing diagnostic process at the time of participating in the experimental session gave consent to use their neuropsychological data. The six participants, who already had received the ADHD diagnosis before being asked to participate in our study, were asked via a postal letter whether they would permit us to also use their diagnostic data for the study. None of them replied, therefore, we only report diagnostic data of nine patients in Table 2.

Participants without ADHD. Participants without ADHD underwent a diagnostic procedure conducted by the same neurologist in his practice consisting of a clinical interview exploring the ICD-10 and DSM-IV criteria for ADHD and the administration of the neuropsychological battery by a research assistant (similarities and block design, digit span forward and backward, TMT forms A and B, d2 test, Go/NoGo, visual scanning). The SKID was applied to rule out other mental disorders besides ADHD. Furthermore, we asked them and their significant others (again boyfriends in most cases) to fill out the questionnaires. Interviews and neuropsychological tests were administered in one session, which took approximately 90 min. One participant in the control group was excluded from the analyses due to high rates of ADHD symptoms. Table 2 presents the differences that emerged in the diagnostic procedure between female college students with and without ADHD. Participants with ADHD differed significantly from the participants without ADHD in the TMT-A, TMT-B, the self-rating of the DEX, the distractibility and slowing in mental processes scale of the FEDA and marginally significant in the fatigue and slowing in activities of daily living scale of the FEDA. Furthermore, the FEDA ratings of significant others differed between groups. The distractibility and slowing in mental processes and fatigue and slowing in activities of daily living scales differed significantly, the decrease in drive scale only differed marginally significant.

Experimental Session Procedure

All experiments were conducted in a quiet laboratory at the university by a female researcher, separate from the diagnostic appointments. Participants worked on the flanker task for approximately 45 min. Afterwards a screening of their cognitive abilities was conducted (similarities and block design; Aster, Neubauer, and Horn 2006) and participants were asked to fill out the psychological functioning questionnaire. The WAIS subtests block design and similarities allow for a screening of cognitive abilities. The block design test was chosen because of its high predictive and diagnostic value (Donders, Zhu, and Tulsky 2001) and the similarities test was chosen to complementary assess verbal reasoning.

Flanker task. The stimulus set of the flanker task consisted of the digits 2 to 9. Each stimulus consisted of three horizontally aligned digits: two identical flanking digits (i.e., flankers) and one (always different as the flankers) central target digit (e.g., 272). Each digit occupied 50 mm vertically and 35 mm horizontally. Participants viewed the screen from a distance of about 50 to 60 cm. All experiments were conducted by a female researcher who left the room after giving the participants detailed instructions about how to complete the task on the computer.

Participants were told that they had to judge the parity (odd, even) of the central target digit by pressing a key located on the right or the left of a standard keyboard. Mapping of keys to parity was counterbalanced between participants. Each trial started with the presentation of a fixation cross for 400 ms, followed by a blank screen for 600 ms, and then the stimulus was presented for 160 ms in white on a black background. In the case of an incorrect response, visual and auditory error feedback was presented for 1000 ms. Otherwise, the next trial started with the presentation of the fixation cross 100 ms after the previous response was elicited.

After 16 practice trials, participants worked on eight blocks consisting of 100 trials each separated by short breaks. The frequency of flanker conflict was manipulated so that in one half of the experiment there was 20% flanker conflict and in the other half there was 80% flanker conflict. Flanker conflict was elicited when the flankers had parity other than the target (flanker incongruent); no flanker conflict was elicited when the flankers had the same parity as the target (flanker congruent). Half of the participants started with 20% flanker conflict; the other half of the participants started with 80% flanker conflict.

Psychological functioning. Table 3 displays the differences in BSI scores between female college students with and without ADHD. The BSI (Franke 2000) provides an overview of self-reported clinically relevant psychological symptoms in adolescents and adults. The BSI is the short version of the SCL-R-90 (Derogatis 1986), which measures the same dimensions. Items for each dimension of the BSI were selected based on a factor analysis of the SCL-R-90, with the highest loading items on each dimension selected for the BSI (Derogatis 1993; Derogatis and Cleary 1977). The BSI requires only 8-10 min to complete and consists of 53 items covering nine symptom dimensions: somatization, obsession-compulsion, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation and psychoticism; and three global indices of distress: Global Severity Index, Positive Symptom Distress Index, and Positive Symptom Total. The global indices measure current or past level of symptomatology, intensity of symptoms, and number of reported symptoms, respectively. The BSI has internal consistencies from $\alpha = .63$ to $\alpha = .85$ and retest-reliabilities from $r = .73$ to $r = .92$. Groups only differed significantly on the scale for Obsessive-Compulsive behavior, with ADHD females showing more Obsessive-Compulsive behavior. No other significant group differences appeared (see Table 3).

Data Preparation Flanker Task

Prior to the statistical analyses, we excluded the following trials: (a) the first three trials of each block (3% warm-up trials), and (b) all trials following an error (3% of the remaining trials). Responses outside the interval of the individual median +/- 3 × the interquartile range were considered as outliers (Tukey 1977; trials were also excluded if they were faster than 200 ms to exclude all responses that could not have been driven by a decision process) and also excluded from the analysis. In total, 8% of all responses were excluded from the analyses. For the analysis of ER and the diffusion modeling, all of the remaining trials were used. The RT analysis was confined to correct responses.

The Diffusion Model

Performances in two-choice selective attention tasks can be described in terms of two dependent variables: ER (accuracy) and RT (speed). In classical analysis these two variables are evaluated separately precluding the investigation of the latent processes that contribute to both variables. As we hypothesized to find differences in the latent processes governing responses in such tasks, we analyzed our data using the Ratcliff diffusion model (Ratcliff 1978). In our case the diffusion model contained three relevant parameters. First, the nondecision time $t0$ is a measure of all processes other than decision processes that contribute to a given response (i.e., the time prior to information accumulation) and is an estimate of preparatory and encoding processes preceding the decisional phase and motor processes of the response system. Second, the response boundary a is a measure of response caution or speed-accuracy tradeoff (i.e., the distance between decision boundaries) and third, the drift rate v is a measure of the amount of information uptake or information accumulation per time unit (i.e., the slope of the diffusion process). Furthermore, the diffusion model contains nuisance parameters taking trial by trial variability in the drift rate (sv), the nondecision time ($st0$) and the starting point (sz) into account. Note that in our design only the drift rate v can vary from trial to trial. The other relevant parameters, the response boundary *a* and the nondecision time $t0$, are assumed to be determined prior to stimulus processing. In other words, as participants know the identity of a stimulus (i.e., congruent or incongruent) only after it appeared, the response boundary *a* and the nondecision time $t0$ cannot vary as a function of congruency of a trial, but between blocks.

