The Role of Effort Allocation in Error Monitoring Abilities in People with Varying Levels of ADHD

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Abstract

Attention-Deficit/Hyperactivity Disorder is a disorder characterized by attention deficits and/or impulsivity and hyperactivity. It also seems to be associated with several cognitive impairments, including poor error monitoring. While healthy adults slow down their responses after an error to increase the chance of getting a correct response, ADHD patients don't seem to do this. A model called the state regulation model tries to explain such cognitive deficits by stating that people with ADHD do not allocate enough effort to compensate for under- and overactivation during tasks. The aim of the present study was to investigate error monitoring in people with varying levels of ADHD symptoms and to see if poor effort allocation could explain a possible deficit in this skill. To examine this, 46 participants performed a task-switching paradigm with a fast, medium and slow presentation rate of stimuli. The performance of all participants on post-error slowing and post-error accuracy were compared across the three event rates. The results showed no significant differences between participants on post-error slowing and post-error accuracy in general and across the event rates. In this study, no evidence was found of error monitoring difficulties or poor effort allocation in patients with ADHD.

Keywords: State regulation model, effort allocation, Attention-Deficit/Hyperactivity Disorder, error monitoring

The Role of Effort Allocation in Error Monitoring Abilities in People with Varying Levels of ADHD

Attention-Deficit/Hyperactivity Disorder is a disorder characterized by attention deficits and/or impulsivity and hyperactivity. These two domains all consist of several symptoms. The category of inattention symptoms consists of 9 symptoms, including 'making careless mistakes' and 'often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort'. The category of hyperactivity and impulsivity also consists of 9 symptoms, including having trouble with waiting on their turn. People with ADHD may show predominantly symptoms of one of these categories or of both (American Psychiatric Association [APA], 2013).

ADHD is a risk factor for (Sayal et al., 2018) and a highly comorbid disorder with various disorders (Onandia-Hinchado et al., 2021). Having ADHD also heightens the risk for negative outcomes such as ''defiant, disruptive, and antisocial behaviours, emotional problems, self-harm, and substance misuse as well as broader negative outcomes, including educational underachievement and exclusion from school, difficulties with employment and relationships, and criminality.'' (Sayal et al., 2018, p. 175).

ADHD is also associated with cognitive impairments. These seem to change with age (Das et al., 2014). One study suggests however that energetic and motivation factors might also have an influence, meaning that the deficits in cognitive performance may not reflect true deficits in cognitive abilities (Kuntsi et al., 2009). A systematic review (Onandia-Hinchado et al., 2021) found problems in various cognitive domains. In this study I will be mainly looking at the domain of executive functions, specifically at error monitoring.

Effort Allocation in ADHD

There are many models that try to explain why these cognitive deficits occur in people with ADHD. One of these is the state regulation model. It was based on the cognitive-energetic model. The model states that task efficiency depends on decisions made by evaluation mechanisms and energy distributions. Here an evaluation mechanism checks and evaluates the current levels of arousal (required for stimulus processing) and motor activation (required for preparing and executing motor responses). When one of these seems to be suboptimal, an effort mechanism compensates this by activating or inhibiting the arousal and activation energetic resources (Van der Meere, 2005). According to the state regulation model, the motor activation is influenced by the presentation rate of stimuli (Sanders, 1998). When the stimulus presentation rate is low, extra effort allocation is needed to raise their activated state, and when stimulus presentation rate is high, extra effort allocation is needed to decrease their activated state (Sanders, 1998; Wiersema et al., 2006). While healthy children and adults can adjust easily to different tasks and the activation levels needed, ADHD patients can’t (Wiersema et al., 2006). For this clinical group, the slow condition leads to underactivation and consequently inaccurate responses. In the fast condition, the patients can get overactivated leading to fast inaccurate response (Van der Meere et al., 1999; Van der Meere et al., 2010). Many studies have supported this model (Wiersema et al., 2005; Wiersema et al., 2006; Winter et al., 2019; Drescher et al., 2021), though not all (Ketch et al., 2009; Raymaekers et al., 2007). A meta-analysis by Metin et al. (2012) found significantly higher reaction times of people with ADHD compared to control groups in the slow event rate and significantly lower accuracy of ADHD patients compared to control groups in the fast event rate. Both support the hypotheses of the state regulation model and are indicative of an impairment in effort allocation.

Error monitoring in ADHD

Error monitoring consists of detecting and evaluating errors as they arise and subsequently adjusting responses in order to prevent disagreeable actions and to perform tasks optimally (Groom et al., 2010; Wiersema et al., 2007). To increase the response accuracy after an error, participants have to slow down their responses (post-error slowing). People with ADHD, however, don’t seem to engage in error monitoring. In a meta-analysis an overall effect was found of ADHD patients showing significantly less post-error slowing and more errors than control groups (Balogh & Czobor, 2016).

Effort allocation and error monitoring in ADHD

The meta-analysis by Balogh & Czobor (2016) also found a relation between post-error slowing and effort allocation. When the interstimulus time was longer (the event rate is slower) the ADHD group showed decreasing PES and the control group increasing PES. One study about the role of effort allocation in error monitoring in ADHD (Mohamed et al., 2016) patients found that there was diminished post error slowing, meaning impaired error monitoring as a result of poor effort allocation.

The present study

The present study builds further on the research of Mohamed et al. (2016) aiming to investigate error monitoring and the role of effort allocation in this cognitive function in people with differing levels of ADHD symptoms.

This study will also aim to address this in the general population rather than the clinical population by using a dimensional approach. This entails participants being gathered with ADHD scores across the whole continuum. This is seen as a strength of this compared to other studies who have used a clinical and control sample. Studies showed that the dimensional approach fits better with the distribution of ADHD scores in real life (Marcus & Barry, 2001). Furthermore, as ADHD is a highly comorbid disorder, including participants with an ADHD diagnosis, will increase the chance of them having another disorder compared to participants that do not have a diagnosis. This could have a negative effect on the outcome.

Using the dimensional approach, therefore lowers this chance.

To look at these variables, a task-switching paradigm was used. In this task, participants have to switch between categorising a colour or a shape. While the Go/No-Go task is frequently used to assess error monitoring (Balogh and Czobor, 2016) as well as effort allocation (Metin et al., 2012) in patients with ADHD, the task-switching paradigm seems a suitable task to research these two cognitive processes as well. The success of the GNG task to test the state regulation model hypotheses seems to be dependent on the possibility of calculating the main variables needed to test them. These include mean reaction time (MRT), response time variability and commission and omission errors (Metin et al., 2012). For the task-switching paradigm, these variables can also be studied, which makes the task a good option. Furthermore, more complex processes seem to play a role in the task-switching task (Crone et al., 2006), making it an interesting one to study.

To assess error monitoring, post-error slowing and post-error accuracy will be investigated. To measure post-error slowing, the reaction time of post-correct and post-error trials will be compared. For post-error response accuracy, the amount of correct responses after an error and after a correct response will be compared. Effort allocation will be measured using an interstimulus interval. Three event rates were used (slow, medium and fast) enabling an examination of quadratic effects (Drescher et al., 2021). In this way, both the underactivation and overactivation can be studied.

