Effortful control and executive attention in typical and atypical development: An event-related potential study

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Key words: executive attention; flanker task; ERP; ERN; effortful control; ADHD; autism spectrum disorder.

Abstract

Executive attention and its relationship with effortful control (EC) were investigated in children with ADHD (*n* = 24), autism spectrum disorder (ASD; *n* = 20), and controls (*n* = 21). Executive attention measures included flanker-performance and event-related potentials (N2, P3, and ERN). EC was assessed using questionnaires. Only the ERN was found to be robustly related to EC across groups. N2 did not differ between groups and only children with ADHD+ODD showed diminished executive attention as expressed in RT and P3. In ADHD, monitoring of incorrect (ERN) and correct (CRN) responses was diminished. Overall, the link between EC and executive attention was less strong as expected and varied depending on group and measure considered. All groups were able to detect conflict (N2) and all but ADHD+ODD were able to allocate extra attention in order to respond correctly (P3). Findings indicate a general reduced response monitoring in ADHD.

Key words: executive attention; flanker task; ERP; ERN; effortful control; ADHD; autism spectrum disorder.

Highlights

- Executive attention and its link with EC in ADHD, ASD, and controls.

- Correlations were often weak and varied depending on group and measure considered.

- Most robust relationship was found with the ERN.

- ADHD+ODD showed diminished executive attention, reflected in RT and P3.

- ERN and CRN were smaller in ADHD, suggesting reduced response monitoring.

1. Introduction

The ability to adjust or regulate behavior in accordance with situational demands is a crucial part of adequate daily functioning. In temperament literature, this self-regulation component is referred to as 'effortful control' (EC; Rothbart & Bates, 2006, p. 109). EC involves both a behavioral (i.e., the ability to inhibit or activate behavior) and an attentional aspect (i.e., the ability to focus or shift attention when needed) and is traditionally measured using questionnaires (e.g., Ellis & Rothbart, 2001; Rothbart, 1989). Most of the early work on self-regulation and EC had a predominantly behavioral focus. However, together with the development of appropriate methods to investigate brain systems involved in higher level cognitive functioning (e.g., non-invasive brain imaging methods), an increased interest emerged in the underlying mechanisms of self-regulation (Posner & Rothbart, 2000). Given that attention to and processing of information from the environment are believed to be essential for adequately regulating behavior (Posner & Rothbart, 2000), a specific focus has been put on attentional networks underlying EC (Rothbart, Ellis, Rueda, & Posner, 2003). Posner and Petersen (1990) have distinguished three attentional networks, each having a different function and corresponding to separable brain regions and neurochemical circuits. The first two networks involve achieving and maintaining an alert state (i.e., the alerting network; Fan, McCandliss, Sommer, Raz, & Posner, 2002) and orienting attention towards a potentially relevant area of the visual field (i.e., the orienting network; Fan et al., 2002; Greenwood, Fossella, & Parasuraman, 2005). A third network, the executive attention network, involves the monitoring and resolving of conflict among thoughts, feelings, and responses. The efficiency of executive attention is traditionally measured using a flanker task (Fan et al., 2002). However, different tasks involving conflict have been used in combination with neuroimaging techniques to identify brain regions related to executive attention. Based on these studies, executive attention has been linked to a neural network that includes the anterior cingulate cortex (ACC) and the lateral prefrontal cortex (LPFC; e.g., Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Posner & Fan, 2004). According to Posner and Rothbart (2000), the executive attention network forms the key underlying mechanism of EC. This theoretical link has been stressed by Rothbart and colleagues through the inclusion of executive attention in the broader definition of EC as "the efficiency of executive attention, including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors" (Rothbart & Bates, 2006, p. 128). Despite the clear theoretical link between both constructs, few studies have focused on the empirical relationship between EC and executive attention. The studies that did try to relate both constructs to each other, yielded inconsistent findings with some studies reporting a significant relationship between EC reports and executive attention performance and others not (e.g., Ellis, Rothbart, & Posner, 2004; Gerardi-Coulton, 2000; Samyn et al., 2013; Simonds, Kieras, Rueda, & Rothbart, 2007). Overall, there is supporting evidence for a relationship between the constructs, but findings are equivocal and vary strongly depending on the measures used. In all, the most robust relationship is found between parent-reported EC and executive attention performance. However, additional research is needed in order to disentangle the interrelationship between executive attention and EC.

Given the importance of the executive attention network in self-regulation, it has also been proposed to be of particular interest in disorders characterized by problems with self-regulation (e.g., Posner & Petersen, 1990). One disorder known to be typified by difficulties in self-regulation and/or attentional regulation is ADHD (Konrad, Neufang, Hanisch, fink, & Herpertz-Dahlmann, 2006). Berger and Posner (2000) have argued that three major theoretical accounts on ADHD (i.e., Barkley, 1998; Sergeant, Oosterlaan, & van der Meere, 1999; Swanson et al., 2000) can actually be reconceptualized in terms of attentional networks and that all of the accounts implicate the executive attention network. Furthermore, functional magnetic resonance imaging (fMRI) studies have identified an ACC dysfunction as an important contributor to inattention and impulsivity (e.g., Bush et al., 1999; Pliszka et al., 2006) and neurochemical studies have identified dopamine (involved in the executive attention network; Bush, Luu, & Posner, 2000) as a major player in the pathophysiology of ADHD (e.g., Sengupta et al., 2002). Another disorder characterized by difficulties in monitoring, self-initiation and modification of behavior, is autism spectrum disorder (ASD; for a review, see Mundy, 2003). It is hypothesized that there is a functional involvement of the ACC and executive attention in social impairments as well as repetitive behavior in ASD (Doyle-Thomas et al., 2013; Mundy, 2003). This hypothesis is in line with findings of decreased metabolism (Haznedar et al., 1997) and activation (Chan et al., 2011) of the ACC in ASD. With the above-mentioned conceptualizations in mind, an increasing number of studies have focused on EC and executive attention in children with ADHD or ASD. Whereas studies on EC have been relatively consistent in showing lower levels of EC in both groups as compared to typically developing (TD) children (e.g., Martel & Nigg, 2006; Konstantareas & Stewart, 2006; Samyn, Roeyers, & Bijttebier, 2011; Samyn, Roeyers, Bijttebier, & Wiersema, 2013), empirical findings on executive attention are inconsistent. Some studies show impairments on flanker task performance in ADHD or ASD (e.g., Adams & Jarrold, 2012; Burack, 1994; Christ, Kester, Bodner, & Miles, 2011; Konrad et al., 2006; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011), whereas others do not (e.g., Adólfsdóttir, Sørensen, & Lundervold, 2008; Booth, Carlson, & Tucker, 2007; Henderson et al., 2006; Keehn, Lincoln, Müller, & Townsend, 2010; Samyn et al., 2013).

In all, studies focusing solely on EC reports and executive attention performance have been proven to be limited in their ability to: (a) clarify the relationship between EC and executive attention, and (b) lead to a better understanding of executive attention processes in ADHD and ASD. Therefore, we suggest that it may be useful to also include physiological indices of executive attention, in specific event related potentials (ERPs). This would enable us to move beyond the mere interpretation of behavioral outcome (i.e., RT, errors) and look at specific self-regulatory processing stages leading to that final product (i.e., how children suppress irrelevant information, control irrelevant responses, and process their mistakes; Wild-Wall, Oades, Schmidt-Wessels, Christiansen, & Falkenstein, 2009). Several ERP components have been clearly linked to the ACC, making them particularly relevant in the context of studying EC and the efficiency of executive attention.

Three ERP components that are elicited during flanker performance are of particular interest for the present study, namely the N2, the P3 and the error related negativity (ERN). The N2 is a fronto-central negative-going waveform that peaks between 200 and 400 ms post stimulus, which is believed to reflect response inhibition, conflict monitoring or both (e.g., Jackson, Jackson, & Roberts, 1999; Kopp, Rist, & Mattler, 1996; Nieuwenhuis et al., 2003; Van Veen & Carter, 2002). The flanker P3 is a slightly more posterior positive displacement between 300 and 500 ms after the stimulus onset and is hypothesized to reflect response inhibition (e.g., Herrmann, Jacob, Unterecker, & Fallgatter, 2003) or the monitoring of the successful outcome of the inhibitory process (e.g., Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005). In line with the fact that the ability to 'detect errors' is considered to be an important part of EC (Rothbart & Bates, 2006, p. 128), a third relevant component is the ERN. The ERN is a fronto-central negative voltage deflection peaking within 160 ms after an error is made (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). It is hypothesized to reflect the activation of an error detection system (Falkenstein et al., 2000; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005; Van Veen & Carter, 2002). Despite debate on the exact functional meanings of these components, they all are clearly related to important aspects of self-regulation and source localized to the ACC (e.g., Bekker, Kenemans, & Verbaten, 2005; Bokura, Yamaguchi, & Kobayashi, 2001; Herrmann, Römmler, Ehlis, Heidrich, & Fallgatter, 2004; Jonkman, Sniedt, & Kemner, 2007a; Neuhaus et al., 2007).