A benefit of diffusion modeling is that all trials are used for analysis (i.e., including RT of error trials). We obtained the diffusion model parameters using the procedures implemented by Voss and Voss (2007, 2008; see Spaniol, Voss, and colleagues 2006, 2008, 2011, for similar analyses of the effect of aging). In total, we estimated 11 parameters per participant: a separate drift rate for congruent and incongruent trials in each of the two conflict frequency conditions (four drift rates in total); a separate response boundary parameter and a separate nondecision time parameter for each of the two conflict frequency conditions (two response boundary and two nondecision times in total); one parameter capturing trial by trial variability for each drift rate, nondecision time, and starting point (three parameters capturing trial by trial variability in total). The response boundaries represented correct and incorrect responses, respectively. Using these specifications, the raw individual data were handed over to fast-dm (Voss and Voss 2007) which obtained individual parameter estimates by minimizing the discrepancy between the observed and predicted full cumulative response time distribution using the Kolmogorov-Smirnoff (KS; Kolmogorov 1941) test statistic. For more details on the fitting procedure we refer to Voss and Voss (2007; 2008).

Model Fit

The product of the *p* value of the KS statistic served as an index of model fit with $p < .05$ signaling misfit (Spaniol et al. 2006, 2008, 2011). This was the case for four participants, one with ADHD and three without ADHD. As the pattern of significant and nonsignificant results did not change when excluding these participants[2], we included them in the following analysis.

Data Analysis

To compare performance of the college students with and without ADHD and to analyze the adaptation to the flanker manipulations, we entered mean RT and mean ER into separate 2 × 2 × 2 mixed between and repeated measure ANOVAs with the factors Group (ADHD vs. control, between), Flanker Conflict (incongruent vs. congruent, within), and Conflict Frequency (20% vs. 80%, within; Table 4 and Figure 2). For nondecision time $t0$ and boundary separation a we computed separate 2 × 2 mixed between and repeated measure ANOVAs with the factors Group (ADHD vs. control, between) and Conflict Frequency (20% vs. 80%, within). For the drift rate v we again computed a 2 × 2 × 2 mixed between and repeated measure ANOVA with the factors Group (ADHD vs. control, between), Flanker Conflict (incongruent vs. congruent, within) and Conflict Frequency (20% vs. 80%, within; Table 5, Figure 3). Age differed between the Groups (see Table 1) and showed correlations to RT, $r = .34$, $p < .05$, nondecision time, $r = .35$, $p < .05$, and boundary separation, $r = .37$, $p < .05$, in the complete sample ($N= 39$). There were no correlations of age to the dependent variables RT, ER, nondecision time, boundary separation, and drift rate when checking in both groups separately, neither the group with ADHD, nor the group without ADHD. Therefore, we did not control for age in the ANOVAs (Miller and Chapman 2001). To explore how adaptation is related to psychological functioning, we correlated the difference score for the conflict adaptation effect (i.e., differences between congruency effect in blocks with frequent incongruent trials and blocks with infrequent incongruent trials) with the scales from the BSI (see Tables 3 and 6). For nondecision time and boundary separation we could not compute a difference score for congruency effect and therefore used adaptation to conflict frequency (i.e., performance in blocks with infrequent conflict minus performance in blocks with frequent conflict) as estimate for adaptation. Large difference scores reflect high adaptation. Age was related to some scales of the BSI (i.e., to Anxiety in the group with ADHD, $r = -.67$, $p < .05$, and to Phobic Anxiety in the group without ADHD, $r = -.45$, $p < .05$). Therefore, we additionally controlled for age in cases where significant differences or correlations between groups emerged.

Results

Classical Analysis

RT. Results for RT showed a main effect for Group (see Table 4). Participants with ADHD responded slower than participants without ADHD (674 - 610 ms, Figure 2). Furthermore, we found the expected congruency effect (i.e., a main effect of Flanker Conflict); participants responded more slowly on incongruent than on congruent trials (657 - 612 ms = 45 ms congruency effect). The Group main effect was qualified by a significant Group by Conflict Frequency interaction. The Conflict Frequency manipulation had a stronger effect on participants with ADHD (difference between high and low conflict blocks was 54 ms) than on participants without ADHD (difference between high and low conflict blocks was 31 ms). Additionally, we found the expected conflict adaptation effect (i.e., a two-way interaction of Flanker Conflict with Conflict Frequency), the congruency effect was smaller when conflict was frequent than when conflict was infrequent (24 vs. 42 ms).

ER. Results for ERs showed a significant main effect for Group (see Table 4), indicating that participants with ADHD tended to produce fewer erroneous responses than participants without ADHD (2.4% vs. 3.9%, Figure 2). Note that this main effect points in the opposite direction than the effect for RT (i.e., participants with ADHD are slower, but produce fewer errors). We again found the expected congruency effect (a main effect of Flanker Conflict). Participants made more errors on incongruent than on congruent trials (4.6% - 2.1% = 2.5% congruency effect). We also found the expected conflict adaptation effect (an interaction of Flanker Conflict with Conflict Frequency). The congruency effect was smaller when conflict was frequent than when conflict was infrequent (1.1% vs. 3.9%). Additionally, the conflict adaptation effect tended to be modulated by Group as indicated by an almost significant three-way interaction of Flanker Conflict, Conflict Frequency, and Group (p = .05). The conflict adaptation to conflict frequency was higher for participants without ADHD than for participants with ADHD. Participants with ADHD exhibited a flanker congruency effect of 1.2% when conflict was frequent and a flanker congruency effect of 2.2% when conflict was infrequent. In contrast, participants without ADHD showed a comparable flanker congruency effect of 1.1% when conflict was frequent, but a considerably stronger flanker congruency effect of 5.1% when conflict was infrequent.

Summary. Taken together, the classical analysis of RT and ER showed differences in the behavior between participants with and without ADHD. Female college students with ADHD were slower but produced fewer errors than female college students without ADHD. Furthermore, participants with ADHD tended to be influenced more by the conflict frequency manipulation than participants without ADHD, as indicated by a significant Group by Conflict Frequency interaction and an almost significant Group by Flanker Conflict by Conflict Frequency interaction. However, the classical analysis does not reveal which of the assumed underlying processes is responsible for this pattern of results. To shed light on this, we performed the diffusion model analysis.

Diffusion Model Analysis

Nondecision time. For nondecision time, our analysis demonstrated a significant Group main effect (see Table 5). Participants with ADHD had higher nondecision times than participants without ADHD (Figure 3, lower row). Hence, participants with ADHD took longer to initiate a decision process than participants without ADHD, prolonging their RT overall (without affecting their accuracy). Furthermore, we found a main effect for Conflict

Frequency. Nondecision time was higher on blocks with frequent conflict indicating that participants during those blocks needed more time to start the decision process (Figure 3, lower row).

Boundary separation. Examining the boundary separation parameter next, we only found a main effect for Group (see Table 5). Participants with ADHD had a higher boundary separation parameter than participants without ADHD (Figure 3, lower row). Hence, the decision process took comparatively longer to reach the decision threshold in the ADHD group, which decreased the probability of an erroneous response. This indicates that participants with ADHD were comparatively more cautious.