In this study, I hypothesize that (1) people with higher levels of ADHD will perform worse on the task in the fast and slow event rate compared to people with lower levels of ADHD (Drescher et al., 2021); (2) people with higher levels of ADHD will low show less post error slowing than people with lower levels of ADHD in general (Balogh & Czobor, 2016); (3) people with higher levels of ADHD will show less post error slowing in the fast and slow condition compared the medium condition (Mohamed et al., 2016).

Methods

Participants

For the following study, all data was collected from an archive from the Department of Clinical and Developmental Psychology from the University of Groningen. Of a total of 50 participants, 20 males, 29 females and 1 unknown, three were excluded due to lack of participation on one of the measures (Conners' Adult ADHD Rating Scales, CAARS) and one was excluded due to lack of participation on all questionnaires. Further exclusion criteria will be mentioned in the results section. The participants were recruited via a convenience sampling method operationalized by "SONA", the software, of only first-year psychology students of the University of Groningen. With a mean age of 19.67 (1.85), the gender ratio was of 1.7 for females, with 37% males (17 in total) and 63% females (29 in total) (see table).

The 46 remaining participants were further asked about relevant mental disorder diagnoses received prior to the research. Thirteen participants chose to refrain from providing information on this matter. Additionally, three participants stated having been diagnosed with ADHD and/or ADD prior to research. Furthermore, participants also reported whether they had been diagnosed with any comorbid disorder from a list of: (any form of) Depression disorder, (any form of) Anxiety disorder, (any form of) Stress disorder, Dyslexia and (any form of) Motor disorder. A total of 17 people reported holding at least one of the abovementioned diagnoses with 7 stating comorbidity of at least two disorders. With comparative performance deficits between people with ADHD and people with the abovementioned disorders (Kim et al., 2019; Mendl, 1999; Moores et al., 2003; Treadway et al., 2012; Yang et al., 2014) it could be relevant to understand how these disorders affect the research. However, due to inconsistencies in the participants statements regarding age related diagnosis as well as disorder expression, the abovementioned comorbidities can be suspect of invalidity. Thus, only those with a reported ADHD diagnosis will be further investigated.

Materials

CAARS

In order to measure the participants' symptom levels, the long form of CAARS questionnaire was used. The questionnaire was conducted online and operationalized through Qualtrics (Qualtrics, 2005), software which then stored the data. This consists of 66 items rated on a 4-point scale (0 = not at all, never; 1 = just a little, once in a while; 2 = pretty much, often; 3 = very much, very frequently). Each item is attributed to one or more of the 8 scales embedded: A, Inattention/Memory Problems; B, Hyperactivity/Restlessness; C, Impulsivity/Emotional Lability; D, Problems with Self-concept; E, DSM-IV Inattentive Symptoms; F, DSM-IV Hyperactive-Impulsive Symptoms; G, DSM-IV ADHD Symptoms Total; and H, ADHD Index). The E, F and G scales group similar symptom expressions in order to identify ADHD symptoms, in accordance with DSM-IV (APA, 2013). For this research, there will be a focus on scale H (ADHD Index) since this scale provides an overall ADHD symptom score that can be illustrative of individual symptom experience. This scale provides a t-score pertaining to how common a participant's symptom expression is in relation to their age and gender (4 categories of age for male and 4 categories of age for female). The CAARS has been deemed highly reliable with only few face validity concerns associated with self-report measures (see Erhardt et al., 1999; Macey, 2003, Suhr et al., 2017).

Task-Switching

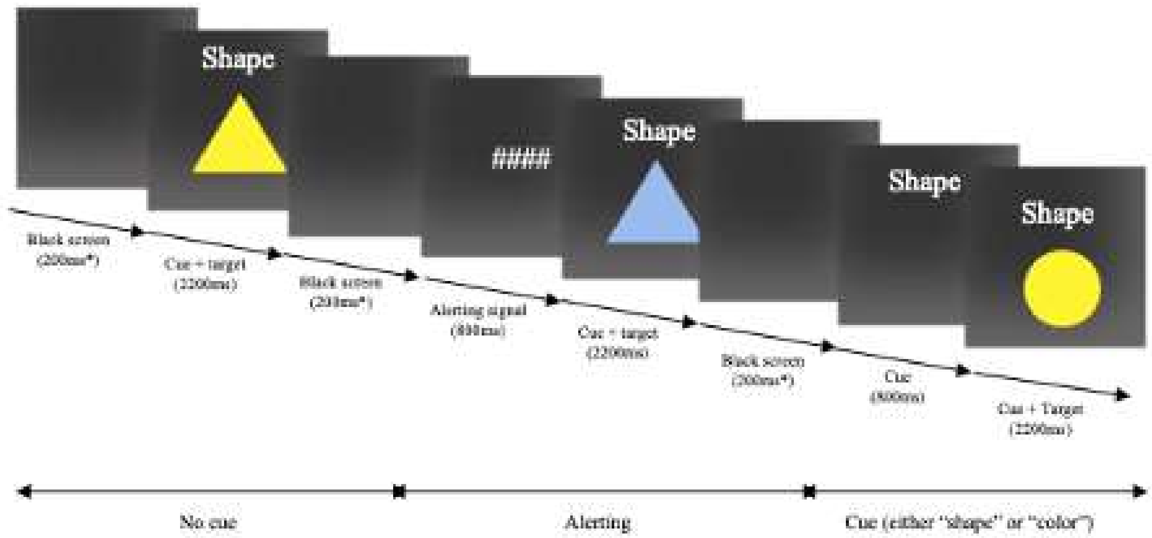
The task-switching paradigm was created with OpenSesame (version 3.2) (Mathôt et al., 2011) and then hosted by Jatos server (Lange et al., 2015). Then, this software further stored the collected data. It consisted of two blocks (unmixed and mixed block) in which the participants had to categorize objects in terms of color or shape. For the unmixed block, a sequence of trials requiring categorization according to color would only ask for shape or color at a time. For the mixed block, instructions would vary and ask randomly for categorization according to color or shape. The instructions were given in the following way: You will see a geometric shape of circle or triangle in blue or yellow colour. Above the geometric shape, you will also see either the word “shape” or the word “colour”. If you see the word “shape”, press “m” = triangle shape, press “z” = circle shape. If you see the word “colour”, press “m” = blue colour, press “z” = yellow colour. Respond as fast and accurately as possible. Note. For some trials the word “shape” or “colour” will precede the presentation of the geometric shape. For other trials, no word or few hashtags “#####” will precede the presentation of the geometric shape. Press any key to see an example of stimulus presentation.

In this way, first the participants were given time to practice (14 trials). A cue was presented for 0.8 seconds per trial. Then, the stimulus (either shape or color) was presented for 2.2 seconds, along with feedback for 1 second, and an interval for 2 seconds. In the real experiment, the cue and stimulus were present the same amount of time as in the practice trials, though there was no feedback and the interval occurred for a varying amount of time. The interval depended on one of the three conditions (slow would have 2 seconds, medium would have 0.8 seconds and fast would have 0.2 seconds). In total, the fast condition included around 102 trials, the medium condition included 66 trials and the slow condition included 30 trials for each of the two blocks. To address the differing trial number, the “error rate” is calculated and explained in the data analysis. For this study, the focus was on the unmixed block with no particular distinction between the three different cue conditions as these were irrelevant for the hypotheses of this research. The event rate (slow, medium and fast) was the main aspect investigated in the task as this was the operationalized effort allocation.

