Title: Does rare error count in impulsivity? Difference in error-negativity

Running head: Does rare error count in impulsivity?

Ádám Takács[1], Andrea Kóbor[2,1], Ferenc Honbolygó[2,1], Valéria Csépe[2,1]

1: Institute of Psychology, Eötvös Loránd University, *Izabella u. 46., H-1064, Budapest, Hungary*

2: Institute of Cognitive Neuroscience and Psychology, Research Centre for Natural Sciences, Hungarian Academy of Sciences, *Magyar tudósok körútja 2., H–1117 Budapest, Hungary*

Manuscript of the article that appeared in:

Journal of Psychophysiology 2015; Vol. 29(2):64-72. doi: 10.1027/0269-8803/a000135

Author Note: Correspondence concerning this article should be addressed to Ádám Takács, Institute of Psychology, Eötvös Loránd University, Izabella utca 46., H-1064, Budapest, Hungary. E-mail: takacs.adam@ppk.elte.hu. Telephone: +36306602756.

Abstract

High impulsive individuals have problems with self-monitoring and learning from their mistakes. The aim of this study was to investigate whether error processing is impaired in high trait impulsivity, and how it is modulated by the task difficulty.

Adults were classified as high (*n* = 10) and low (*n* = 10) impulsive participants based on the Barratt Impulsiveness Scale, and they participated in a modified flanker task. The flanker trials had three levels of task difficulty manipulated by visual degradation of the stimuli. We measured RTs and ERP components (Ne, Pe) related to erroneous responses.

Low impulsive participants responded significantly faster than high impulsive participants. The two groups did not differ in accuracy. The Ne amplitude was smaller in high than in low impulsivity in case of medium and high difficulty levels, but not at low difficulty level. However, the groups did not differ either in the amplitude or in the latency of Pe. We suggest that trait impulsivity is characterized by impaired error detection.

Keywords: error-negativity, error-positivity, flanker task, impulsivity

1. Introduction

Personality traits, like anxiety, depression, impulsivity or sensation seeking are strong risk factors for developing psychiatric conditions (Olvet & Hajcak, 2008). Impulsivity can be conceptualized as a multifaceted dimension, often described as acting without thinking, and it is associated with externalizing disorders, such as ADHD or substance abuse (Boy et al., 2011; Hall, Bernat, & Patrick, 2007; Potts, George, Martin, & Barratt, 2006). Moreover, impulsivity is the second most frequent of the symptoms listed in the DSM-IV (Boy et al., 2011). High impulsive adults have problems with response inhibition, learning from errors, and from negative feedbacks (Potts et al., 2006). The present study was conducted in order to elucidate the neurocognitive underpinnings of impulsivity by examining its impact on ERPs related to self-monitoring behavior.

The error-negativity (Ne, Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991) or error-related negativity (ERN, Gehring, Goss, Coles, Meyer, & Donchin, 1993) is a negative deflection that occurs approximately 50 ms after an erroneous response with a fronto-central maximum (Olvet & Hajcak, 2008; Simons, 2010). The Ne is related to error detection and could trigger behavioral adjustment to fulfill task requirements (Endrass, Klawohn, Gruetzmann, Ischebeck, & Kathmann, 2012). The background mechanism of this regulatory effect is controversial (Endrass et al., 2012; Hall et al., 2007; Olvet & Hajcak, 2008). Task difficulty could attenuate the Ne amplitude as detecting an error is more complicated in uncertain conditions (Endrass et al., 2012). In addition, the Ne is sensitive to the level of cognitive conflict (Olvet & Hajcak, 2008). A higher level of task difficulty could increase the required effortful control and performance monitoring in order to attain an optimal achievement in the task (Johnstone, Watt, & Dimoska, 2010), which should be mirrored in an enhanced Ne. The Ne is usually followed by a positive deflection with a centro-parietal maximum. This error-positivity (Pe) is hypothesized to reflect error awareness, and it is related to a compensatory post-error slowing on the error-subsequent trial (Simons, 2010). ERPs elicited by commission errors have been studied in cognitive conflict paradigms such as Stroop, Simon, Go/No-Go, or flanker tasks (Meyer, Riesel, & Proudfit, 2013; Simons, 2010). The error rate is usually low in those tasks, however, the minimum number errors required to derive Ne ranges between 5 and 300 (Olvet & Hajcak, 2009). Furthermore, Ne from the flanker task seems to be the most reliable, even with relatively low number of errors (Meyer et al., 2013).