Drift rate. We found a main effect of Flanker Conflict (see Table 5), indicating that the drift rate was lower for incongruent than for congruent trials. This finding suggests that participants gathered less information per trial on incongruent trials. Next, we found a main effect of Conflict Frequency, indicating that drift rate was lower for infrequent than for frequent conflict. This finding suggests that on blocks with infrequent conflict, participants gathered less information per trial. Furthermore, we found an interaction of Group × Flanker Conflict indicating that the congruency effect of the drift rate was smaller in the ADHD group. Analysis of simple main effects of Flanker Conflict showed that there was only a difference between women with and without ADHD for congruent, $F(1, 37) = 4.96, p = .03$, but not for incongruent trials, $F(1, 37) = 0.66, p = .42$ (Figure 3, upper row). Participants with ADHD seemed to be less able than participants without ADHD to use the benefits of the flanking digits when these were congruent with the target for accumulating evidence to give the correct response. Finally, we found an interaction of Group with Frequency. Analysis of simple main effects within Groups indicated that women with ADHD did not show a main effect of Conflict Frequency, $F(1, 14) = 0.41, p = .53$, whereas women without ADHD did, $F(1, 23) = 20.29, p < .001$. This shows that women with ADHD, in contrast to women without ADHD, had no increased information uptake when conflict was frequent. It seemed that participants without ADHD were more focused in the block with frequent conflict (hence the higher drift rate), whereas participants with ADHD seemed not to be able to adapt in this way.

Summary. The diffusion model analysis showed that the inconsistent differences between women with and without ADHD found in RT and ER are due to differences in all cognitive processes assumed by the diffusion model. Women with ADHD had higher nondecision times, and higher boundary separation parameters. Regarding the drift rate, women with ADHD benefitted less from the congruent information for congruent trials and were less able to adapt to the Conflict Frequency.

Psychological Functioning

Groups differed in none of the BSI scales except from the Obsessive-Compulsive behavior scale, with women with ADHD showing more Obsessive-Compulsive behavior (see Table 3). The marginally significant differences in Paranoid Ideation disappeared when controlling for age, $F(4, 36) = 0.76$, *ns*. The correlations of the conflict adaptation effects (i.e., differences between congruency effect in blocks with frequent incongruent trials and blocks with infrequent incongruent trials) with the scales from the BSI are displayed in Table 6. The difference score for conflict adaptation of RT and ER was not related to any of the BSI scales. High adaptation in nondecision time was related to less Hostility and this correlation remained significant when controlling for age, $r(36) = -.35$, $p < .05$. High adaptation in boundary separation was related to high Phobic Anxiety. This relation was only marginally significant when controlling for age, $r(36) = .30$, $p < .10$. Furthermore, high adaptation in boundary separation was related to high global impairment as indicated by the Global Severity Index, also after controlling for age, $r(36) = -.33$, $p < .05$. High adaptation in drift rate was related to low Paranoid Ideation. However, this relation disappeared when controlling for age, $r(36) = -.23$, $p = ns$. Furthermore, high adaptation drift rate was related to low scores in the Global Severity Index, which remained significant, $r(36) = -.38$, $p < .05$ after controlling for age. The correlation between adaptation drift rate and the Global Symptom Distress Index, only remained marginally significant after controlling for age, $r(36) = -.29$, $p < .10$.

Summary. In sum, correlations of difference scores as estimates of adaptation with questionnaires indicate that high adaptation of nondecision time was related to less Hostility, high adaptation of boundary separation was related to high Global Impairment, and high adaptation of drift rate is related to less Global Impairment.

Discussion

The aims of this study were first to compare performance on a flanker task in female college students with and without ADHD, second to compare the amount of focused attention, third to explore the adaptation of focused attention, and finally, to relate such adaptation to psychological functioning.

Differences in Flanker Performance

Our first research question asked if female college students with ADHD differ from female college students without ADHD in RT, ER, non-decision time, boundary separation, and drift rate. A classical analysis of RT and ER displayed inconsistent results. As expected, female college students with ADHD showed prolonged RTs. However, this response slowing was associated with a reduction in ERs. To clarify these results, we utilized a diffusion model analysis that allowed us to explore the underlying latent cognitive processes. The model revealed higher nondecision time, higher boundary separation, and differences in the drift rate between the two groups. A higher nondecision time represents longer nondecisional processes or basic processing like encoding and motor preparation. Which of these two, encoding or motor processing, is impaired cannot be answered from our data. However, other studies have found that deficient performance in ADHD is due to suboptimal activation leading to problems in motor organization rather than due to suboptimal arousal leading to problems in encoding (cognitive-energetic model; Sergeant 2005). Therefore, our finding of longer nondecision time provides an indication of suboptimal activation in the ADHD group.

Participants with ADHD had an overall higher boundary separation parameter: they were more cautious than participants without ADHD (in terms of speed-accuracy tradeoff, they leaned more towards accuracy than participants without ADHD). This, as the finding of lower ERs in the ADHD groups, is contrary to the common understanding that ADHD is marked by high impulsivity and therefore a tendency of making fast but inaccurate choices. However, Mulder et al. (2010) found a higher boundary separation in the speed condition. In the accuracy condition, however, the ADHD group showed a lower boundary separation. This suggests that participants with ADHD do not set lower boundaries in general, but that the boundary separation depends on the task demands. One possible explanation for our finding of higher boundaries in the ADHD group is that our task might have stressed speed more than accuracy. Participants without ADHD set their boundaries lower to meet this demand whereas participants with ADHD did not. Since we did not include different instructions stressing either speed or accuracy as in the study designed by Mulders et al. (2010) this would be a valuable direction for future studies. Another possible explanation is that this strategy is specific for our sample of female college students. Female college students with ADHD might have developed the strategy of being cautious (i.e., setting high boundaries) to compensate for their deficits.

Participants with ADHD did not show an overall impaired drift rate, although there was a tendency for lower drift rates in the ADHD group. Others (Huang-Pollock et al. 2012; Karalunas et al. 2012) have found lower drift rates in the continuous performance test and a forced-choice RT paradigm and have argued that this points to a deficit in central processing, (i.e., information uptake, memory search, and decisional processes). However, as we found that participants with ADHD had lower drift rates than participants without ADHD for congruent trials and adapted their drift rate less to the conflict frequency, our results are in line with conclusions that ADHD may be related to deficits in central processing.

In sum, our findings showed that students with ADHD displayed prolonged RTs accompanied by fewer errors compared to students without ADHD. Results from diffusion model analyses demonstrated that the ADHD group leaned more towards accuracy than the group without ADHD (i.e., setting higher boundaries), that the ADHD group showed deficits in nondecisional processes (i.e., higher nondecision time), and that the ADHD group was less able to use certain helpful information indicating deficits in decisional processes (i.e., lower drift rates).

Differences in Focused Attention

Our second research question was whether female college students with ADHD show less or more focused attention compared to female college students without ADHD. A highly focused attention is indicated by a small congruency effect. To explore this in more detail, we focused on the interaction of Group × Flanker Conflict. Again, when using RT and ER there was no interaction and hence no clear answer. However, we found a significant Group × Flanker Conflict interaction on drift rate. The congruency effect in the ADHD group was smaller (i.e., they profited less from congruent flankers and experienced less interference from incongruent flankers), which leads to the conclusion that they show a more focused attention. Participants with ADHD had a lower drift rate (i.e., were not able to extract information as quickly as participants without ADHD), especially on congruent trials when the flanking and target digits were mapped on the same correct response. This implies that the interaction was caused mainly by the ADHD group not being able to profit from the distractors. The finding of a more focused attention is contrary to previous findings of children with ADHD showing a higher congruency effect (Mullane et al. 2009). This, as well as the finding of slightly higher boundaries, seems to be specific for female college students with ADHD. Interestingly, participants who exhibited less information uptake in the congruent trials reported more obsessive-compulsive behavior, $r = -.33$, $p = .05$. Therefore, we assume that the students with ADHD were cautious - showing a more focused attention - which lead to lower information uptake on congruent trials in which distractors are helpful for reacting fast and accurate. This behavior might represent obsessive-compulsive behavior in everyday life.