Corresponding errors and mean reaction times in the performance on these tasks were used to analyse error monitoring.

Figure 1

Schematic presentation of the task-switching paradigm



Note. The figure above intends to illustrate the order and time frame of each slide that was presented to the participants. However, it was adapted for readability purposes and so, the font and shape sizes are not accurate to the original task.

*Time frame attributed to the "Black Screen" slide is dependent on the Event Rate condition. In the figure above, this slide is presented for 200ms which corresponds to the fast condition. For the slow condition this slide appeared for 8000ms. For the medium condition the slide appeared for 3000ms.

Procedure

The study was approved by the Ethical Committee of Psychology of the University of Groningen. Due to ongoing external limitations, the study was fully conducted online. First, participants gave informed consent for participating. Then, the participants that decided to participate in the study, were asked to fill in two questionnaires: the CAARS and the Weiss

Functional Impairment Rating Scale (WFIRS). They were also asked to indicate if they had any of the following disorders: ADHD, ADD, depressive disorder, anxiety disorder, stress, dyslexia or motor disorder and if they had it during childhood or adulthood. They were also asked about their age, gender and any use of medication. After filling out the questionnaires, they had to perform two online reaction time tasks: the task switching paradigm and the Stroop task. The order of these two was randomized. For each task (condition), participants first did several practice trials before starting the actual task. The participants were given the opportunity to take two 5-minute breaks to separate conditions within each task. If chosen to take these breaks, each task would have taken 44 minutes (either the Stroop task or the task-switching task). Due to the length of the experiment, the study was divided into two sessions. The WFIRS and Stroop task were part of a bigger study and will not be used in this specific study. After filling out the questionnaires, the participants were given a debriefing sheet regarding the true intentions of the study as well as emotional support.

Data analysis

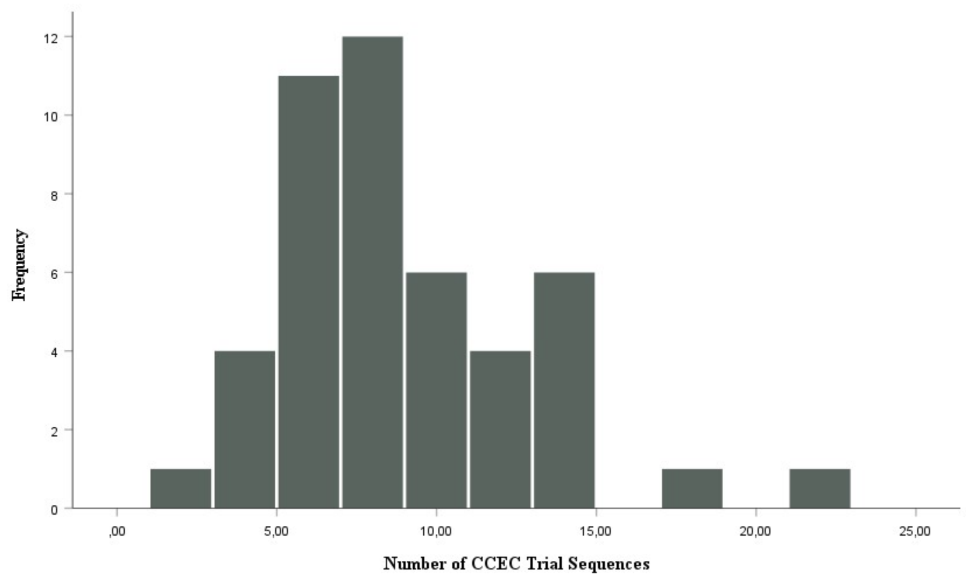
Preparation of the data for error monitoring

First, the amount of correct and incorrect responses were counted per stimulus presentation rate per participant and per participant in general. Due to the differences in number of trials between the fast, medium and slow event rate the error rate was computed. This was done by dividing the amount of errors by the amount of trials. This gives a better picture of the accuracy of each participant. Mean Reaction Time was also calculated per event rate, participant and both together.

With these, the Traditional Post-Error Slowing (PES) and then Robust PES were calculated. For the prior mentioned, MRTs of correct answers following an error (EC) and MRTs of correct answers following a correct response (CC) were computed. This way the difference between the two should reveal whether a participant demonstrated PES in comparison to the speed at which they responded after having a correct response (see Dutilh et al., 2012 for thorough explanation of both calculations of PES).

For the Robust PES, instances of CCEC trial sequences were counted when (1) the trial of focus had an incorrect response, (2) the two trials before had correct responses and (3) the trial after also had a correct response. Subsequently, the reaction time of the post-error was subtracted from the reaction time of the pre-error. This was calculated for each participant on the different event rates and overall. For robust in general, there is a mean of 8.41 trials with a standard deviation 3.89. The distribution of trials can be seen in Figure 2. Using Mohamed et al.'s (2016) 10-trial reference, the amount of trials were too little to be able to compute a trustworthy mean. Therefore, both the traditional and the robust method will be used in order to get a better understanding of post-error slowing.

Figure 2



Note.

A significant difference between Post-Error Accuracy (PEA) and Post-Correct Accuracy (PCA) would mean that the (possible) slowing down of a participant after making an error would lead to getting an accurate response during the next trial. PEA was calculated by dividing the amount of times an error was followed by a correct response (EC) by the total amount of errors. PCA was calculated by dividing the amount of times a correct response was followed by another correct response by the total number of correct responses. PCA and PEA were also computed for each participant on the different event rates and overall.

Task manipulation

To validate whether the task manipulation was successful, a comparison of the mean reaction times (MRTs) per event rate condition was made through Repeated Measures ANOVA. To check whether this measure was appropriate, assumptions were checked. For normality, a Shapiro Wilk test (Shapiro & Wilk, 1965) was conducted and it evidenced a violation in the distribution of the fast condition (p = .01). According to the Central Limit Theorem, when the sample size is large enough ($N > 30$, with the current sample being N = 46), sample means tend to be well-approximated by a normal distribution despite the data not being normally distributed (Kwak & Kim, 2017). For sphericity, a Mauchly's sphericity test (Mauchly, J. W., 1940) was performed and revealed evidence for a violation of sphericity (p = .033), which was then corrected for with a Huynh-Feldt correction.

Hypothesis 1 ADHD and effort allocation

To look at the interaction between effort allocation and ADHD, a Repeated Measures ANCOVA was conducted. The within subjects variable consisted of the MRTs registered per person and further divided into the three levels (these were then attributed the event rate conditions: slow, medium and fast). Then, the ADHD index t-scores of the participants were added as a covariate (note: none of the assumptions changed substantially from the last analysis).