Up till now, few studies included ERP measures of executive attention while investigating the relationship with EC. Also, comparison between studies is being hampered because of differences in (1) administered task (e.g., flanker task, go/no go), (2) measures of EC (e.g., the effortful control scale, the child behavior questionnaire), (3) ERP components (e.g., N2, P3), and (4) participants (e.g., age ranges, different clinical groups). Overall, there seems to be evidence for a relationship between N2 and P3 amplitudes and EC in children, although findings on the direction of the relationship are inconsistent (e.g., Buss, Dennis, Brooker, & Sippel, 2011; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Wiersema & Roeyers, 2009). Despite the potential pertinence of error-related ERPs in EC (i.e., the inclusion of the ability to 'detect errors' in the definition of EC), to our knowledge, no study so far investigated the relationship between the ERN and EC reports.

With regards to differences between TD children, children with ADHD, and children with ASD in terms of ERP measures of executive attention, only a limited number of studies focused on the flanker N2, P3 and/or ERN. Some studies showed no differences in N2 amplitudes in children with ADHD or ASD as compared to TD peers (Johnstone & Galletta, 2013; Tsai, Pan, Wang, Tseng, & Hsieh, 2011), whereas others do (e.g., Albrecht et al., 2008; Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; Johnstone, Watt, & Dimoska, 2010; Jonkman, van Melis, Kemner, & Markus, 2007b; Kratz et al., 2011; Wild-Wall et al., 2009).

Findings on the flanker P3 in ADHD or ASD are inconsistent with some studies showing reduced P3 (e.g., Kratz et al., 2011) and others finding no amplitude differences compared to TD peers (e.g., Johnstone et al., 2010; Tsai et al., 2011). Similar heterogeneous results have been found for the ERN. Some studies showed an unaffected ERN (e.g., Jonkman et al., 2007b; Wild-Wall et al., 2009), whereas others found reduced or even enhanced ERN compared to TD peers (e.g., Albrecht et al., 2008; Henderson et al., 2006; Santesso et al., 2011; South, Larson, Krauskopf, & Clawson, 2010; Van Meel et al., 2007;). In sum, studies comparing children with ADHD or ASD and TD children on these flanker ERPs are rather scarce and have yielded mixed results. Furthermore, to the best of our knowledge, no study so far has directly compared ADHD and ASD in terms of the flanker N2, P3, and ERN despite the fact that this could provide us with valuable information. Several studies have shown that children with ADHD and children with ASD share many symptoms, including inattention and hyperactivity (e.g., Mayes, Calhoun, Mayes, & Molitoris, 2012), which complicates differentiating between the disorders and may result in an overestimation of comorbid ADHD in ASD, up to 78% (for a review, see Gargaro, Rinehart, Bradshaw, Tonge, & Sheppard, 2011). Examining differences in the efficiency of executive attention processes by means of ERPs may identify cognitive markers that can help differentiate between ADHD and ASD and identify false cases of comorbidity.

The first aim was to investigate the relationship between EC and ERP-based measures of executive attention. Based on previous findings and on the theoretical link between both constructs, we expected to find significant relationships between reports on EC and the N2, the P3, and the ERN. In specific, we expected higher levels of EC to be associated with smaller N2 difference scores (and thus with a lesser amount of flanker-induced conflict-effect (e.g., Jonkman et al., 2007b), with smaller P3 difference scores (and thus with a lesser amount of effort allocation), and with larger ERN/CRN differences (and thus with better error monitoring). The second aim of the present study was to investigate whether TD children, children with ADHD and children with ASD differ from each other based on performance measures and ERP indices of executive attention. Given the equivocal results concerning group differences on executive attention performance and related ERPs (N2, P3, and ERN), it was difficult to put forward specific hypotheses as to potential differences between the three groups. However, based on the abovementioned theoretical conceptualizations, we expected the clinical groups to show less efficient executive attention performance (i.e., larger congruency effect based on RTs and/or errors of commission) on the flanker task in comparison with TD children. Also, we expected to find reduced N2 and P3 congruency-effects, and a reduced ERN accuracy-effect in the clinical groups. Additionally, we evaluated the impact of comorbid Oppositional-Defiant Disorder (ODD) on our findings given that an increasing number of studies suggest that the presence of comorbid ODD or CD can account for some effects presumably caused by ADHD (e.g., Kuntsi, Oosterlaan, & Stevenson, 2001).

2. Method

2.1. Participants

65 children aged 10-15 years with an estimated full scale IQ (FSIQ) of 80 or higher participated in our study. 21 children were TD (66% boys; age: M = 13.58, SD = 1.66; estimated FSIQ: M = 110.00, SD = 9.45), 20 children had a formal diagnosis of ASD (75% boys; age: M = 12.61, SD = 1.83; estimated FSIQ: M = 104.35, SD = 16.63), and 24 children had a formal diagnosis of ADHD (63% boys; age: M = 12.82, SD = 1.64; estimated FSIQ: M = 101.13, SD = 10.79). All children with ASD or ADHD were previously diagnosed by a multidisciplinary team using established criteria, as specified in DSM-IV-TR (APA, 2000). Diagnosis of ASD was confirmed by the Dutch translation of the SRS (Constantino & Gruber, 2005; Roeyers, Thys, Druart, De Schryver, & Schittekatte, 2011). 30 percent of the boys in

the ASD group had an SRS Total T-score between 60 and 75, indicating the presence of mild ASD or high functioning autism. 70 percent of the boys had a T-score of over 75, indicating the presence of severe autism. All children with ASD were free of medication. Diagnosis of ADHD was verified using the disruptive behavior module of the Diagnostic Interview Schedule for Children for DSM-IV (DISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). The DISC-IV was also used for establishing the presence of comorbid ODD and/or Conduct Disorder (CD). The ADHD group included 9 children with primarily Inattentive subtype, three with primarily Hyperactive/Impulsive subtype and 12 with the Combined subtype. Ten boys also met criteria for ODD, none of the children met criteria for CD. Given that several studies suggest that the presence of comorbid ODD/CD can account for some effects presumably caused by ADHD (e.g., Kuntsi, Oosterlaan, & Stevenson, 2001) and given that several children in our ADHD-sample had comorbid ODD, we performed additional analyses to evaluate whether or not this influenced the findings. However, we want to stress that these findings have to be interpreted with caution because of the limited size of the ADHD-only (n = 14) and the ADHD+ODD (n = 10) samples. 18 children took medication for ADHD symptoms on a regular basis, which was discontinued at least 48 hours prior to the testing. Groups did not differ significantly in age ($F(2, 62) = 2.80$, $p = .068$, $\eta^2 = .08$) or estimated full scale IQ (FSIQ; $F(2, 62) = 2.85$, $p = .065$, $\eta^2 = .08$).

2.2. Instruments

2.2.1. EC questionnaires

The Effortful Control Scale (ECS), the Attentional Control Scale (ACS) and the self- and parent-report of the Early Adolescent Temperament Questionnaire-Revised (EATQ-R-s and EATQ-R-p, respectively) were used to tap EC. The ECS (Lonigan & Phillips, 2001) measures behavioral and attentional aspects of EC and consists of 24 self-report items to be rated on a 5-point Likert scale. It yields a total score (α = .85[1]) and two subscale scores, namely Persistence/Low Distractibility (12 items; e.g., "I have a hard time concentrating on my work because I'm always thinking about other things" and "I have difficulty completing assignments on time"; α = .81) and Impulsivity (12 items; e.g., "I can easily stop an activity when told to do so"; α = .74). Lower scores on the Impulsivity subscale indicate higher levels of impulsivity. The ECS shows acceptable psychometric properties (e.g., Verstraeten, Vasey, Claes, & Bijttebier, 2010).

The ACS (Derryberry & Reed, 2002) measures the ability to focus and shift attention by means of 20 self-report items to be rated on a 4-point Likert scale. It yields a total score (α = .83) and two subscale scores, namely Attention Focusing (nine items; e.g., "My concentration is good even if there is music in the room around me"; α = .71) and Attention Shifting (11 items; e.g., "I can quickly switch from one task to another"; α = .77). The ACS shows acceptable psychometric properties (e.g., Verstraeten et al., 2010).

The EATQ-R (Ellis & Rothbart, 2001) self-report consists of 65 items, the parent-report version consists of 62 items. Items are grouped into 12 clusters and four higher-order scales (Positive Reactivity, Negative Affectivity, Affiliativeness and Effortful Control) and have to be rated on a 5-point Likert scale. For the purpose of this study, only the EC scale (α = .90 for the EATQ-R-p, α = .81 for the EATQ-R-s), consisting of the item clusters Inhibitory Control (e.g., "When someone tells me to stop doing something, it is easy for me to stop"), Attentional Control (e.g., "I pay close attention when someone tells me how to do something") and Activation Control (e.g., "I put off working on projects until right before they're due"), was included. The EATQ-R shows acceptable psychometric properties (e.g., Muris & Meesters, 2009).

2.2.2. Neuropsychological measure of executive attention

[1] All reported alphas refer to inter-item correlations in the present study.