Differences in Adaption to Conflict Frequency

Our third question was whether female college students with ADHD show less adaptation to a conflict manipulation (20% vs. 80% incongruent trials) compared to female college students without ADHD. The conflict frequency manipulation had a stronger effect on RT in the ADHD group; they slowed down more in blocks with frequent conflict. However, since this was not qualified by a congruency effect, this finding does not mean that the ADHD group showed a higher adaptation of focused attention. Regarding ER, the almost significant three way interaction of Group × Flanker × Frequency indicated that the ADHD group showed less adaptation of ER. Both groups had a comparable congruency effect (i.e., incongruent minus congruent trials) in blocks with frequent conflict, they diverged in blocks with infrequent conflict. In these blocks participants with ADHD had a markedly smaller congruency effect than participants without ADHD. This indicates that, in fact, students with ADHD showed less adaptation to conflict – or the other way round, they showed less adaptation when there was no conflict. As discussed above female college students with ADHD showed more focused attention and did not adapt their focus of attention to task conditions.

Regarding nondecision time and boundary separation, we did not find an interaction of

Group × Frequency and therefore no differences in adaptation. The conflict frequency manipulation had a stronger effect on drift rate in participants without ADHD. They had overall higher drift rates in the frequent conflict blocks, whereas this was not the case for participants with ADHD (i.e., no increased information uptake when conflict was frequent for participants with ADHD). Overall, the adaptation to a conflict manipulation showed that participants with ADHD displayed more adaptation in RTs, but less adaptation of focused attention, which is expressed in ERs. They also show less adaptation in drift rates. As the boundary separation findings indicated before, participants with ADHD put more emphasis on accuracy rather than speed, adapting their ERs rather than the RTs. Furthermore, they do not adapt their drift rate. Lower drift rates have been interpreted as deficits in the effort pool of the cognitive-energetic model (Sergeant 2005) and/or the central computational process that the effort pool feeds (i.e., processes directly related to information accumulation and decision making; Huang-Pollock et al. 2012, Karalunas, et al. 2012). Therefore, a failure to adapt the drift rate can be interpreted as an insufficient allocation of effort. According to the cognitive-energetic model a suboptimal arousal or activation state can be compensated for by effort (Van der Meere 2002). As discussed before, we found deficient nondecisional processes (i.e., higher nondecision time) in the ADHD group but it seems that they are not capable of compensating these by the allocation of effort (i.e., the adaptation of drift rate).

Conflict Adaptation and Psychological Functioning

Our fourth research question was how adaptation to conflict is related to psychological functioning. The ADHD group showed a similar psychological functioning as the control group, except that the ADHD group showed more obsessive-compulsive behavior. This matches well with our findings of cautious behavior in the flanker task in female college students with ADHD. Correlations of estimates of adaptation with questionnaires suggested that high adaptation of nondecision time was related to less hostility, high adaptation of boundary separation was related to high global impairment, and high adaptation of drift rate was related to less global impairment. Although we checked the correlations for outliers to make sure that they were not influenced by single cases, these correlations have to be interpreted with caution because double difference scores in a small sample can yield some methodological problems, as, for instance, lower reliabilities and increased likelihood of Type II errors (i.e., failure to detect the presence of a meaningful relationship between the discrepancy score in the sample; Edwards 2001). However, it is possible that especially the failure of adaptation of nondecisional processes is related to the high rates of hostility in adult ADHD (Barkley 1996). The relation between high adaptation of boundary separation and high global impairment is counterintuitive, since Mulder et al. (2010) showed that high adaptation of boundary separation is related to less ADHD symptoms and might be specific to our sample of female college students. However, the finding that high adaptation of drift rate is related to less general impairment matches well with the suggestion that drift rate is a measure of effort (Huang-Pollock et al. 2012) and that the suboptimal arousal or activation state typical for ADHD can be compensated for by effort (Van der Meere 2002).

In sum, our findings suggest a preference of accuracy over speed in the ADHD group, indicated by slower RTs, lower ERs, higher boundary separation, a more focused attention (i.e., higher congruency effect on drift rate), more adaptation of RTs (i.e., slowing down in blocks with high conflict) but less adaptation of ERs and drift rate (i.e., no heightened ERs in high conflict blocks, no heightened information uptake). This pattern of cautious behavior is supported by higher rates of obsessive-compulsive symptoms in the female college students with ADHD. Furthermore, we found deficient nondecisional processes (i.e., higher nondecision time) and insufficient effort allocation (i.e., less adaptation of drift rate) in female college students with ADHD. We suggest that these results might indicate a compensation mechanism in female college students with ADHD (Adler 2004; Frazier et al.

2007). To counteract their deficient nondecisional processes (i.e., higher nondecision time), which could be due to a nonoptimal arousal and/or activation state and their problems with sufficiently allocating effort (i.e., adapting drift rate to task demands) they compensate this by trading speed of for accuracy (i.e., setting higher boundaries) and therefore produce less errors. The deficient nondecisional processes and the problem of sufficient effort allocating are typical for the ADHD population and this has been stated in the cognitive-energetic model (Sergeant 2005; Van der Meere 2002). However, we assume that the compensatory strategy of being cautious and trading speed over accuracy is unique to the subpopulation of female college students with ADHD.

Implications for Theories of ADHD

There is a discussion whether deficits in ADHD can be conceptualized as fixed core deficits or as dynamic context dependent deficits (Sonuga-Barke et al. 2010). Focusing only overt behavior (such as RT and ER) as indicators of executive dysfunction makes it hard to say if our ADHD group displayed a deficit or not: They show prolonged RTs but, lower ERs. This finding is consistent with the heterogeneous results of neuropsychological performance in adults with ADHD in general (Boonstra, Oosterlaan, Sergeant, and Buitelaar 2005; Frazier, Demareem, and Youngstrom 2004; Hervey, Epstein, and Curry 2004) and college students with ADHD in particular (Weyandt and DuPaul 2008). Such ambiguous findings stress the importance of studying not only fixed core deficits but the adaptation to different environmental demands (i.e. experimental manipulation of tasks conditions), and the examination of the underlying cognitive processes.

When using the well-established Ratcliff diffusion model (e.g., Wagenmakers 2009) to analyze the unobservable cognitive processes it becomes apparent that the group of female college students with ADHD displays deficits in basic processing and that they act more cautiously compared to a control group, trading speed of for accuracy. Our findings speak against a fixed core deficit in higher order executive functions like inhibition. Rather, our findings suggest deficits in basic nondecisional processing like motor preparation and a deficit in adapting decisional processes like information uptake to task demands. The finding of higher nondecisional time and less adaptation of drift rate is in line with theories of ADHD. However, the finding of higher boundary separation is not, but might be explained by compensatory mechanisms.