Hypothesis 2 ADHD and error monitoring

To test if post-error slowing is different for varying levels of ADHD symptoms, two different approaches were taken. For the traditional measure, a Repeated Measures ANCOVA was performed with correctness as a within subject variable (EC and CC) and the CAARS scores as a covariate. The general traditional measure per person, a mean of the measures for the three event rates, was used. Normality checks showed that the MRTs of EC ($W = .98$, $p = .61$) as well as the MRTs of CC ($W = .97$, $p = .22$) were normal. With correctness only having two levels, the assumption of sphericity could not be checked. Therefore, no correction will be used.

For the robust measure, a correlation between robust PES and CAARS scores was computed. The general robust PES per person, not taking event rate into consideration, was used. A Shapiro-Wilk test was used to test for normality of the data. Though the distribution of the CAARS scores seemed to be normal ($W = .98$, $p = .622$), the robust PES failed the assumption of normality ($W = .95$, $p = .04$). Despite this violation, the Pearson correlation was calculated as the sample size of this study was big enough.

To be able to say something about error monitoring, the general PEA and PCA per participant were investigated. A Repeated Measures ANCOVA with within subject variable correctness (EC and CC) and covariate CAARS ADHD index t-scores was executed. The results of a Shapiro-Wilk test ($W = .93$, $p = .01$) indicated that normality was violated. The assumption of sphericity could not be tested for correctness due to the insufficient amount of levels. No correction will be used.

Hypothesis 3 ADHD, effort allocation, error monitoring

For traditional PES, a repeated measures ANCOVA was carried out. For this, the PES for each event rate condition was introduced as 2 within subjects variables. These variables consisted of correctness with two levels (EC and CC) and event rate with three levels (fast, medium and slow). Furthermore, a covariate was added to the measure (CAARS ADHD index t-scores). Upon assumption checking, evidence for a violation of normality for 2 conditions was registered (PES EC slow [$W = .88$, $p < .001$]; PES CC fast [$W = .94$, $p = .017$]). For the other conditions, no violation of normality was observed. Additionally, a violation of sphericity was noted for both levels (event rate [$W = .73$, $p < .001$]; event rate * correctness [$W = .64$, $p < .001$]). In this way, a Greenhouse-Geisser correction was in order (event rate: $\varepsilon = .78$; event rate * correctness: $\varepsilon = .73$).

For the robust PES, each event rate condition was introduced as 1 within subjects variable with levels fast, medium and slow. Furthermore, a covariate was added to the measure (CAARS ADHD index t-scores). Upon assumption checking, evidence for a violation of normality for the fast event rate was registered ($W = .88$, $p = <.001$). There was no evidence for a violation of sphericity ($p = .181$.)

Lastly, for PEA and PCA, the within subject variables were event rate (fast, medium and slow) and correctness (EC and CC). The covariate added was CAARS ADHD index t-scores. Significant violations of normality on all conditions (all $p <.001$) and significant violation of sphericity (event rate [$W = .71$, $p < .001$]; event rate * correctness [$W = .56$, $p < .001$]) were found. However, with an understanding of the limited options for a non-parametric test for repeated measures ANCOVA, the parametric variant was deemed most appropriate. Thus, to correct for the sphericity violation, a Greenhouse-Geisser correction was applied (event rate [$\varepsilon = .78$]; event rate * correctness [$\varepsilon = .69$]).

Results

In the sample for this study, there were three people that stated to ever have been diagnosed with ADHD. All analyses were done with and without them. The three participants did not have such a big impact on the results that they had to be removed from the study. Consequently, all outcomes can be applied to every participant.

Descriptive statistics

Table 1 shows the means and standard deviations of the MRTs and response accuracy per event rate and in general.

Table 1

Descriptive statistics

	Slow	Medium	Fast	Total
Error rate	*M* = .15, *SD* = .18	*M* = .16, *SD* = .17	*M* = .17, *SD* = .18	*M* = .16, *SD* = .17
MRT	*M* = 933, *SD* = 238	*M* = 850, *SD* = 226	*M* = 718, *SD* = 195	*M* = 834, *SD* = 187

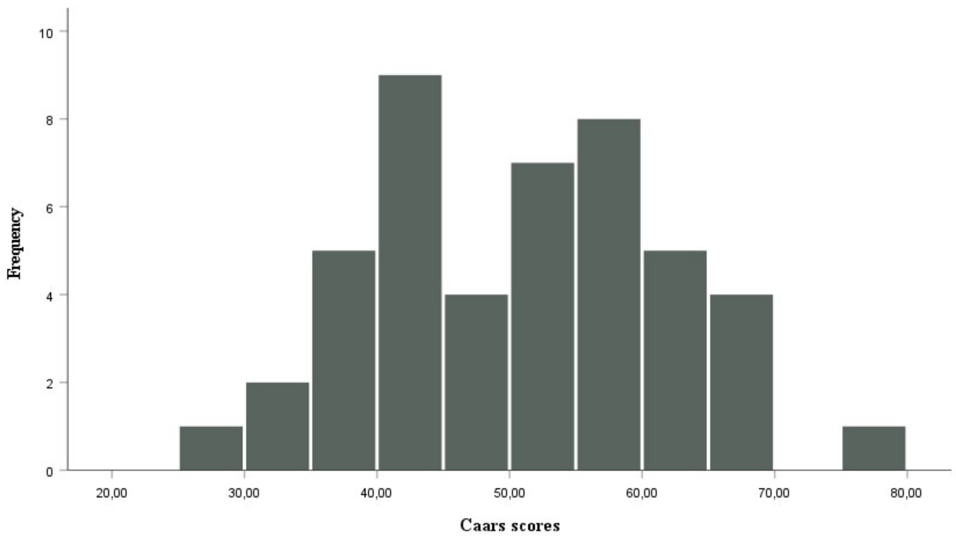
Note. The numbers displayed for the error rates are the proportion of errors per person in every condition.

CAARS scores

The mean score on the CAARS was 49.27 (*SD* = 10.03) overall and specifically 48.10 (*SD* = 9.41) for females and 51.28 (*SD* = 11.01) for males. Graph 1 shows the distribution of the CAARS scores.

Graph 1

Distribution of CAARS scores



Note.

Task manipulation

The results for the repeated measures ANOVA showed that event rate seems to differ significantly, $F(1.81) = 26.59$, $p = <.001$, $\eta^2p = .37$. To further investigate which event rates differed from each other, pairwise comparisons were performed. The results indicate that all three event rates differ significantly from each other. As can be seen in table 1, the MRT for fast are 131.76 lower than for medium ($p = <.001$) , the MRT for medium is 83.11 lower than for slow ($p = .048$), and the MRT for slow is 214.87 higher than for fast ($p = <.001$). All p-values were adjusted using the Bonferroni method.

Hypothesis 1 ADHD and effort allocation

For the first hypothesis, a repeated measures ANCOVA was performed. The test showed no significant values for event rate ($p = .09$, $\eta^2p = .06$) or for the interaction of event rate and CAARS scores ($p = .69$, $\eta^2p = .01$).

Hypothesis 2 ADHD and error monitoring

For the second hypothesis, a Repeated Measures ANCOVA was carried out. No significant results were found ($p = .40$, $\eta^2p = .02$). Graph 3 displays the change in traditional PES for varying levels of CAARS scores.