Executive attention was measured using a modification of the Eriksen flanker paradigm (Eriksen & Eriksen, 1974). The flanker task administered in the present study was very comparable to the one Jonkman and colleagues (2007b) and van Meel and colleagues (2007) used to study the N2 and the ERN in school-aged children. Participants had to evaluate whether the middle arrow of five horizontally arranged arrows is pointing left or right by pressing one of two possible keys in the keyboard. The efficiency of executive attention was assessed by measuring the impact of flankers on RT and accuracy. Flankers could be either congruent (i.e., target and flankers pointed in the same direction) or incongruent (i.e., flankers pointed in the opposite direction to the target). Each trial began with the presentation of a fixation cross at the center of the screen for the duration of 500 ms. Then, target and flankers were displayed for 200 ms, followed by a fixation cross of variable duration (1,100-1,300 ms). The task consisted of a practice block (20 trials), followed by 4 blocks of 100 test trials. Within each block, trials were presented randomly. Executive attention scores were calculated by subtracting mean RT in the congruent flanker condition from the incongruent flanker condition. The underlying idea is that in the congruent condition, flankers and target point in the same direction and will elicit the same response whereas in the incongruent condition, flankers provide conflicting information and conflict resolution will be needed in order to be able to respond correctly to the target. Therefore, the flanker interference effect (i.e., RT difference between congruent and incongruent conditions) should provide a measure of executive attention with larger interference scores reflecting less efficient executive attention.

2.3. Procedure

The study was approved by the Ethical Committee of Ghent University. Once parents were informed about the aims of the study and written consents were obtained, we first asked parents and children to complete a set of questionnaires. Next, parents and children visited the laboratory on two occasions. During the first session the DISC-IV was administered to the parents (only for the ADHD group) and IQ of children was estimated based on four subtests (Vocabulary, Similarities, Picture Arrangement and Block Design) of the Wechsler Intelligence Scale for Children III (WISC-III; Kort et al., 2002). The estimated FSIQ correlates strongly with FSIQ (Grégoire, 2005). During the second session the flanker task combined with the EEG measurement was administered. Upon arrival in the laboratory, the child was familiarized with the procedure. After attachment of the electrode cap, task instructions were given and practice trials were performed. Test blocks were started once participant thoroughly understood the task. Between blocks, breaks were provided to minimize the effects of fatigue.

2.4. Electrophysiological measures

EEG activity was recorded with 127 active electrodes, mounted in a customized cap (EasyCap Active; EasyCap GmbH) according to the 10/5 International System (Oostenveld & Praamstra, 2001). The ground electrode was placed in the cap at Fpz. Electro-oculogram (EOG) was recorded with electrodes enclosed in the cap near the eyes and an additional electrode, placed below the right eye. Data were digitized with a sampling rate of 500 Hz and amplified with an open pass-band from DC to 100 Hz, by means of a Brain Vision Quickamp amplifier (Brain Products, Gilching, Germany), which uses an average reference. All signals were offline filtered with a high pass filter of 0.1 Hz (24 dB/octave), a low pass filter of 30 Hz (24 dB/octave), and a 50 Hz notch filter. Eye movement correction was conducted using the Gratton and Coles algorithm (Gratton, Coles, & Donchin, 1983), as implemented in Brain Vision Analyzer (version 2.0.1).

2.4.1. Stimulus-locked ERP analyses

To investigate processing of response conflict by means of the N2 and P3 components, stimulus-locked ERP analyses were performed. Signals were segmented into epochs of 200 ms before to 1000 ms after stimulus onset for trials to which subjects responded correctly. Signals were baseline-corrected to the 200 ms pre-stimulus baseline. Epochs with physiological artefacts in any EEG channel were rejected before averaging. Criteria for artefact rejection were: (1) a voltage step of more than 50 µV between sample points, (2) a voltage difference of more than 200 µV within an epoch, and (3) activity lower than 0.5 µV. Next, signals were averaged according to congruency to obtain congruent and incongruent stimulus-locked ERPs. Topographical maps showed that N2 was most pronounced at Fz and FCz, therefore N2 peak amplitude was determined at these electrode sites in a time window from 230 to 370 ms post-stimulus[2]. The P3 amplitude, maximal at Cz, CPz, and Pz, was defined as the mean voltage computed in the time window 400 to 600 ms post-stimulus (all relevant electrode sites and boundaries were chosen based on topographical evaluation of the ERPs and on visual inspection of the grand average difference wave-forms between congruent and incongruent stimuli, respectively).

2.4.2. Response-locked analyses

To investigate the ERN, signals were segmented into epochs of 400 ms before to 800 ms after response onset. Signals were baseline-corrected to a -400 to -200 ms pre-response baseline[3]. Epochs with physiological artefacts in any EEG channel were rejected in accordance with the above mentioned criteria for artefact rejection before averaging. Then, signals were averaged according to accuracy to obtain correct and incorrect response locked ERPs. In order to be sure that our findings were not compromised by some kind of cognitive control "carry-over" effect from stimulus related processing, response locked ERPs were

[2] We also performed the analyses using N2 mean amplitudes in a time window from 280 to 330 ms post-stimulus (based on visual inspection of the grand averages and topographical map of the N2), all results remained the same.

[3] We also performed the analyses using the average voltage of the entire averaging epoch as the baseline (Luck, 2005), all results remained the same.

obtained from incongruent trials only[4]. The ERN was most pronounced at Fz and FCz. Peak amplitude of the ERN was determined at these sites in a time window from -25 to 100 ms post-response (relevant electrode sites and boundaries were chosen based on topographical analysis of the ERP and on visual inspection of the grand average difference wave-forms between correct and incorrect responses, respectively). Due to the absence of a clear ERN-like negativity from -25 to 100 ms in the correct response-locked ERPs in several participants, the correct-related negativity (CRN) was determined in a time window of 16 ms around the time point at which the ERN occurred in the individual ERPs for incorrect trials (e.g., Jonkman et al., 2007b).

2.5. Data analysis

2.5.1. Data trimming and outlier analysis

For the RT-based measures, all RTs from errors and all RTs shorter than 150 ms were eliminated[5]. To prevent extreme RTs from influencing the means for each participant, we applied a within-subject trimming procedure that is robust to non-normality (Wilcox & Keselman, 2003; Friedman et al., 2008): for each participant, observations that deviated from the median by more than 3.32 times the median absolute deviation in each condition were excluded. For each variable used in the analyses, observations farther than 3 SDs from the group means were replaced with values that were 3 SDs from the group mean. This final trimming stage affected no more than 0.6 % of the observations[6].

2.5.2. Statistical analyses performance measures

Performance measures included percentage errors of commission (%EOC; i.e., pressing the wrong button), mean reaction time (RT), and efficiency scores of executive

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[4] Analyses were repeated using response-locked ERPs to congruent and incongruent trials collapsed, all results remained the same.

[5] An RT of less than 150 ms is taken to indicate that the subject's response was anticipatory and not an authentic response per se. Such anticipatory RTs are therefore discarded (Jensen, 2006, p. 63).

[6] Analyses were repeated using the non-trimmed data, all results remained the same.

attention (i.e., $RT_{incongruent} - RT_{congruent}$; $\%EOC_{incongruent} - \%EOC_{congruent}$). Mean error rates and RT were entered into a mixed-model repeated-measures ANOVA with group (TD, ASD, ADHD) as between-subject factor and flanker (congruent, incongruent) as within-subject factor. To evaluate the relationship between performance and EC reports by means of correlational analyses, executive attention efficiency scores were used.

2.5.3. Statistical analyses ERP measures

Mean N2, P3, and ERN amplitudes were compared across conditions (congruent vs. incongruent for the N2 and P3 and correct vs. incorrect for the ERN) by separate repeated measures ANOVAs. All analyses comprised a between-subjects factor "group" (TD, ASD, ADHD). The N2 and P3 related analyses included "flanker" (congruent, incongruent) and "electrode position" ('Fz, FCz' and 'Cz, CPz, and Pz', respectively) as within-subjects factors. The ERN analyses included "accuracy" (correct, incorrect) and "electrode position" (Fz, FCz) as within subjects-factors.

The average number of segments included in the averaged stimulus-locked ERPs was 115 (SD 37) for congruent trials and 99 (SD 35) for incongruent trials. The average number of segments in the averaged response-locked ERPs was 214 (SD 67) for correct trials and 30 (SD 21) for incorrect trials. Four children (3 TD, 1 ADHD) were omitted from the response-locked ERP analyses (but not from the behavioral analyses and the stimulus-locked ERP analyses) due to an insufficient number of error trials for reliable analyses.

To address the research question regarding the relationship between EC and the ERPs, bivariate correlations were computed between EC scores and N2, P3, and ERN amplitude difference scores ($N2_{incongruent} - N2_{congruent}$; $P3_{incongruent} - P3c_{ongruent}$; ERN – CRN, respectively). Given that the repeated measures ANOVAs revealed no interaction-effects with electrode site (suggesting that neither the congruency- nor the accuracy-effect differed between electrode sites), mean difference scores were calculated for the cluster of relevant electrode sites per ERP (Fz and FCz for the N2 and the ERN; Cz, CPz, and Pz for the P3).

3. Results

3.1. The relationship between executive attention and EC

3.1.1. Basic EC findings

Groups were compared on the different EC scales by means of ANOVAs and Bonferroni post hoc analyses. Means, standard deviations, and F values are shown in Table 1. Significant group differences were found for all scales with the exception of self-reported activation control. Both clinical groups scored significantly lower than the TD group on all total scales, parent-reported inhibitory and attentional control and child-reported persistence and attentional control. Children with ADHD (but not ASD) showed more impulsivity and less inhibitory control compared to TD children.