Compensation

Compensation, a specific form of adaptation (Backman and Dixon 1992), might help to understand the heterogeneity of ADHD in adulthood. Compensation occurs when a mismatch between internal state and environmental demands is detected and counterbalanced by the investment of more time or effort (drawing on normal skills), utilization of latent (but normally inactive) skills, or acquisition of new skills (Backman and Dixon 1992). Even more factors seem to influence neuropsychological functioning in adults with ADHD as compared to children, causing more heterogeneity in the disorder in adulthood (Boonstra et al. 2005; Frazier et al. 2004; Hervey et al. 2004). One of these factors might be that adults with ADHD have lived with their disorder for several years and usually learned how to compensate to some degree for the accompanying impairments (Adler 2004; Frazier et al. 2007).

Our sample, like other samples of college students with ADHD, showed a low rate of impairment compared to the general ADHD population as indicated by high performance in tests of cognitive performance and the neuropsychological diagnostic tests. With regards to psychological impairment measured with the BSI, the ADHD and the control group only differed in obsessive-compulsive behavior. However, compared to the control group as implicated by their diagnosis and all of the diagnostic questionnaires (i.e., DEX and FEDA), the ADHD group still showed marked impairment. It seems that female college students with ADHD are able to compensate for their deficit in nondecisional processes and failure of adaptation to task demands by trading speed of for accuracy (i.e., setting higher boundaries) and therefore produce less errors. This compensation could cause heterogeneity by disguising deficits in less impaired individuals with ADHD, making it look as if they had no impairment in observable processes like RT and ER.

Implications for ADHD Diagnosis and Intervention

Although this is only a first finding and has to be explored in more depth before drawing implications for general practice of diagnostics and interventions, this study already has intriguing implications. If, for instance, compensatory processes in female college students with ADHD can be replicated, these processes could disguise deficits when using neuropsychological tasks in diagnostic procedures, since deficits can be disguised by compensatory strategies. Furthermore, compensatory strategies can be taught in interventions if they prove to be helpful for individuals with ADHD. This has been brought forward before (Newark and Stieglitz 2010). However, we still lack knowledge of which compensatory strategies are used by individuals with ADHD and which of these are adaptive and which are maladaptive. It is even possible that the same strategy is helpful or maladaptive depending on the frequency of use. For example, a high rate of obsessive-compulsive behavior or a generally higher caution could help college students with ADHD to make fewer errors and therefore pass exams. However, if this behavior becomes to pronounced it could become a comorbid condition causing even further impairment in quality of life over and above the ADHD symptoms.

Limitations

Certainly, our study entails several limitations. First and foremost, the groups differed significantly in age. There is research on the cognitive effects of aging that employs a diffusion model analysis and reliably shows age differences (e.g., Spaniol et al. 2011; Starns and Ratcliff 2010). Given the age difference in our sample (mean difference of seven years), these findings could question the conclusion drawn in our study. However, in the two studies cited above, the minimum mean age difference between college aged participants and older aged participants was approximately 30 years (Spaniol et al. 2011; Starns and Ratcliff 2010). To our knowledge there is no study in which age differences emerged in a flanker task between young adults whose age differences were equally small as in our sample. If age is systematically related to the defining characteristic of psychopathologic groups, removing variance associated with age though an ANCOVA would remove meaningful variance, leaving an undercharacterized grouping variable (Miller and Chapman 2001). Therefore, it is not recommended to use age as a covariate in the analyses if it is highly related to the grouping variable and if there are reasons why this might be the case. Thus, it is characteristic for college students with ADHD to be older because they often take longer time till graduation, change their study subject more often, and have more difficulties finding the subject they are interested in as compared to students without ADHD (Biederman et al. 1994; Krause and Krause 2006). Students with ADHD drop out more often from university education due to several reasons. Primary reasons are ADHD symptoms as impulsivity and inattention (Babinski et al. 2011); secondary reasons might be failed exams or homework assignments as well as pregnancy (indeed, our data shows that female students with ADHD are more often mothers of children as compared to female students without ADHD). Consequently, we had difficulties recruiting female college students with ADHD who are younger than 25 years old because most of them did not receive their diagnosis at that age (i.e., in our sample only three participants received their diagnosis before the age of 25 and none before the age of 20). Most of them started to think about a diagnosis of ADHD when repeatedly failing to finish their studies or when their children were diagnosed with ADHD. Therefore, we believe that our sample of female college students with ADHD represents the population of female college students with ADHD in Germany nowadays. As the public awareness of ADHD has been raised during the last years, it might be easier now to recruit women with ADHD that have been diagnosed already in childhood.

A second limitation is that we did not apply a quantified cut-off for the ADHD symptomatology or the neuropsychological tests we used. We did not use critical values to decide whether a participant was assigned to the ADHD or to the control group. Unfortunately, only nine participants signed the consent to publish the neuropsychological outcomes whereas six participants did not reply. Hence, our groups cannot be separated on the basis of objective criteria. However, we made our diagnosis on the basis of recent recommendations by the German Medical Association (German Medical Association, 2005). Thus, we used a diagnostic checklist but left it up to the experience of the diagnostician to judge if intensity of ADHD symptoms and impairment through the symptoms is sufficient to diagnose ADHD. Furthermore, as recommended we used a battery of neuropsychological test but did not use a cut-off to include or exclude participants. The neuropsychological data of all participants was reviewed by the diagnostician. Since we followed the diagnostic recommendations closely we believe that we made a reliable diagnosis. Even participants from the control group underwent the extensive diagnostic procedure to make sure that they do not have ADHD. Finally, if quantified cut-offs for questionnaires and neuropsychological tests would be recommended, it would be difficult to apply those measures in college students because of an overall higher performance (Nelson and Gregg 2012).

Third, although this study was designed to investigate neuropsychological functions of female college students as an understudied subgroup of adults with ADHD in particular, it would be valuable to study other groups of participants both with ADHD and without ADHD (e.g., females who did not gain admittance to secondary education, male college students). In particular, a comparison group of females with ADHD who dropped out of school might be important to study as one could investigate the strategic use of slow-but-precise answers in detail (this strategy should not be prevalent in this particular group of women with ADHD). However, as previous studies have demonstrated, women with ADHD who drop out of school frequently suffer from comorbid disorders, making it difficult to recruit this group without confounding factors (Kessler et al. 2006).

Finally, as ADHD is a lifelong disorder, it would be interesting to not only run cross-sectional but also longitudinal studies. For instance, analyzing impairment not only in overt behavior but also unobservable processes and adaptation over time starting with children or adolescents at risk and not at risk of an ADHD diagnosis promises useful results for understanding the disorder (Biederman et al. 2007; Biederman et al. 2008). To study compensatory mechanisms, longitudinal studies are indispensable, for understanding when compensatory strategies in development emerge, and how such mechanisms might change over time. Studying especially populations with successful adaptations to their disorder, such as female college students, might be a promising endeavor for developing effective interventions for less successful populations.