Graph 3

Changes in traditional PES for varying levels of CAARS scores

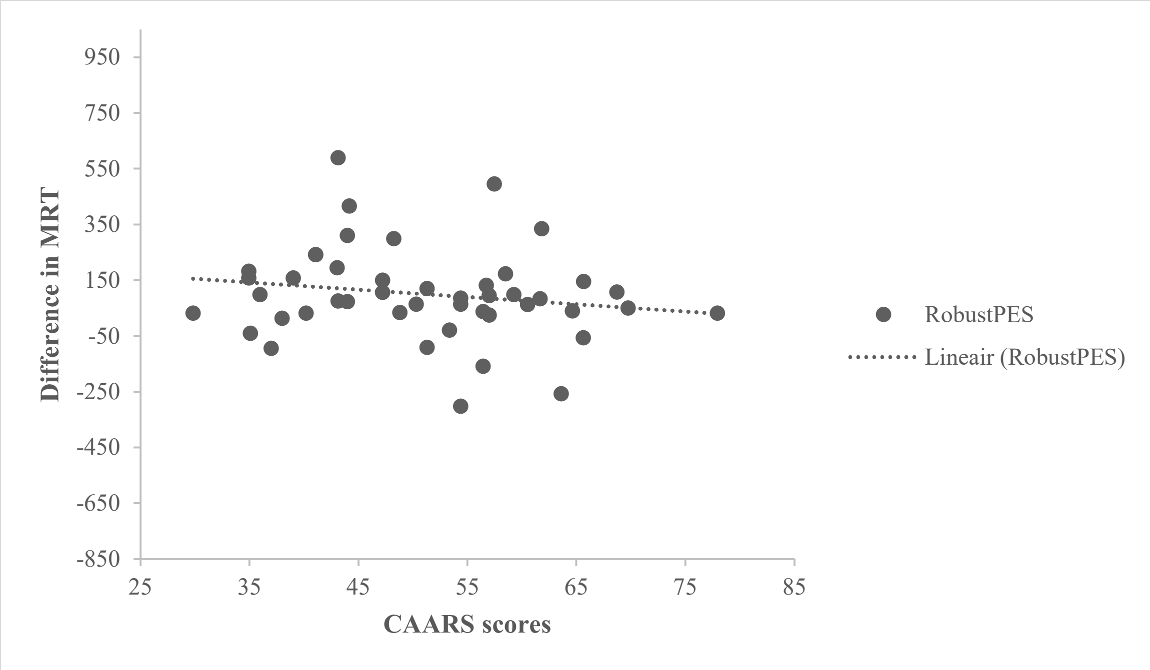
Note. To make the graph more comprehensible, the CAARS scores were divided in tertiles. The lower tertile includes the people with CAARS scores ranging from 29.81 to 43.99, the medium tertile from 44.15 to 56.72 and the higher tertile from 57 till 77.94. The numbers presented represent the mean reaction time of a correct trial following a correct trial (CC) and of a correct trial following an error (EC).

Robust PES

A small, negative, non-significant Pearson correlation (r = -.173, p = .249) was found. Graph 4 shows the relationship between RobustPES and the CAARS scores.

Graph 4

Scores for robust PES for varying levels of CAARS scores



Note. The calculation of 'Difference in MRT' is described in the data analysis. The bigger the difference in MRT, the more robust PES someone has.

PEA and PCA

The outcome of the Repeated Measures ANCOVA did not show evidence of a difference in PEA and PCA in general (p = .514, η^2p = .01) and across differing levels of ADHD symptoms (p = .23, η^2p = .03).

Hypothesis 3 ADHD, effort allocation, error monitoring

For the third hypothesis, a Repeated Measures ANCOVA with the traditional PES was performed. No significant results were found (p = .49, η^2p = .01). Graphs A1 to A3 display the traditional PES separately for each of the three event rates.

For the robust PES, a Repeated Measures ANCOVA with the traditional PES was also performed. The event rates did not seem to differ significantly (p = .80, η^2p = .01).

To assess the difference between PCA and PEA, while considering the event rate and ADHD, a Repeated Measures ANCOVA was executed. People with different levels of ADHD do not seem to differ significantly (p = .55, η^2p = .01) in PEA and PCA for any event rate.

Discussion

In this study, the role of effort allocation in error monitoring in people with varying levels of ADHD symptoms was investigated. Though research is not conclusive, error monitoring seems to be impaired in people with ADHD. According to one study, this may be a consequence of impaired effort allocation in these patients. In this study, three hypotheses were tested: (1) people with higher levels of ADHD will perform worse on the task in the fast and slow event rate compared to people with lower levels of ADHD; (2) people with higher levels of ADHD will low show less post error slowing than people with lower levels of ADHD in general, (3) people with higher levels of ADHD will show less post error slowing in the fast and slow condition compared the medium condition. The results showed no significant differences between the performance of the different people or the performance on the different event rates.

Task manipulation

The significant differences in performance of the participants on the three event rates, shows that the task manipulation was effective and the operationalization of effort allocation was successful (Van der Meere, 2005). Therefore, we can conclude that the found nonsignificant results do not stem from a problem with the task.

Hypothesis 1 ADHD and effort allocation

The finding that the interaction between event rate and CAARS is not significant, goes against the first hypothesis of this study. This may lead to the conclusion that the participants in this study do not differ in effort allocation. This goes against most studies stating that there are differences in event rates (Drescher et al., 2021; Metin et al., 2012).

A study by Raymaekers et al. (2007) also finding no significant difference between a control group and ADHD in the slow condition, may explain our findings. They state their outcomes may be due to several reasons, one being the presence of the experimenter in the same room as the children performing the task. A study by Van der Meere et al. (1995) proved that when an experimenter was present the participants showed better performance than when the experimenter was absent. In this study, the participants had to do the tasks in their own home. It is may be possible that other people were home at the same time, leading to increased performance. The presence of others on the performance of students with ADHD symptoms may be something interesting to be investigated further.

A different interesting finding of the Repeated Measures ANCOVA performed to test this hypothesis, is that adding CAARS as a covariate makes the main effect of event rate non-significant. This seems to suggest that though the two variables do not interact significantly, ADHD can still explain some variance in the MRTs related to unforeseen factors.

Hypothesis 2 ADHD and error monitoring

The results showed that people with higher levels of ADHD symptoms do not significantly differ in the amount of post-error slowing from people with lower levels of ADHD. This may lead to the conclusion that having more ADHD symptoms do not interfere with error monitoring skills. These findings contradict the study by Mohamed et al. (2016), who did find decreased post-error slowing in people with high levels of ADHD symptoms compared to low levels of ADHD symptoms. The inconsistency of the findings may be due to several reasons, namely the sample or testing environment. First of all, Mohamed et al.'s (2016) study included 19 participants reporting an ADHD diagnosis compared to 3 in this study. It may be that having more extreme symptoms leads to a greater deficit in error monitoring, while minor levels of symptoms do not bring any deficits along. Secondly, while the study by Mohamed et al. (2016) was tested in a lab where the experimenters have control over the testing environment, the present study was done online which may have had aversive consequences as described above.