3.1.2. Behavioral measures and EC

Means, standard deviations, and *F* values are shown in Table 1. Bivariate correlations between executive attention (RT- and %EOC-based) and EC (sub)scales were computed. For the total group, we found no relationship between EC reports and RT-based executive attention (*r*s ranging from -.00 to -.18). However, we did find a trend for a relationship between self-reported attention focusing (ACS) and RT-based executive attention (r = -.23, p = .06). This trend became significant after controlling for FSIQ (r = -.25, p = .045). In specific, higher levels of attention focusing were related to a lower RT-based conflict score. We found no relationship between EC reports and error-based executive attention (*r*s ranging from -.06 to -.23), with the exception of the relationship with impulsivity (r = -.25, p = .049). In specific, children that reported being less impulsive showed a lower error-based conflict score. All results remained the same after controlling for age and FSIQ.

3.1.3. ERPs and EC

For the total group, we found no relationship between the N2, the P3 and any of the EC scales (see Table 2). The ERN however, was significantly related to (subscales of) each of the EC questionnaires. The significant correlations were small to modest with r*s* ranging from -.27 to -.37. When correcting for multiple comparisons using the Bonferroni-Holm procedure, only the relationship between the ERN and self-reported attention focusing and attentional control (ACS) remained significant. In specific, higher levels of attentional control were associated with a larger ERN/CRN difference score (see Figure 1[7]). All results remained the same when controlling for age and gender.

To get an indication of potential group differences considering the interrelationship between EC and executive attention related ERPs, correlations were computed for the three groups separately (see Table 3). Given the relatively small number of participants in the separate groups, only the magnitude of the correlation coefficients was interpreted (*r*s: .30 - .50 = moderate; r*s* ≥ .50 = large; Cohen, 1988). The N2 was unrelated to EC in TD children, but modestly related to attention control (EATQ-R-s and -p) and impulsivity in ADHD. In ASD, the N2 was strongly related to attention shifting (EATQ-R-s and -p) and modestly to inhibitory control (EATQ-R-p). The P3 was unrelated to EC in ASD, but moderately related to attentional control (EATQ-R-s), activation control (EATQ-R-p), and impulsivity (ECS) in TD children, and with impulsivity in ADHD. For the ERN, moderate to large correlations were present in all three groups. In TD children, strongest correlations were found for attentional (ACS, EATQ-R-s) and inhibitory control (EATQ-R-s), whereas in ASD the strongest relationships were found for attentional control (ACS and EATQ-R- p) and activation control (EATQ-R-p). In the ADHD group, activation control (EATQ-R-s) showed the highest correlation.

[7] There seemed to be one outlier. However, additional analyses excluding the outlier did not change our findings.

3.2. Performance measures

Means, standard deviations, and *F* values are shown in Table 1.

3.2.1. Flanker main-analysis: incorrect responses

There was a main effect of flanker ($F(1, 62) = 136.27$, $p < .001$, $\eta^2 = .69$), reflecting more errors in the presence of incongruent flankers. There was a *trend* ($F(2, 62) = 2.92$, $p = .065$, $\eta^2 = .09$) for a group difference for mean error rate, with children with ADHD showing slightly elevated error levels in comparison with their TD peers ($p = .056$). Additional analyses show that children with ADHD made significantly more errors than TD children, but only in the congruent condition ($F(1, 43) = 6.77$, $p = .013$, $\eta^2 = .14$). There was no interaction effect of flanker and group ($F(2, 62) = 0.33$, $p = .718$, $\eta^2 = .01$). Results remained the same when controlling for gender and differences in FSIQ. Given that the %EOC was not significantly related to age, requirements for analyses of covariance were not met. Consequently, we did not control for age.

Additional analyses were performed to investigate whether comorbid ODD in ADHD influenced these findings. Results remained the same when excluding children with ADHD+ODD. When excluding children with ADHD-only, the trend for a group difference became non-significant ($p = .205$).

3.2.2. Flanker main-analysis: RT

There was a main effect of flanker ($F(1, 62) = 152.82$, $p < .001$, $\eta^2 = .71$), all children responded slower to the target if it was accompanied by incongruent flankers. There was no main effect of group ($F(2, 62) = 1.90$, $p = .158$, $\eta^2 = .06$) nor was there an interaction effect of flanker and group ($F(2, 62) = 2.36$, $p = .103$, $\eta^2 = .07$). Results remained the same when controlling for gender and age differences. Given that RT was not significantly related to FSIQ, requirements for analyses of covariance were not met. Hence, we did not control for FSIQ.

Results remained the same when excluding children with ADHD+ODD. When excluding children with ADHD-only, we found a *trend* for a main effect of group ($F(2, 48) = 3.06$, $p = .056$, $\eta^2 = .11$) and a significant interaction effect of flanker and group ($F(2, 48) = 6.33$, $p = .004$, $\eta^2 = .21$). In specific, additional analyses showed that groups did not differ in terms of reaction time on congruent trials ($F(2, 48) = 1.62$, $p = .208$, $\eta^2 = .06$), whereas groups did differ in terms of reaction time on incongruent trials ($F(2, 48) = 4.11$, $p = .022$, $\eta^2 = .15$) in that children with ADHD+ODD responded slower than TD children ($F(1, 29) = 4.57$, $p = .041$, $\eta^2 = .14$) and children with ASD ($F(1, 28) = 5.17$, $p = .031$, $\eta^2 = .16$), indicating less efficient executive attention in ADHD+ODD.

3.3. Event-related potential measures

Grand average waveforms following congruent and incongruent stimuli for each group are shown in Figure 2 (N2) and Figure 3 (P3). Grand average waveforms following correct and incorrect responses for each group are depicted in Figure 4.

3.3.1. Stimulus-locked N2

There were main effects of flanker ($F(1, 62) = 4.83$, $p = .032$, $\eta^2 = .07$) and electrode ($F(1, 62) = 79.36$, $p < .001$, $\eta^2 = .56$), reflecting more negative N2 amplitudes in the incongruent condition than in the congruent condition and more negative N2 amplitudes at Fz than at FCz. There was no significant main effect of group on N2 amplitude ($F(2, 62) = 0.65$, $p = .527$, $\eta^2 = .02$), nor was there an interaction effect of flanker and group ($F(2, 62) = 0.22$, $p = .800$, $\eta^2 = .01$) or any other interaction effect. Requirements for analyses of covariance were not met since N2 amplitudes were not significantly related to either age, gender or FSIQ. Therefore, we did not control for these factors.

Results remained the same when excluding children with ADHD+ODD or with ADHD-only.

3.3.2. Stimulus-locked P3

There were main effects of flanker ($F(1, 62) = 54.18$, $p < .001$, $\eta^2 = .47$) and electrode ($F(2, 61) = 91.11$, $p < .001$, $\eta^2 = .75$), reflecting larger P3 amplitudes in the incongruent condition as compared to the congruent condition and larger P3 amplitudes at CPz than at Cz and Pz. There was no significant main effect of group on P3 amplitude ($F(2, 62) = 0.34$, $p = .710$, $\eta^2 = .01$). However, we did find an interaction of group and flanker ($F(2, 62) = 3.93$, $p = .025$, $\eta^2 = .11$). In specific, we found that the flanker-effect was present in TD children ($F(1, 20) = 34.97$, $p < .001$, $\eta^2 = .64$) and in children with ASD ($F(1, 19) = 31.34$, $p < .001$, $\eta^2 = .62$), but not in children with ADHD ($F(1, 23) = 3.99$, $p = .057$, $\eta^2 = .15$). There were no other significant interaction effects. Results remained the same after controlling for age and gender. P3 amplitudes were not significantly related to FSIQ, therefore, we did not control for differences in FSIQ.

Additional analyses were performed in order to investigate the potential influence of comorbid ODD in ADHD. When excluding children with ADHD+ODD all results remained the same with the exception that the interaction effect of group and flanker lost significance ($F(2, 52) = 0.86$, $p = .428$, $\eta^2 = .03$). When excluding the ADHD-only group, the interaction effect of group and flanker remained significant ($F(2, 48) = 8.38$, $p = .001$, $\eta^2 = .26$). Additional analyses showed that there was a P3 congruency-effect in TD children ($F(1, 20) = 34.97$, $p < .001$, $\eta^2 = .64$) and children with ASD ($F(1, 19) = 31.34$, $p < .001$, $\eta^2 = .62$), but not in children with ADHD+ODD ($F(1, 9) = 0.19$, $p = .672$, $\eta^2 = .02$).

3.3.3. Response-locked ERN

We found main effects of accuracy ($F(1, 58) = 48.39$, $p < .001$, $\eta^2 = .46$) and electrode ($F(1, 58) = 29.70$, $p < .001$, $\eta^2 = .34$), reflecting more negative amplitudes after an erroneous response (ERN) than after a correct response (CRN) and larger (ERN as well as CRN) amplitudes at Fz than at FCz. We also found a group difference ($F(2, 58) = 5.22$, $p = .008$, $\eta^2 = .16$) in that children with ADHD seemed to show smaller amplitudes in comparison with

TD peers (p = .007). The reduced amplitudes were present for correct (CRN) as well as incorrect (ERN) trials as is reflected by the lack of a significant interaction effect of group and accuracy ($F(2, 58) = 0.79$, $p = .459$, $\eta^2 = .03$). This result remained the same after controlling for age and gender, suggesting that children with ADHD tend to show a general reduction of response-related negativity in comparison with TD children. ERN amplitudes were not significantly related to FSIQ, therefore, we did not control for differences in FSIQ.