Conclusion

By implementing different conditions to investigate adaptation of focused attention and analyzing the data with the Ratcliff diffusion model to study underlying processes, the present research revealed that female college students with ADHD show deficient nondecisional processes (i.e., higher nondecision time) and problems with sufficiently allocating effort (i.e., adaptation of drift rate). Female college students with ADHD used the cautious strategy of trading speed for accuracy (i.e., setting higher boundaries) and therefore produced less errors. We assume that the deficient nondecisional processes and problems with sufficiently allocating effort are typical for the ADHD population and they are in line with theories of ADHD. However, the strategy of trading speed of for accuracy seems to be specific to the subgroup of female college students with ADHD. This pattern of cautious behavior is supported by higher rates of obsessive-compulsive symptoms in the female college students with ADHD and might be interpreted as a compensation mechanism. Compensation could disguise deficits in less impaired individuals with ADHD which would have implications for diagnosis and intervention. Future research might want to investigate adaptation to environmental demands and underlying processes in other groups of participants both with and without ADHD (e.g., females who did not gain admittance to secondary education, male college students) to study whether this compensation mechanism is specific to the subgroup of female college students with ADHD.

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Footnote

[1]A fourth parameter, the starting point z, is not relevant in the current study. The starting point is a measure of bias towards one of the decision bounds. In our analysis the decision bounds are correct and incorrect responses, respectively. Therefore, a bias towards one of them is *a priori* impossible. Consequently, we fixed z to $a/2$.

[2]The only exception was the main effect of condition for the nondecision time $t0$. Whereas this main effect was significant when all participants were entered into the analyses, $F(1, 37) = 5.00$, $p = .03$, it was only marginally significant when the four critical participants were excluded, $F(1, 33) = 3.90$, $p = .057$.

Table 1
Characteristics of the Sample by Group

	ADHD Group (*n* = 15)		Control Group (*n* = 24)		Group Difference
WAIS similarities (*SD*)	96.00	(12.56)	102.29	(13.83)	.512
WAIS block design (*SD*)	101.33	(10.60)	102.92	(9.88)	.654
Age (*SD*)	30.20	(5.93)	22.58	(2.53)	.000
Marital status: Divorced (%)	13.33		0.00		.066
Part time job (%)	40.00		12.50		.047
Children: Yes (%)	20.00		0.00		.023
Highest educational level:					
University entrance diploma (%)	100.00		100.00		
Income: < 1.500 € (%)	80.00		100.00		.023

Note. WAIS = Wechsler Adult Intelligence Scale German Version (Aster, Neubauer, and Horn 2006): IQ norm scores, maximum score for similarities = 33 and maximum score for block design = 26, group difference = *p* values (χ^2 tests for marital status, part time job, children, highest educational level, and income; *t* tests for the other comparisons).

Table 2
Diagnostic Data of the Sample by Group

	ADHD Group (n = 9)		Control Group (n = 23)		Group Difference
Digit span forward percentile (*SD*)	48.00	(24.02)	51.15	(29.12)	.845
Digit span backward percentile (*SD*)	51.89	(28.69)	50.87	(24.51)	.705
TMT-A in s (*SD*)	36.33	(12.44)	22.52	(6.14)	.003
TMT-B in s (*SD*)	78.44	(33.88)	53.35	(17.49)	.029
d2 errors in % (*SD*)	5.83	(4.94)	4.07	(2.83)	.296
Go/NoGo RT in ms (*SD*)	448.39	(35.38)	435.56	(73.08)	.498
Go/NoGo errors (*SD*)	0.11	(0.33)	0.39	(1.12)	.407
Visual scanning (*SD*)	41.11	(6.51)	47.43	(13.73)	.357
DEX self-rating (*SD*)	48.78	(14.17)	38.24	(7.05)	.003
DEX significant other (SD)	37.33	(17.90)	37.45	(10.95)	.672
FEDA self-rating (*SD*)					
Distractibility and slowing in mental processes	31.25	(11.28)	52.33	(6.79)	.056
Decrease in drive	13.87	(3.18)	23.71	(3.54)	.721
Fatigue and slowing in activities of daily living	19.25	(7.61)	33.62	(3.95)	.020
FEDA significant other (SD)					
Distractibility and slowing in mental processes	44.75	(9.85)	56.63	(5.42)	.020
Decrease in drive	18.12	(6.29)	24.86	(4.33)	.064
Fatigue and slowing in activities of daily living	27.00	(9.39)	34.45	(5.42)	.006

Note. Nine of 15 participants in the ADHD and 23 of 24 participants in the control group gave consent to use their diagnostic data from the diagnostic procedure, TMT = the Trail-Making-Test (Lewis and Rennick 1979), DEX = dysexecutive questionnaire (Wilson et al. 1996), FEDA = questionnaire of experienced deficits in attention (presented are ratings of the distractibility subscale; Zimmermann et al. 1991).

Table 3
Brief Symptom Inventory Scores of our Sample by Group

	ADHD Group (n = 15)		Control Group (n = 24)		Group Difference
Somatization	1.44	(0.30)	1.59	(0.34)	.155
Obsessive-Compulsive	1.63	(0.45)	1.26	(0.49)	.024
Interpersonal Sensitivity	1.33	(0.55)	1.30	(0.57)	.867
Depression	1.54	(0.34)	1.53	(0.38)	.935
Anxiety	1.49	(0.25)	1.39	(0.36)	.386
Hostility	1.56	(0.57)	1.52	(0.40)	.782
Phobic Anxiety	1.72	(0.35)	1.72	(0.34)	.965
Paranoid Ideation	1.30	(0.34)	1.60	(0.52)	.062
Psychoticism	1.55	(0.45)	1.77	(0.36)	.101
Global Severity Index	80.13	(9.12)	80.75	(11.99)	.866
Positive Symptom Distress Index	1.90	(0.14)	1.92	(0.09)	.599
Positive Symptom Total	42.13	(5.26)	42.00	(2.80)	.919

Note. Global Severity Index = Sum of all items of the Brief Symptom Inventory; Positive Symptom Distress Index = Mean of all items divided by number of items in which impairment was reported; Positive Symptom Total = Number of self-reported symptoms / Number of items in which impairment was reported.

Table 4
Results of the Classical Analysis for RT and ER for the Group x Flanker Conflict x Conflict Frequency ANOVAs

Factor	*df*	MSE	*F*	η_G^2	*p*
			Response Times		
Group	1, 37	19020.67	8.08**	.16	.007
Flanker	1, 37	251.35	139.20***	.04	< .001
Group × Flanker	1, 37	251.35	2.48	.00	.12
Frequency	1, 37	1748.74	12.94***	.03	< .001
Group × Frequency	1, 37	1748.74	4.29*	.01	.045
Flanker × Frequency	1, 37	209.29	11.91**	.00	.001
Group × Flanker × Frequency	1, 37	209.29	0.15	.00	.71
			Error Rates		
Group	1, 37	0.0020	4.40*	.06	.04
Flanker	1, 37	0.00072	28.78***	.13	< .001
Group × Flanker	1, 37	0.00072	2.56	.01	.11
Frequency	1, 37	0.00055	10.94**	.04	.002
Group × Frequency	1, 37	0.00055	0.26	.00	.61
Flanker × Frequency	1, 37	0.00052	10.99**	.04	.002
Group × Flanker × Frequency	1, 37	0.00052	3.99†	.01	.053