The finding that the MRT for a correct trial after an error (EC) was higher than for correct trial following another correct trial (CC) indicates that there is some sort of post-error slowing across the different people (graph 3). The difference between EC and CC does grow , however, with an increase in CAARS scores, disconfirming the hypothesis that higher levels of ADHD symptoms lead to decreased post-error slowing. The difference between the people is not significant though, which makes any explanation invalid.

Graph 4 shows a different picture. There, CAARS scores and robustPES are negatively correlated. This means that the higher the ADHD symptoms, the lower the robust post-error slowing. This proves evidence for the hypothesis, though a real conclusion cannot be made due to the non-significance.

The different conclusions based on the graphs for the traditional and the robust method lead to a difficult interpretation of the results. An explanation, is the problems that both measures have which will be discussed later.

To assess error monitoring in its totality, post-error accuracy must be also be investigated. Just as post-error slowing was not significant, neither was the difference between PEA and PCA with and without having CAARS as a covariate.

Hypothesis 3 ADHD, effort allocation, error monitoring

The outcomes did not show evidence for an interaction between event rate, CAARS scores and PES. This disconfirms the third hypothesis that error monitoring in people with varying levels of ADHD symptoms varies for the multiple event rates. Furthermore, this goes against the findings of Mohamed et al. (2016) who did significant differences between these three variables.

When looking at graphs A1 to A3, an interesting patterns appears. For the fast condition, EC and CC differ quite substantially, in the medium condition they appear much closer, and in the slow condition the EC and CC seem to completely change position for the lower and medium group. Especially this third observation seems to be going against general expectations. The lower and medium group seem to speed up after making an error, while the higher group does not. The difference in the graphs seems to point toward an interaction between the traditional measure and CAARS scores, though not significant when looking at the results. This difference in graphs between the event rates, can also be seen in the graphs for the robust measure (graphs A4 to A6). While in the fast condition an instance of post-error speeding appears, participants seem to slow down after an error in the two other conditions. The degree to which they do that does differ.

Just as for the second hypothesis, post-error accuracy was investigated. Again PEA and PCA did not seem to differ significantly.

Limitations

This study has several limitations, that may explain the occurrence of the nonsignificant results.

As previously mentioned, problems were encountered when calculating post-error slowing. Two different approaches were used, namely the traditional and the robust measure. Firstly, as the traditional only looks at instances of two following trials (EC or CC), the measure may over- or underestimate the actual post-error slowing (Dutilh et al., 2012). The robust measure does not have this problem as it looks at longer instances of four trials (CCEC). In our study, however, there were not enough instances of robustPES to be able to calculate a reasonable mean. The fact that both measures had problems may lead to wrong results and conclusions about error monitoring.

This small amount of instances of robust PES can partly be explained by the fact that the unmixed block was used. This was problematic, as a majority of the participants did not make many mistakes or made long sequences of mistakes. The unmixed block was used as this part of the task switching paradigm was less influenced by the skill of set-shifting. Using the mixed block would have led to problems with confounding factors and a very complex procedure trying to account for them.

A further problem was the sample. The sample size was quite small, leading to a small power. This reduces the chance of finding a true effect.

Furthermore, the sample was retrieved through convenience sampling and existed entirely out of students. A literature study (Weyandt & DuPaul, 2006) has shown that students with ADHD do not differ significantly from students without ADHD on neuropsychological testing. It may be that this demographic is in a phase of their life where ADHD symptoms does not lead to deficits in certain skills.

Also, partly due to the student sample, a dimensional approach was used in this study. This may have lead to small variance in the CAARS scores, which ultimately may have caused the lack of interactions between ADHD and the other two variables.

The last limitations were related to the procedure. Due to circumstances, the study had to be done fully online. The participants made the tests in completely different environments from each other. There was also no control over confounding factors, such as distraction or motivation. This leads to problems with validity of the data.

Future studies

In conclusion, effort allocation and error monitoring in people with ADHD may be impaired, though more research must be done to confirm this. Though this study had many limitations, it may be interesting as a starting point for more research in this field.

Theoretical implications from this study are difficult to formulate due to the many limitations. If effort allocation is indeed impaired in people with ADHD, it may be an important deficit to address in the treatment of ADHD. If not, then the focus must be put on different problems ADHD patients experience.

Future research in the field of ADHD, effort allocation and error monitoring should have a bigger sample size, to ensure a statistical power that is large enough, a sample consisting of a different demographic, and a more difficult task. Making the task more difficult, will lead to more errors, and more errors may lead to more error monitoring in people who do not have problems with this skill.

Conclusions

The nonsignificant findings may be due to several limitations, including the small sample size, though it is also possible that minor levels of ADHD symptoms do not bring along error monitoring or effort allocation deficiencies. More research should be done, leading to a better understanding of ADHD and the problems that come along with having this disorder. This will hopefully lead to a better treatment in the end.

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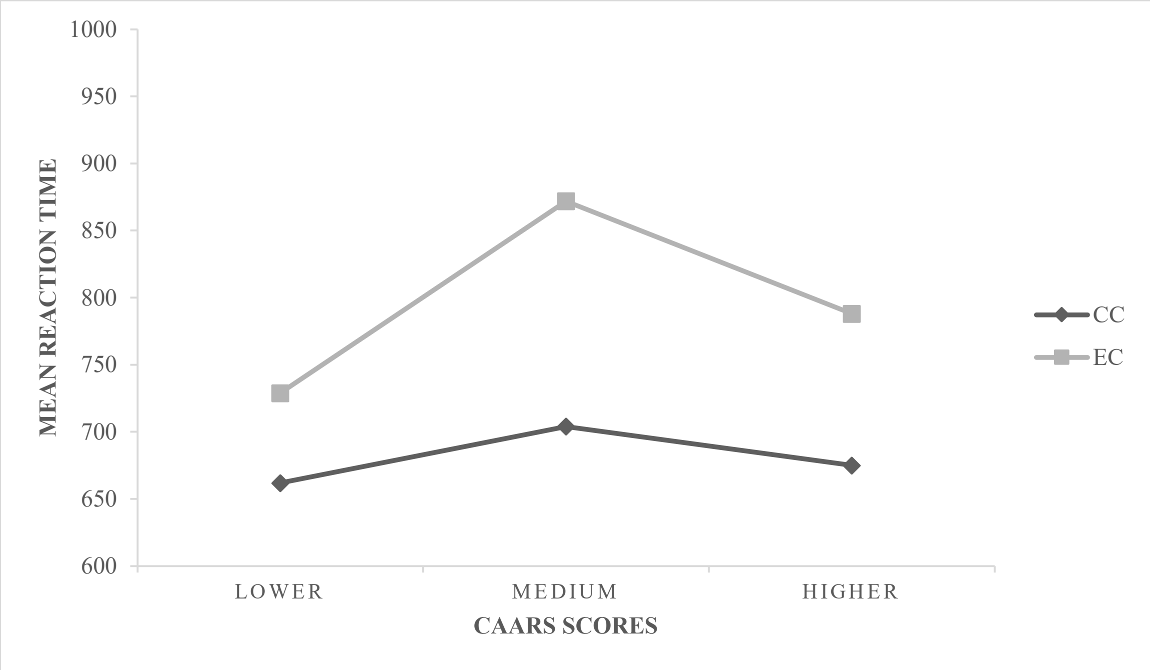
Appendix