Results remained the same when excluding children with ADHD+ODD or ADHD-only.

4. Discussion

The first aim of the present study was to investigate the relationship between (performance and ERP measures of) executive attention and EC. In line with our previous findings (e.g., Samyn et al., 2013), we found performance measures of executive attention to be mostly unrelated to EC reports. Two exceptions, higher levels of attention focusing and lower levels of impulsivity were associated with more efficient executive attention (RT- and error-based, respectively). However, correlations were small ($r < .30$). When looking at the relationship between ERPs and EC, results were similar in that we found no relationship between the stimulus-locked ERPs (N2, P3) and EC. The ERN was poorly to modestly related to EC reports in that higher levels of attentional control were associated with more efficient error monitoring. Given the strong theoretical link between EC and executive attention, we expected to find a stronger relationship between both constructs, especially for the ERPs which are believed to be more objective indices of executive attention. To evaluate whether the absence of a strong link between EC and executive attention, as measured with ERPs, may be related to a divergent association between the two constructs within the groups, additional correlational analyses were performed for the three groups separately. Given the limited number of participants in the three subgroups, only the magnitude of the correlation coefficients was considered (*r*s from .30 to .50 = moderate, .50 or higher = large; Cohen, 1988) and results have to be interpreted with caution. The N2 seemed to be unrelated to EC in TD children, but moderately related to attentional control and impulsivity in ADHD, and strongly related to attention shifting in ASD. Direction of the correlations indicated that higher EC scores were associated with smaller N2 difference-scores and thus with a lesser amount of flanker-induced conflict-effect (e.g., Jonkman et al., 2007b). P3 amplitude was unrelated to EC in ASD, but moderately related to attentional control, activation control, and impulsivity in TD children, and to impulsivity in ADHD. Direction of the correlations indicated that higher EC scores were associated with smaller P3 difference-scores and thus with a lesser amount of effort allocation. For the ERN, findings were more consistent across groups in that there were moderate and/or large correlations present in all groups. In TD children, strongest correlations were found for attentional and inhibitory control, whereas in children with ASD, the ERN correlated strongly with attentional and activation control. In children with ADHD, the ERN correlated strongest with activation control. Direction of the correlations suggested that higher EC scores were associated with larger ERN/CRN differences and thus with better error monitoring. Despite decreased power caused by the limited number of participants in each group, it is apparent that whether or not we found a relationship between EC and executive attention depended on the groups, the EC measures, and the ERPs that were considered. The most robust results were found for the ERN/CRN difference-scores which were significantly related to EC, regardless of group.

The second aim of the present study was to investigate whether there is a difference in the efficiency of executive attention between TD children, children with ADHD, and children with ASD. We used flanker-task performance and event-related potentials (ERPs) as measures of executive attention. There were no major group differences in performance on the flanker task, although children with ADHD did show slightly elevated error levels in comparison with TD children. Given that this increase was not specific for incongruent trials, it cannot be attributed to inefficient inhibition of conflicting information. More likely, this reflects an under-aroused response system in ADHD (e.g., Sergeant, 2000), which is in line with previous findings (e.g., Johnstone et al., 2010; Van De Voorde, Roeyers, Verté, & Wiersema, 2011). The fact that we did not find group differences for the conflict-effect on a behavioral level, is in agreement with some previous flanker studies in children (e.g., Adólfsdóttir et al., 2008; Booth et al., 2007; Keehn et al., 2010; Samyn et al., 2013) but in contrast to others (e.g., Konrad et al., 2006; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011). Nonetheless, this result is not surprising. Findings based on performance measures in general are often inconclusive and vary depending on a multitude of factors including, among other things, task characteristics (i.e., presentation rate of the stimuli; Wiersema, van der Meere, Roeyers, Van Coster, & Baeyens, 2006), context factors (e.g., Sonuga-Barke, Wiersema, van der Meere, & Roeyers, 2010), and sample characteristics (i.e., clinical diagnosis, comorbidities, age, intelligence; Nigg, 2001) which are not always taken into account when interpreting findings. Given that an increasing number of studies suggest that the presence of comorbid ODD or CD can account for some effects presumably caused by ADHD (e.g., Kuntsi, Oosterlaan, & Stevenson, 2001) and given that we allowed comorbid ODD in our ADHD-sample, we performed additional analyses to evaluate whether or not this influenced our findings. Although results have to be interpreted with caution because of the limited ample size of the ADHD-only (n = 14) and the ADHD+ODD (n = 10) samples, RT-based findings seem to be influenced by ODD comorbidity. Children in the ADHD-only group did not differ from the other children in terms of the efficiency of executive attention, whereas children with comorbid ODD did. In specific, they showed higher executive attention scores than TD children and children with ASD, reflecting less efficient executive attention only in children with ADHD+ODD as compared to other children.

In order to evaluate specific self-regulatory processes preceding and following the behavioral outcome in terms of flanker-performance (i.e., RT, %EOC), we included ERP measures of executive attention in the present study. In specific, we focused on the stimulus-locked N2 and P3 and on the response-locked ERN/CRN.

As to be expected when it is related to conflict processing, the N2 component was enhanced for incongruent trials in comparison with congruent trials (e.g., Van Veen & Carter, 2002; Yeung, Cohen, & Botvinick, 2004). This enhancement of the N2 for incongruent trials is generally explained in terms of conflict monitoring in that it reflects the process of detecting conflict and alerting systems involved in top-down control to resolve the conflict (e.g., Van Veen & Carter, 2002). Given that this N2 congruency-effect did not differ between groups, our results seem to suggest that all groups were equally able to successfully attend to the target and detect conflicting information provided by the flankers. This fits well with our finding that the groups did not differ in terms of the number of incorrect responses on incongruent trials. Furthermore, this result is in agreement with previous findings on the flanker N2 in ASD (Tsai et al., 2011) and in line with some previous studies on the N2 in ADHD (e.g., Johnstone & Galletta, 2013; Kratz et al., 2011), but in contrast to others that showed either a general (e.g., Wild-Wall et al., 2009) or an incongruency-specific decrease in N2 amplitude (e.g., Albrecht et al., 2008; Johnstone et al., 2009; Johnstone et al., 2010) in ADHD as compared to TD peers. A possible explanation for these inconsistent findings may lie in sample characteristics and, in specific, in the heterogeneous ADHD sample used in the present study. Whereas most studies that found decreased N2 amplitudes only focused on children with ADHD combined type, we also included children with primarily inattentive type (ADHD-IA) and primarily hyperactive/impulsive type (ADHD-HI). One might argue that the decreased N2 is perhaps less present in children with ADHD-IA which may have obscured differences that were present in the combined group. To the best of our knowledge, only one study so far compared both subtypes on the flanker N2 (Kratz et al., 2011) and found no subtype differences in terms of the N2 conflict-effect. Additional analyses including only children with ADHD-combined type (*n* = 12) yielded the same results as those obtained for the original ADHD-group. Furthermore, analyses comparing ADHD-IA (*n* = 9) and ADHD-combined type for N2 amplitude, revealed no group differences (or group interactions). Although results must be interpreted with caution given the limited sample sizes of the ADHD-subgroups, they are in agreement with findings of Kratz and colleagues (2011) and suggest that the inclusion of different ADHD subtypes does not account for our findings. Up till now, a very limited number of studies have focused on the impact of ODD/CD comorbidity on physiological measures in ADHD. Findings are mixed, but suggest that, in some cases, the presence of comorbid ODD/CD may have an influence on ERP findings (e.g., Banaschewski et al., 2003; Overtoom et al., 1998; Wiersema et al., 2006). Additional analyses taking comorbid ODD into account yielded identical results in that neither the ADHD-only nor the ADHD+ODD subgroup differed from the other groups in terms of the N2 amplitude. Therefore, it seems unlikely that allowing comorbid ODD in our ADHD group influenced our findings in terms of the N2.

Although groups did not differ in terms of the N2 amplitude, we did find a group difference for the P3 in that the conflict-specific P3 effect (i.e., larger amplitude for incongruent trials as compared to congruent trials) was missing in children with ADHD. In the literature, enhanced P3 amplitudes to incongruent stimuli are generally explained as extra effort allocation (e.g., Banaschewski et al., 2005; Johnstone et al., 2010) needed to respond correctly to conflicting information. In terms of the effort allocation theory of the P3 (Johnstone & Galletta, 2013) and keeping in mind that incorrect responses are not taken into consideration when calculating group P3 averages, our findings suggest that TD children and children with ASD but not children with ADHD were able to allocate extra effort in order to correctly respond to incongruent trials. The fact that we found no group differences in the P3 amplitude or the P3 congruency effect between TD children and children with ASD is in line with previous findings (Tsai et al., 2011). Our finding that the P3 congruency effect was missing in ADHD is in line with some previous studies (e.g., Wild-Wall et al., 2009), but in contrast to others (e.g., Johnstone et al., 2010) that found no group differences in conflict-effect between TD children and children with ADHD. Given that stimulus modality has no significant effect on P3 amplitude (Szuromi, Czobor, Komlósi, & Bitter, 2011), it appears implausible that differences in flanker-stimuli (arrow heads and equals signs in the study of Johnstone and colleagues (2010) vs. arrow heads in the current study) account for the mixed findings. An alternative explanation may lie in sample characteristics. Although our participants were older (10-15 years) than the children participating in the study of Johnstone and colleagues (2010, 7-14 years), we do not believe that age-differences can account for our findings based on previous studies showing that P3 amplitudes increase with age and that this developmental change is not significantly affected by the presence of ADHD (e.g. Liotti et al., 2007). However, Johnstone and colleagues excluded children with ADHD and comorbid behavioural disorders. Given that we included children with comorbid ODD in our ADHD group, we performed additional analyses to evaluate whether or not this influenced our findings. Further analyses showed that our original finding in terms of a missing conflict-effect for the P3 in ADHD, was entirely attributable to the ADHD+ODD group. In all, our findings show that TD children, children with ASD, and children with ADHD appeared to be *able* to allocate extra effort in order to respond correctly to incongruent trials whereas children with ADHD+ODD were not.