Note. MSE represent mean square errors for the corresponding error term. η_G^2 represent the recommended effect size for repeated measure designs, generalized eta squared; .02 is considered as a small, .13 as a medium and .26 as a large effect (Bakeman 2005).
† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5

Results of the Diffusion Model Analysis for the Group x Flanker Conflict x Conflict Frequency ANOVA (for Drift Rate) and the Group x Conflict Frequency ANOVAs (for Boundary Separation and Nondecision Time)

Factor	*df*	MSE	*F*	η_G^2	*p*
			Nondecision Time (t_0)		
Group	1, 37	0.0025	5.00*	.10	.03
Frequency	1, 37	0.00040	51.32***	.16	< .001
Group × Frequency	1, 37	0.00040	0.33	.00	.97
			Boundary Separation (*a*)		
Group	1, 37	0.26	5.99*	.09	.02
Frequency	1, 37	0.15	0.32	.00	.57
Group × Frequency	1, 37	0.15	0.68	.01	.42
			Drift Rate (*v*)		
Group	1, 37	1.90	3.39†	.06	.07
Flanker	1, 37	0.43	103.90***	.29	< .001
Group × Flanker	1, 37	0.43	6.92*	.03	.01
Frequency	1, 37	0.42	11.44**	.04	.002
Group × Frequency	1, 37	0.42	6.00*	.02	.02
Flanker × Frequency	1, 37	0.17	3.53†	.01	.07
Group × Flanker × Frequency	1, 37	0.17	0.16	.00	.69

Note. MSE represent mean square errors for the corresponding error term. η_G^2 represent the recommended effect size for repeated measure designs, generalized eta squared; .02 is considered as a small, .13 as a medium and .26 as a large effect (Bakeman 2005)
† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 6

Correlations between Brief Symptom Inventory and Conflict Adaptation of RT, ER, Drift Rate, Boundary Separation, and Nondecision Time

	RT[a]	ER[a]	Nondecision Time (t_0)[b]	Boundary Separation (a)[b]	Drift Rate (v)[a]
Somatization	-.022	-.079	.041	.164	-.214
Obsessive-Compulsive	.153	.006	.219	-.038	.195
Interpersonal Sensitivity	.078	-.146	.101	.097	-.291
Depression	-.059	.061	-.192	.102	-.244
Anxiety	.268	.273	.027	.271	-.169
Hostility	-.139	-.003	-.325*	.154	-.217
Phobic Anxiety	.012	-.034	.307	.331*	-.260
Paranoid Ideation	-.064	.235	.060	-.131	-.318*
Psychoticism	-.023	.193	-.164	-.248	-.181
Global Severity Index	.022	-.110	.218	.347*	-.397*
Positive Symptom Distress Index	.077	.090	.050	.136	-.322*
Positive Symptom Total	.077	.177	-.050	.001	-.197

Note. [a]Conflict adaptation effect [i.e., congruency effect (incongruent minus congruent trials) in blocks with infrequent conflict minus congruency effect (incongruent minus congruent trials) in blocks with frequent conflict]; [b]Adaptation to conflict frequency (i.e., performance in blocks with infrequent conflict minus performance in blocks with frequent conflict).
*p<.05; **p<.01

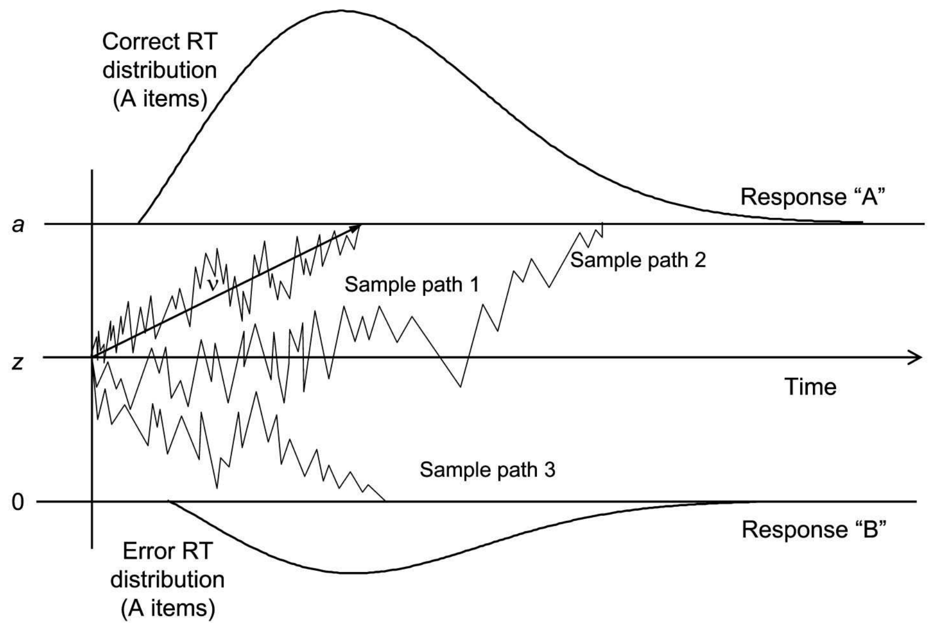

Figure 1. Graphical illustration of a diffusion process for a response to a category A item, in a task requiring the discrimination of items into category A or category B (taken from Spaniol, Madden, and Voss 2006). The diffusion process begins at the starting point *z* and is driven toward the upper boundary *a* ("A" response) by a positive drift rate, *v*. A single drift rate is shown, although drift rates assumingly normally distributed across trials. Sample paths 1 and 2 result in the correct ("A") response, whereas sample path 3 drifts toward the lower boundary 0 ("B") response, resulting in an error (Spaniol et al. 2006).