Graph A1

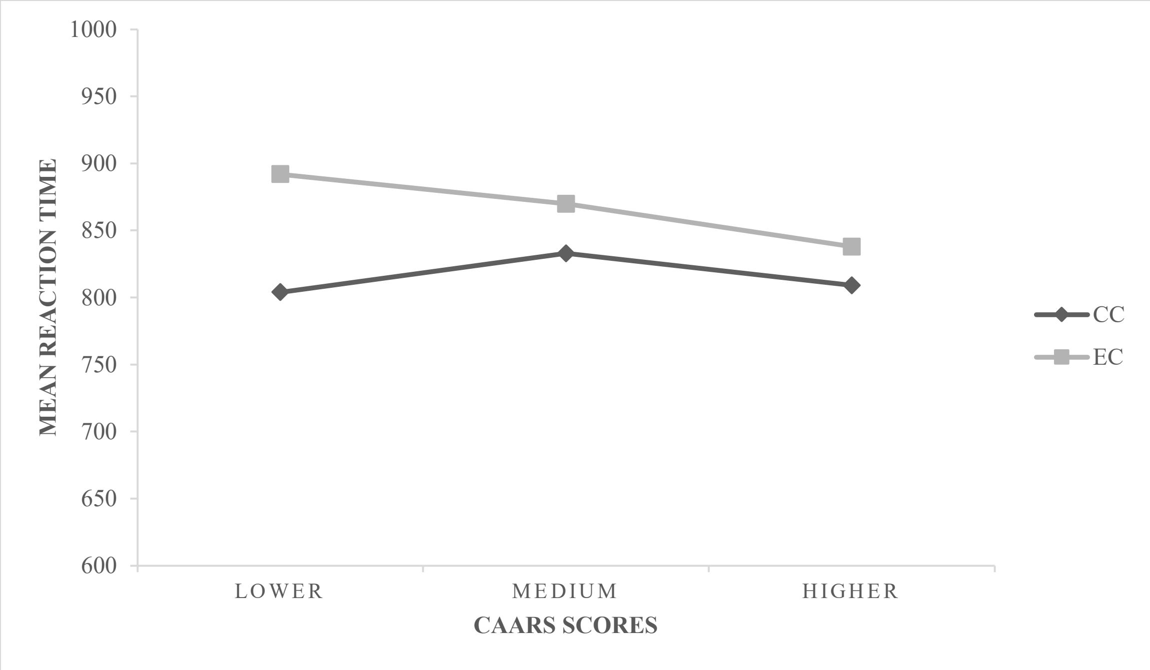
Changes in traditional PES for varying levels of CAARS scores in the fast condition



Note. To make the graph more comprehensible, the CAARS scores were divided in tertiles. The range of CAARS scores per tertile are mentioned in the notes of graph 3. The numbers presented represent the mean reaction time of a correct trial following a correct trial (CC) and of a correct trial following an error (EC).

Graph A2

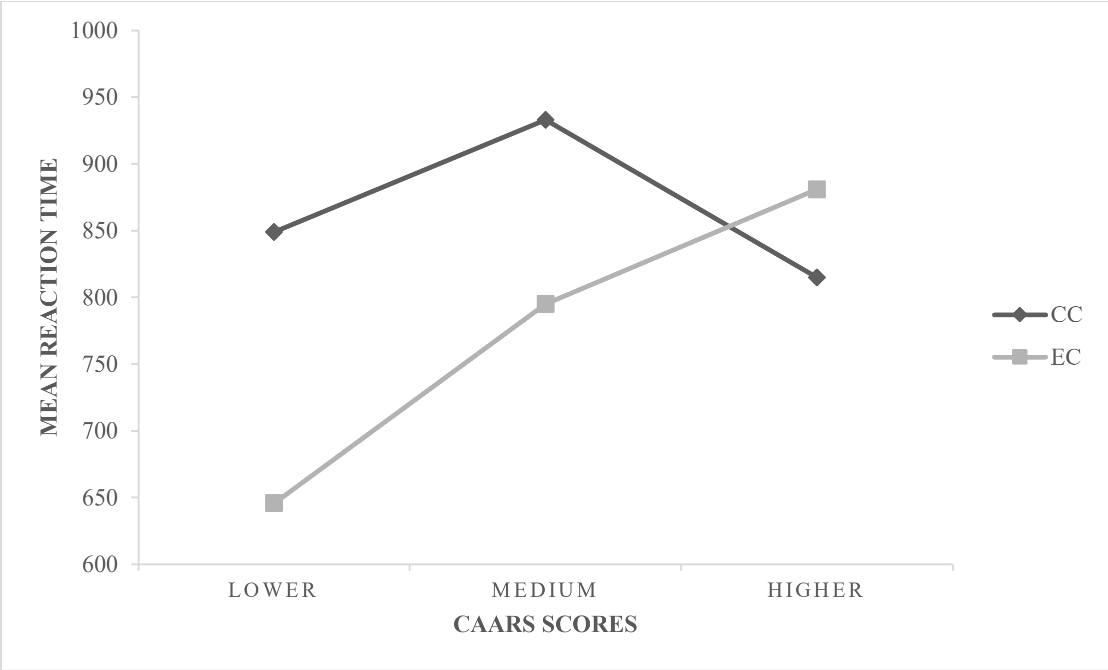
Changes in traditional PES for varying levels of CAARS scores in the medium condition



Note. To make the graph more comprehensible, the CAARS scores were divided in tertiles. The range of CAARS scores per tertile are mentioned in the notes of graph 3. The numbers presented represent the mean reaction time of a correct trial following a correct trial (CC) and of a correct trial following an error (EC).

Graph A3

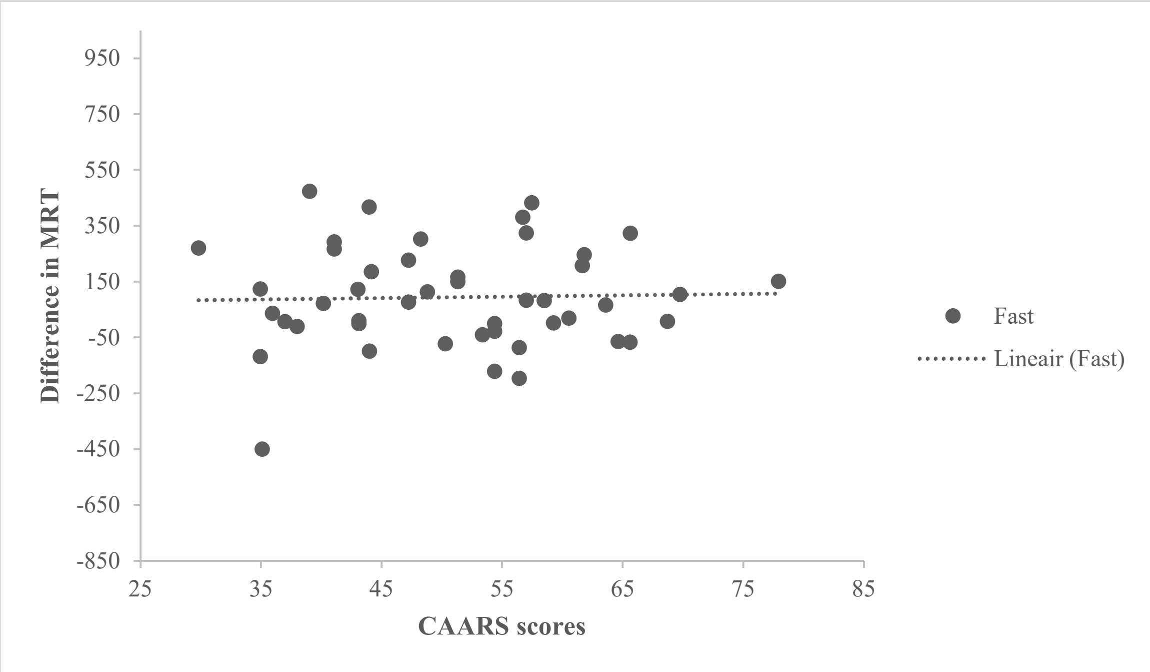
Changes in traditional PES for varying levels of CAARS scores in the slow condition