With respect to response-locked ERPs, children with ADHD tended to show a reduced ERN as compared to TD peers. However, this reduction was also present for correct trials (CRN). The fact that an ERN-like negativity is sometimes observed after a correct response is not unusual and it has led Falkenstein and colleagues (2000) to conclude that the ERN in fact represents the process of 'response checking' (i.e., the comparison between the actual response and the required response), rather than error detection. The CRN would then be explained by the fact that on some correct trials, the representation of the required response was not present (e.g., there was some uncertainty about which button to press; in this case, the correct response would have been a lucky guess), resulting in an 'ERN' caused by a mismatch between the (correct) response and the incorrect or absent response representation. In terms of this hypothesis, our results seem to suggest that in children with ADHD this process of 'response checking' was less pronounced than in TD children, indicating a general reduction of response monitoring in ADHD which could account for the fact that the ADHD group made more errors than the TD group. The lack of a group-effect in terms of ERN/CRN difference scores is in line with some previous studies (e.g., Jonkman et al., 2007b; Wild-Wall et al., 2009), but in contrast to others (e.g., Albrecht et al., 2008; Van Meel et al., 2007). Given that the flanker-task used in the current study was very similar to the one administered by Albrecht and colleagues (2008) and van Meel and colleagues (2007), it seems unlikely that task characteristics can account for inconsistent findings. Additional analyses showed that ADHD-subtype or ODD-comorbidity had no impact on the results, suggesting that also these sample-characteristics cannot account for the mixed findings. It is possible that ERN/CRN differences are simply not universally present in all children with ADHD or that they are influenced by other factors, not included in the present study. Future studies will have to further address this issue.

An important limitation of the present study needs to be addressed, namely the limited (sub)sample sizes. Our findings illustrated the importance of taking into account ADHD-comorbidities when interpreting findings on executive attention. However, the limited number of participants in the ADHD-subgroups (ADHD-only vs. ADHD+ODD) made it difficult to do an in depth analyses of the exact nature of the effects of comorbid ODD on (ERP) findings in ADHD. Similarly, although our findings clearly illustrated that the relationship between EC and executive attention differs between groups, limited group-sizes confined us in our ability to fully explore the exact nature of these differences.

Future research will have to replicate our findings in larger (sub)samples. Furthermore, for future work, we would like to stress the importance of taking into account comorbidities while interpreting findings on ADHD. In order to disentangle the differential/additive effect of comorbid ODD in ADHD in terms of the efficiency of executive attention processes, it will be essential to include ADHD-only, ADHD+ODD as well as ODD-only samples.

To conclude, despite the strong theoretical link between EC and executive attention we were unable to find high, consistent correlations between both constructs in our total group. Additional findings suggest that the (magnitude of the) relationship between EC and executive attention ERPs differs between groups and depends on the EC scales considered. Overall, indices of error monitoring (ERN/CRN difference scores) showed the most robust findings across groups and indicate that higher levels of EC were associated with better performance monitoring. In addition, performance-based data revealed that children with ADHD+ODD, but not children with ADHD-only, showed less efficient executive attention in comparison with TD children and children with ASD. The ERP findings suggest that all children were equally able to successfully attend to the target and detect conflicting information provided by the flankers. Also, all children except children with ADHD+ODD were able to allocate extra effort in order to respond correctly to conflicting information. Finally, we found evidence for a general reduction of response monitoring in ADHD as compared to TD children.

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Tables

Table 1 Descriptive information on the EC questionnaires and the flanker task for the three subgroups.

Table 2 Bivariate correlations between EC scales and amplitude difference scores for the N2, P3, and ERN for the total group.

Table 3 Bivariate correlations between EC scales and amplitude difference scores for the N2, P3, and ERN for the three subgroups.

Figure captions

Fig. 1. Scatterplots of the correlation between the ERN and CRN mean amplitude difference score and the attention focusing scale of the ACS (a) and between the ERN and CRN mean amplitude difference score and the total scale of the ACS (b).

Fig. 2. Grand average stimulus-locked ERPs at Fz and FCz for the three groups to congruent (full line) and incongruent (dotted line) stimuli.

Fig. 3. Grand average stimulus-locked ERPs at Cz, CPz, and Pz for the three groups to congruent (full line) and incongruent (dotted line) stimuli.

Fig. 4. Grand average response-locked ERPs at Fz and FCz for the three groups to correct (full line) and incorrect (dotted line) responses.

Table 1

Descriptive information on the EC questionnaires and the flanker task for the three subgroups.

Measures		TD (*n* = 21)	ASD (*n* = 20)	ADHD (*n* = 24)	Group differences
		M(SD)	*M(SD)*	*M(SD)*	*F*(2,62)
Parent-rated EC					
EATQ-R	Total	3.45(0.57)[a]	2.48(0.60)[b]	2.50(0.53)[b]	21.01***
	Inhibitory control	3.85(0.60)[a]	2.80(0.79)[b]	2.80(0.44)[b]	20.39***
	Activation control	3.01(0.91)[a]	2.24(0.84)[b]	2.46(0.85)[a,b]	4.35*
	Attentional control	3.65(0.64)[a]	2.48(0.60)[b]	2.29(0.49)[b]	35.68***
Child-rated EC					
ECS	Total	85.71(9.92)[a]	73.55(13.06)[b]	71.88(12.28)[b]	8.80***
	Pers./low distr.	47.81(5.52)[a]	38.45(6.93)[b]	39.25(7.86) [b]	11.99***
	Impulsivity	37.90(6.27)[a]	35.10(7.10)[a,b]	32.63(6.73)[b]	3.48*
ACS	Total	54.19(9.11)[a]	44.85(7.53)[b]	43.46(6.06)[b]	12.73***
	Focusing	24.05(4.18)[a]	21.25(3.48)[a]	17.79(3.50)[b]	15.93***

	Shifting	30.14(5.94)[a]	23.60(5.17)[b]	25.67(3.84)[b]	9.27***
EATQ-R	Total	3.48(0.59)[a]	3.01(0.44)[b]	2.91(0.57)[b]	6.90**
	Inhibitory control	3.46(0.59)[a]	3.17(0.66)[a, b]	2.89(0.55)[b]	4.97**
	Activation control	3.20(1.01)[a]	2.69(0.88)[a]	2.84(0.91)[a]	1.61
	Attentional control	3.75(0.57)[a]	3.15 (0.57)[b]	2.99(0.64)[b]	9.64***
Behavioral measure					
Flanker task	mRT congruent	450.80(68.56)[a]	450.99(55.48)[a]	485.11(109.08)[a]	1.29
	mRT incongruent	524.09(73.43)[a]	515.49(71.04)[a]	581.55(160.09)[a]	2.28
	Executive attention - RT	73.30(24.70)[a]	64.50(26.33) [a]	96.43(76.45) [a]	2.36
	%EOC congruent	3.19(3.33)[a]	7.06(8.04)[a,b]	9.23(10.16)[b]	3.36*
	%EOC incongruent	13.26(9.03)[a]	15.70(10.65)[a]	19.33(10.34)[a]	2.09
	Executive attention - % EOC	10.07(6.52) [a]	8.64(6.38) [a]	10.10(6.88) [a]	0.33

Note. Pers./low distr. = Persistence/low distractibility; % EOC = percentage errors of commission. *P*-values are derived from one-way ANOVA. Superscripts reflect subgroup differences derived from post-hoc Bonferroni Test; different letters indicate differences between particular groups, identical letters indicate that there were no differences between those particular groups.

*p < .05.

**p < .01.

***p < .001.

Table 2

Bivariate correlations between EC scales and amplitude difference scores for the N2, P3, and ERN for the total group.