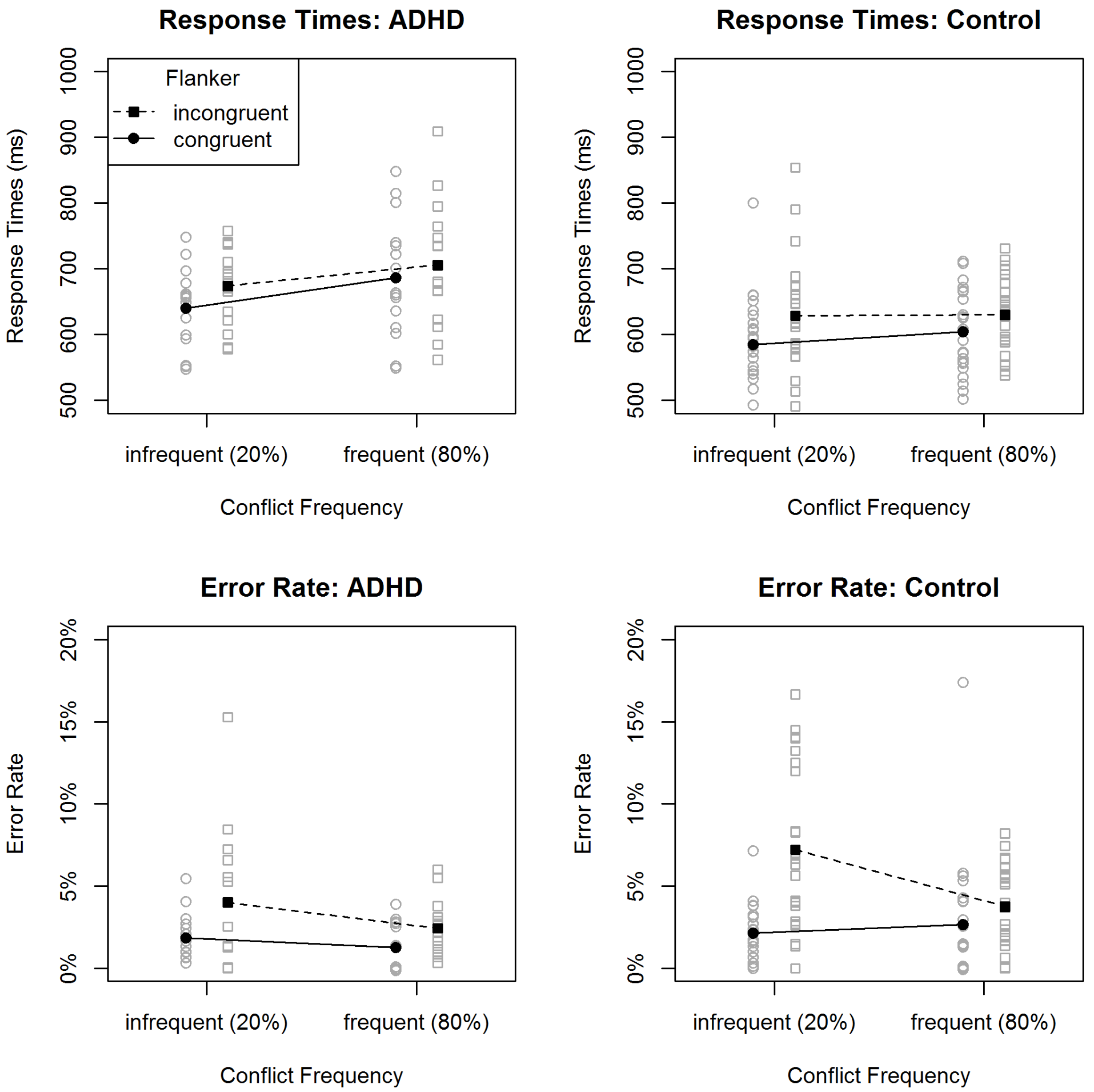

Figure 2. Response times (upper row) and error rates (lower row) from ADHD (left column) and control participants (right column) on the flanker task with blocks with frequent and infrequent conflict (conflict is operationalized as incongruent trials). Mean values are plotted in black. The raw data is plotted in gray to show the dispersion of the data. The difference between squared and round black points at each x-axis tick depict the congruency effects (i.e., incongruent minus congruent means).

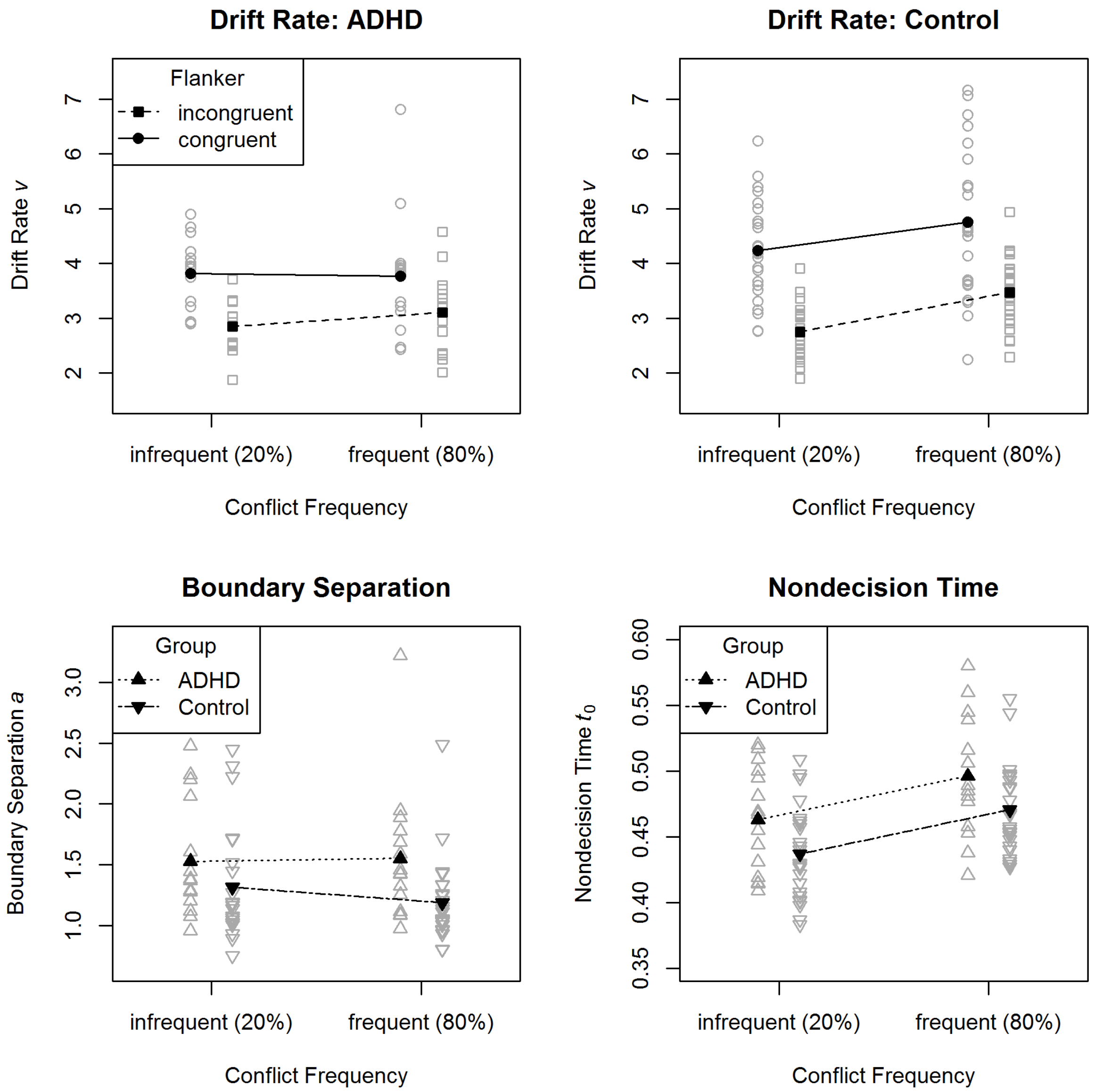

Figure 3. Parameters of the diffusion model fitted to the flanker data. The drift rates are plotted in the upper row (ADHD participants on the left, control participants on the right). The boundary separation parameter is plotted in the lower left plot, the nondecision time in the lower right plot. Mean values are plotted in black. The raw data is plotted in gray to show the dispersion of the data. The difference between squared and round black points (upper row) at each x-axis tick depict the congruency effects (i.e., incongruent minus congruent means).