Note. To make the graph more comprehensible, the CAARS scores were divided in tertiles. The range of CAARS scores per tertile are mentioned in the notes of graph 3. The numbers presented represent the mean reaction time of a correct trial following a correct trial (CC) and of a correct trial following an error (EC).

Graph A4

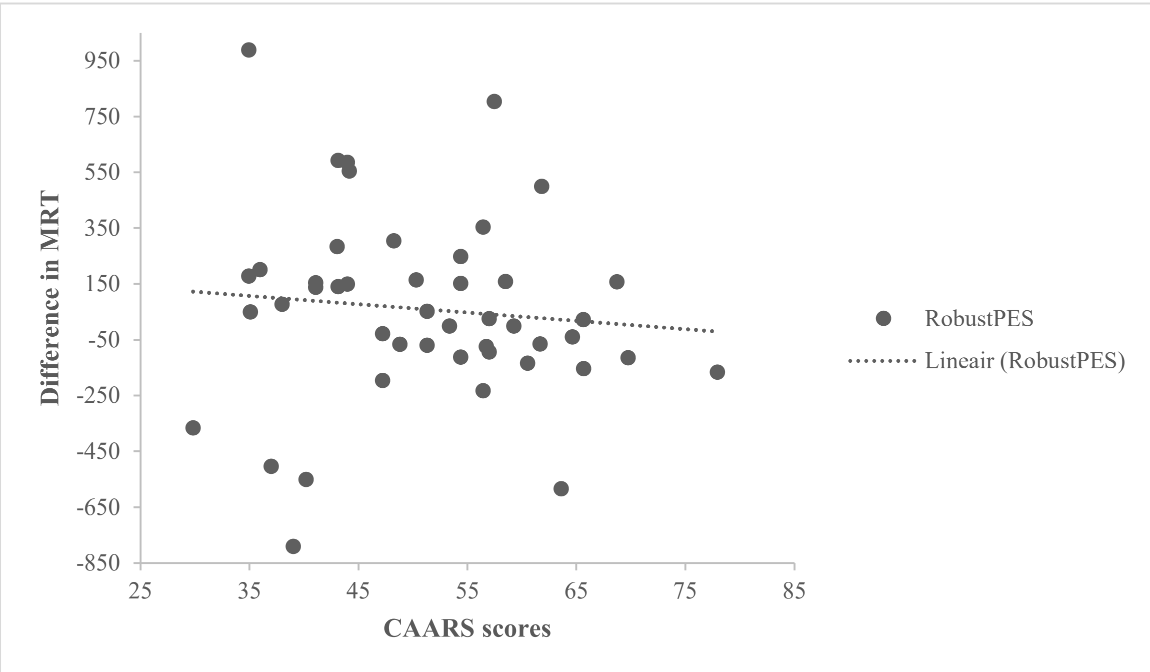
Scores for robust PES for varying levels of CAARS scores in the fast condition



Note. The calculation of 'Difference in MRT' is described in the data analysis. The bigger the difference in MRT, the more robust PES someone has.

Graph A5

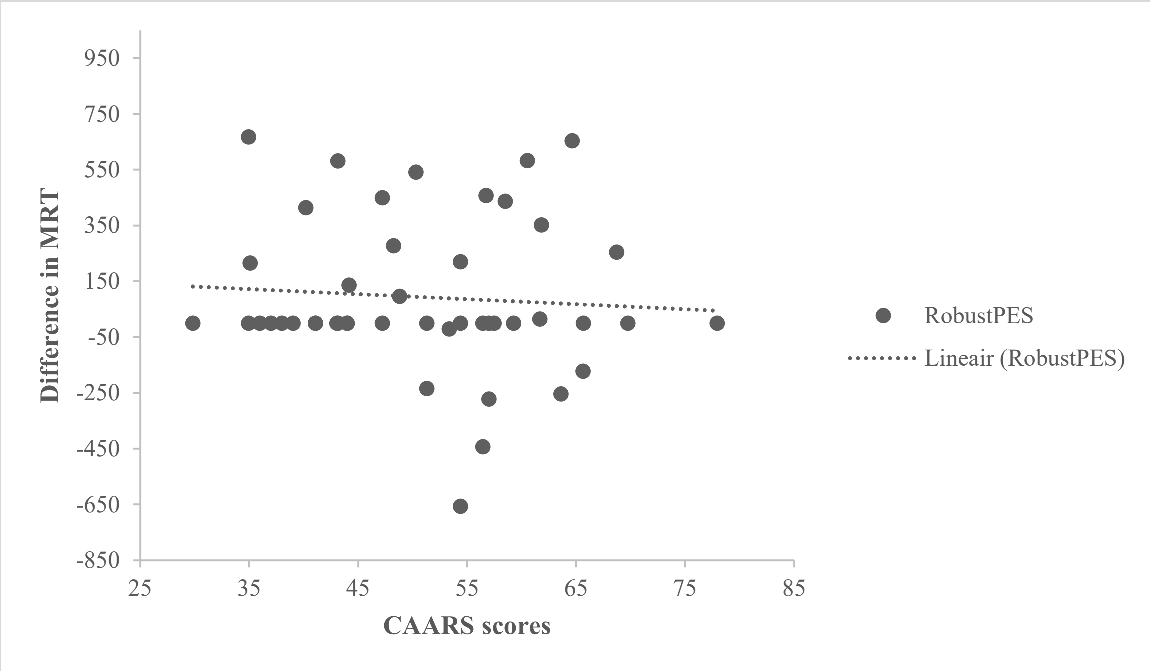
Scores for robust PES for varying levels of CAARS scores in the medium condition



Note. The calculation of 'Difference in MRT' is described in the data analysis. The bigger the difference in MRT, the more robust PES someone has.

Graph A6

Scores for robust PES for varying levels of CAARS scores in the slow condition



Note. The calculation of 'Difference in MRT' is described in the data analysis. The bigger the difference in MRT, the more robust PES someone has. In this graph, a large amount of numbers is 0. In the slow condition, many participants did not make any mistakes which led to the problem of not being able to calculate robust PES.