		ERPs		
Questionnaires		N2	P3	ERN
Parent-rated				
EATQ-R	Total	.003	.085	-.314*
	Inhibitory control	-.019	.197	-.106
	Activation control	.004	-.049	-.323*
	Attentional control	.014	.125	-.309*
Child-rated				
ECS	Total	.097	-.021	-.183
	Pers./low distr.	.014	.042	-.196
	Impulsivity	.167	-.088	-.118
ACS	Total	.167	.066	-.366**

	Focusing	.062	.093	-.333**
	Shifting	.215	.030	-.304*
EATQ-R	Total	.103	.061	-.379**
	Inhibitory control	.052	.117	-.305*
	Activation control	.086	.006	-.312*
	Attentional control	.095	.042	-.273*

Note. Pers./low distr. = Persistence/low distractibility; N2 = mean amplitude difference score (incongruent – congruent) for the cluster Fz and FCz; P3 = mean amplitude difference score (incongruent – congruent) for the cluster Cz, CPz, and Pz; ERN = amplitude difference score (incorrect – correct) for the cluster Fz and FCz.

|r| .01 – 0.3 = small; |r| 0.3 – 0.5 = medium; |r| > 0.5 = large (Cohen, 1988).

*p < .05.

**p < .01.

Table 3

Bivariate correlations between EC scales and amplitude difference scores for the N2, P3, and ERN for the three subgroups.

		ERPs								
		N2			P3			ERN		
Questionnaires		TD	ASD	ADHD	TD	ASD	ADHD	TD	ASD	ADHD
Parent-rated										
EATQ-R	Total	.081	.019	.110	-.333	-.104	.059	.029	-.619**	-.216
	Inhibitory control	-.149	.368	-.122	.049	.210	-.128	.240	-.179	-.089
	Activation control	.201	-.257	.057	-.393	-.247	.141	-.058	-.599**	-.271
	Attentional control	-.012	.071	.333	-.271	-.139	-.009	-.002	-.678**	-.096
Child-rated										
ECS	Total	.180	-.113	.372	-.285	.000	-.250	.031	-.287	-.090
	Pers./low distr.	.092	-.241	.270	-.157	-.071	-.111	-.024	-.240	-.174
	Impulsivity	.203	.027	.363	-.313	.070	-.326	.072	-.294	.040
ACS	Total	.201	.326	.276	-.083	.032	-.260	-.497*	-.273	-.153

	Focusing	.187	-.038	.200	-.144	-.140	-.125	-.321	-.302	-.266
	Shifting	.177	.501*	.252	-.027	.141	-.296	-.532*	-.196	.000
EATQ-R	Total	.204	-.05	.225	-.117	-.087	-.041	-.371	-.373	-.335
	Inhibitory control	.143	.152	-.032	.100	.057	-.138	-.395	-.213	-.214
	Activation control	.175	-.099	.176	-.064	-.112	.020	-.225	-.292	-.422*
	Attentional control	.170	-.123	.347	-.313	-.090	-.022	-.372	-.191	-.149

Note. Pers./low distr. = Persistence/low distractibility; N2 = mean amplitude difference score (incongruent – congruent) for the cluster Fz and FCz; P3 = mean amplitude difference score (incongruent – congruent) for the cluster Cz, CPz, and Pz; ERN = amplitude difference score (incorrect – correct) for the cluster Fz and FCz.

$|r|$ 0.3 – 0.5 = medium; $|r| > 0.5$ = large (Cohen, 1988).

*$p < .05$.

**$p < .01$.

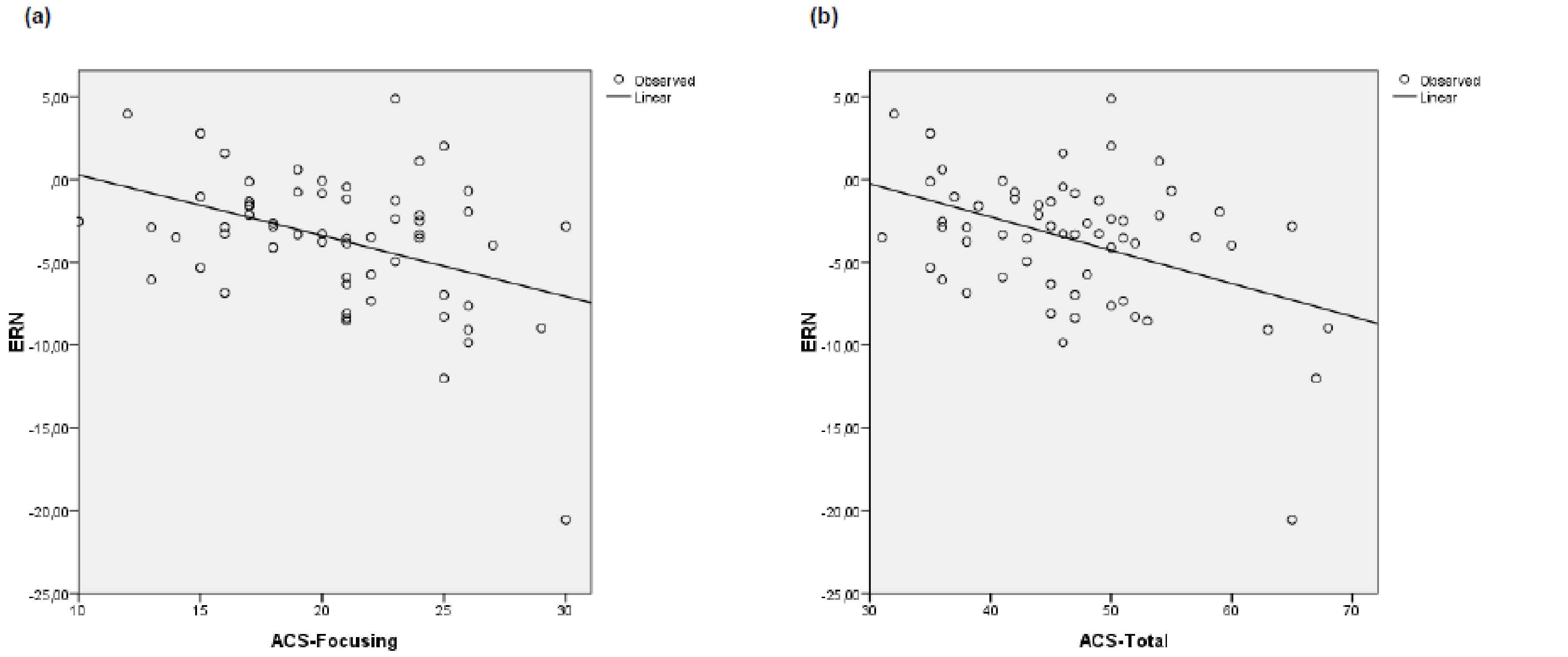

Fig. 1. Scatterplots of the correlation between the ERN and CRN mean amplitude difference score and the attention focusing scale of the ACS (a) and between the ERN and CRN mean amplitude difference score and the total scale of the ACS (b).

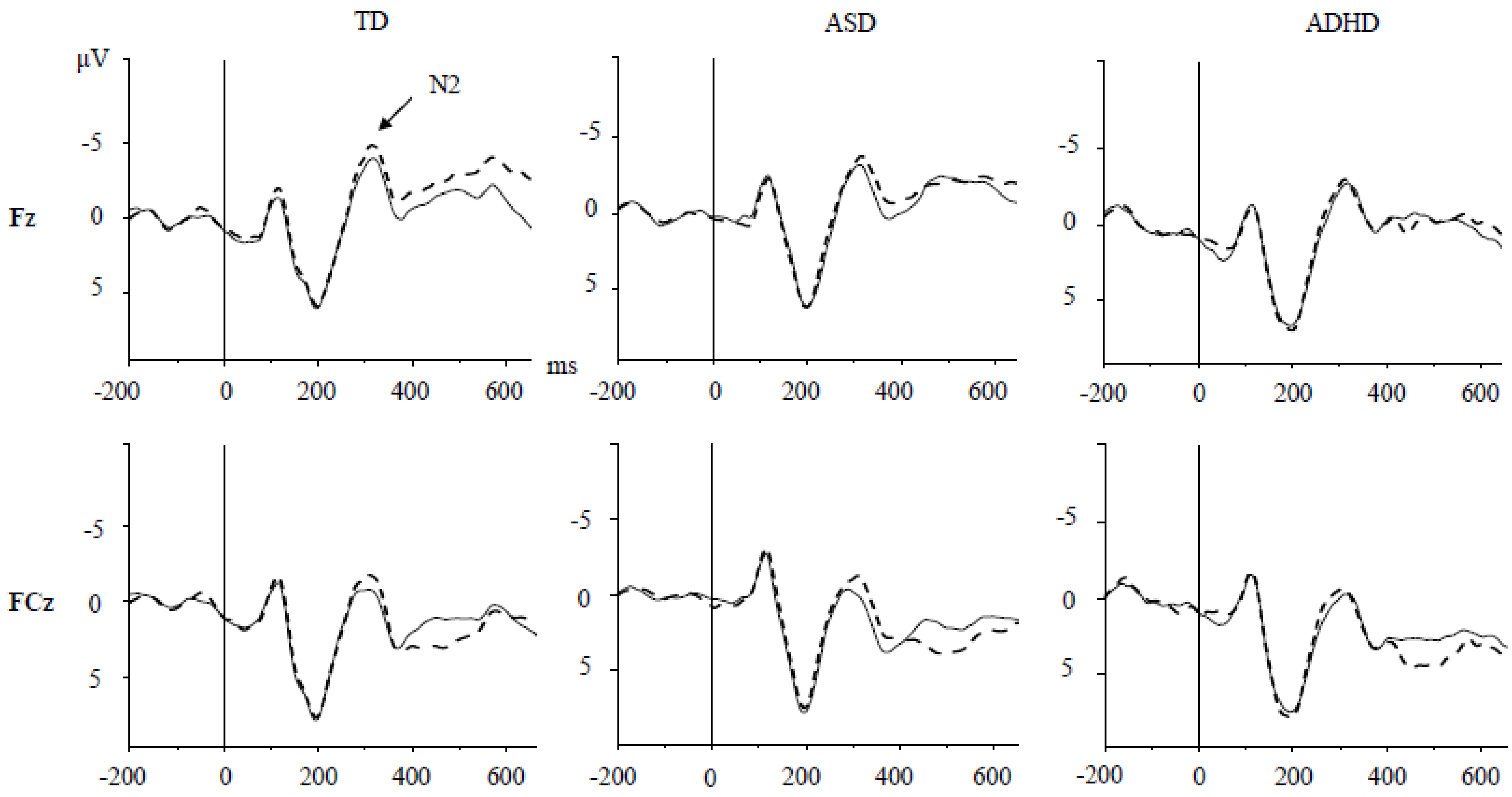

Fig. 2. Grand average stimulus-locked ERPs at Fz and FCz for the three groups to congruent (full line) and incongruent (dotted line) stimuli.

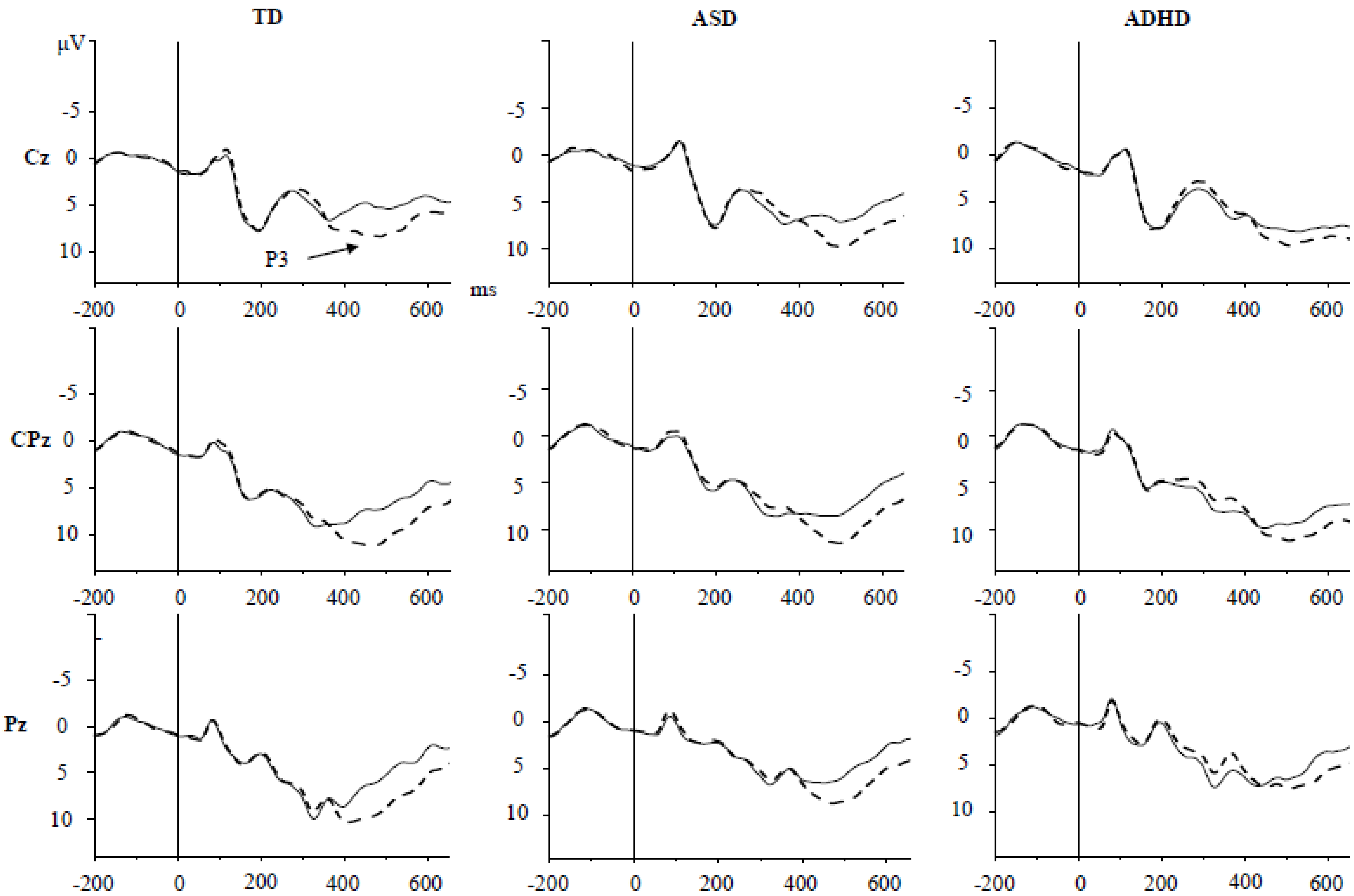

Fig. 3. Grand average stimulus-locked ERPs at Cz, CPz, and Pz for the three groups to congruent (full line) and incongruent (dotted line) stimuli.

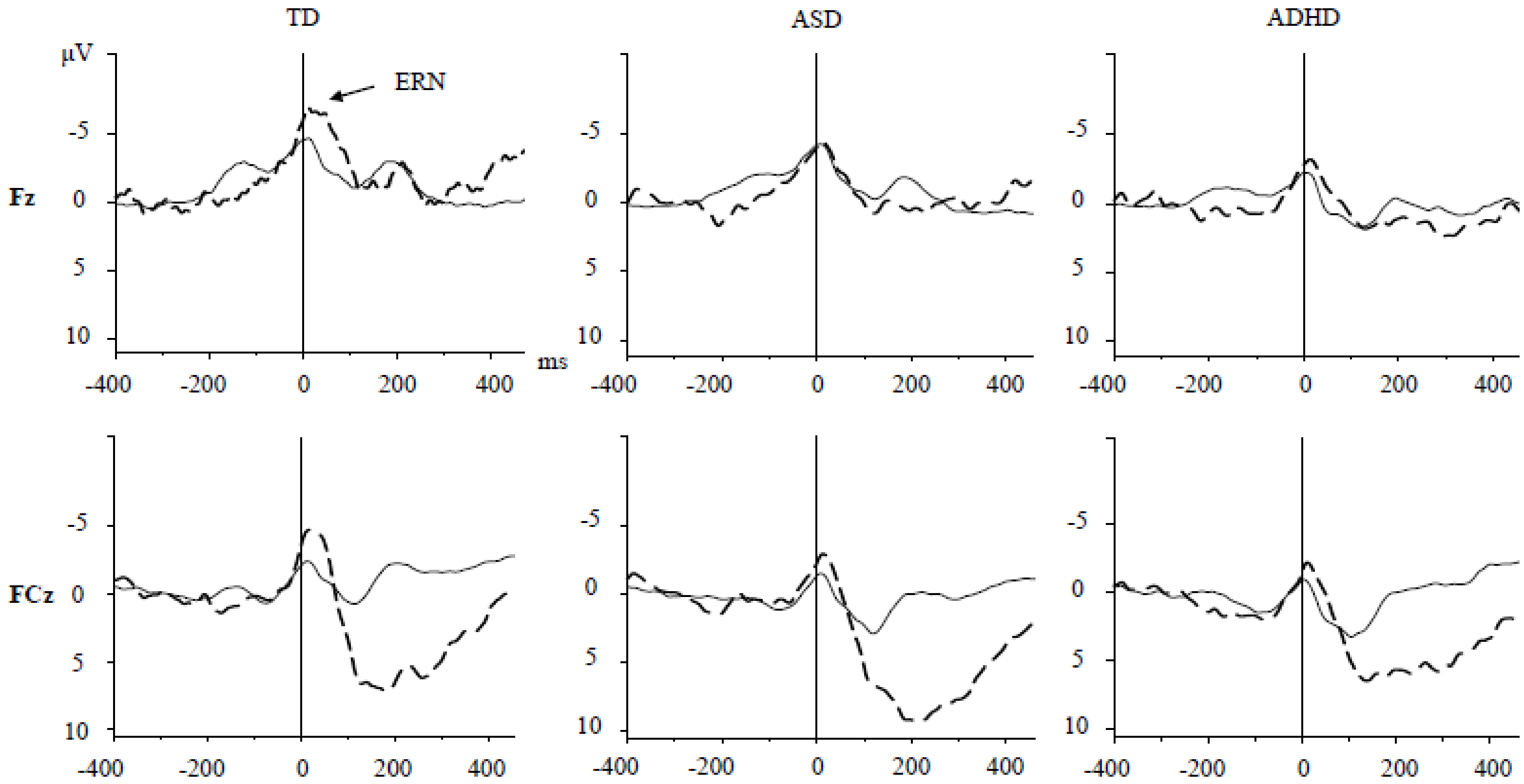

Fig. 4. Grand average response-locked ERPs at Fz and FCz for the three groups to correct (full line) and incorrect (dotted line) responses.