While anxiety and depression is characterized by an increased sensitivity to committing errors indicated by the larger Ne amplitudes, impulsiveness and externalization is related to lower Ne and decreased error monitoring (Hall et al., 2007; Olvet & Hajcak, 2008; Potts et al., 2006). High externalizing undergraduate students showed decreased Ne amplitude compared to their low externalizing counterparts in a modified letter version of the flanker task, and this attenuation correlated with a self-report measure of externalizing trait (Hall et al., 2007). Externalizing is related to antisocial behavior, substance use disorders an aggression, and it has a functional significance to impulse control problems. Another study demonstrated that the high end of the impulsive antisocial dimension of psychopathy was characterized by smaller Ne amplitude (Heritage & Benning, 2013), indicating that decreased error detection and self-monitoring could lead to aggressive and impulsive behavior.

Using the framework of the Behavioral Inhibition System (BIS, indicating higher level of attention, arousal, vigilance, and anxiety) and the Behavioral Activation System (BAS, indicating enhanced motivation to reward and avoiding punishment), a study proposed to integrate personality traits and adaptive control mechanisms (Amodio, Master, Yee, & Taylor, 2008). In a Go/No-Go paradigm, higher scores of self-reported BIS was associated with enhanced Ne amplitude, however the BAS was not related to the error-negativity (Amodio et al., 2008).

As a behavioral index of adaptive control, post-error slowing is a tendency to slow down after an error has occurred (Li et al., 2006, Farr et al., 2012, Simons, 2010). Diminished post-error slowing has been reported previously in a variety of impulsivity related disorders, such as cocaine (Li et al., 2008) and alcohol abuse (Lawrence et al., 2009), or ADHD (Wiersema et al., 2009). However, Farr et al. (2012) did not find difference in post-error slowing between low and high impulsive participants.

Despite the effort dedicated to understand the relationship between personality and error processing, only two studies were conducted in the field of trait impulsivity (Martin & Potts, 2009; Potts et al., 2006). A study examined undergraduate students, assigned to high (HI) and low impulsive (LI) groups by a median split on the Barratt Impulsiveness Scale (BIS-11) total score, in a rewarded flanker task (Potts et al., 2006). High impulsive participants showed smaller Ne, but only when the potential outcome was a monetary loss, indicating decreased punishment sensitivity. Another study (Martin & Potts, 2009) focused on reward and punishment processing in impulsivity in relation to risk-taking behavior. HI participants showed smaller Ne than LI participants after risky choices, indicating attenuated sensitivity to punishment.

Most of the studies investigating Ne in impulsivity focused on altered motivation. However, characteristics of impulsivity should be studied at the cognitive level, as well. More specifically, the flexible regulation of behavior in order to meet varying task requirements seems to be a crucial competence to adaptive social life (Boy et al., 2011). In the present study, we used a modified flanker paradigm with three levels of task difficulty to model the regulation of behavior, and we compared Ne and Pe components elicited by erroneous responses between HI and LI adults. In line with previous results (Martin & Potts, 2009; Potts et al., 2006), our main hypothesis was that HI participants would show an overall decreased Ne amplitude as compared to LI participants. Based on the premise that our manipulation of task difficulty induces more effortful control to be allocated in order to maintain performance, we assumed that the amplitude of Ne would increase with task difficulty level in the LI group because of increased self-monitoring imposed by task requirements, whereas HI participants would not show such effect. Without previous data, our investigation on the Pe component in trait impulsivity was exploratory. Based on the characteristics of impulsivity, we assumed that error awareness would be decreased, indicated by smaller Pe amplitude in the HI group. Similarly, we assumed deficient post-error slowing in the HI group compared to the LI group.

2. Method

2.1. Participants

Participants were selected from a larger sample of undergraduate students from two local universities, who completed the BIS-11 (Stanford et al., 2009) as a screening assessment. Thirty-nine participants were selected based on their BIS-11 total score. Participants having a total score from the range of 56–58 were assigned to the LI group, and those having 72 or above to the HI group. Three participants were excluded due to high number of omission errors, caused by not following instructions or not paying attention to the task. We could not analyze data of four another participants because of technical reasons. For the error trials, we analyzed incongruent flankers only, where the error rates were sufficiently high (see Data analysis), similar to the method of Holroyd and Coles (2002). Furthermore, participants with less than five artifact-free error-related ERP segments at each difficulty level of the incongruent condition were removed from the sample (see Data analysis section below). Accordingly, thirteen participants were excluded because of low error rates or excessive artifacts. In our final sample, ten young adults remained in each group with five males and five females. The data was collected in the same study as reported by Kóbor et al. (2014), where stimulus locked ERPs were analyzed for correct trials. The experimental procedures were in accordance with the Declaration of Helsinki, including a signed informed consent, and were approved by the institutional committee of research ethics. Participants received extra course credits for taking part in the experiment.

2.2. Stimuli and procedure

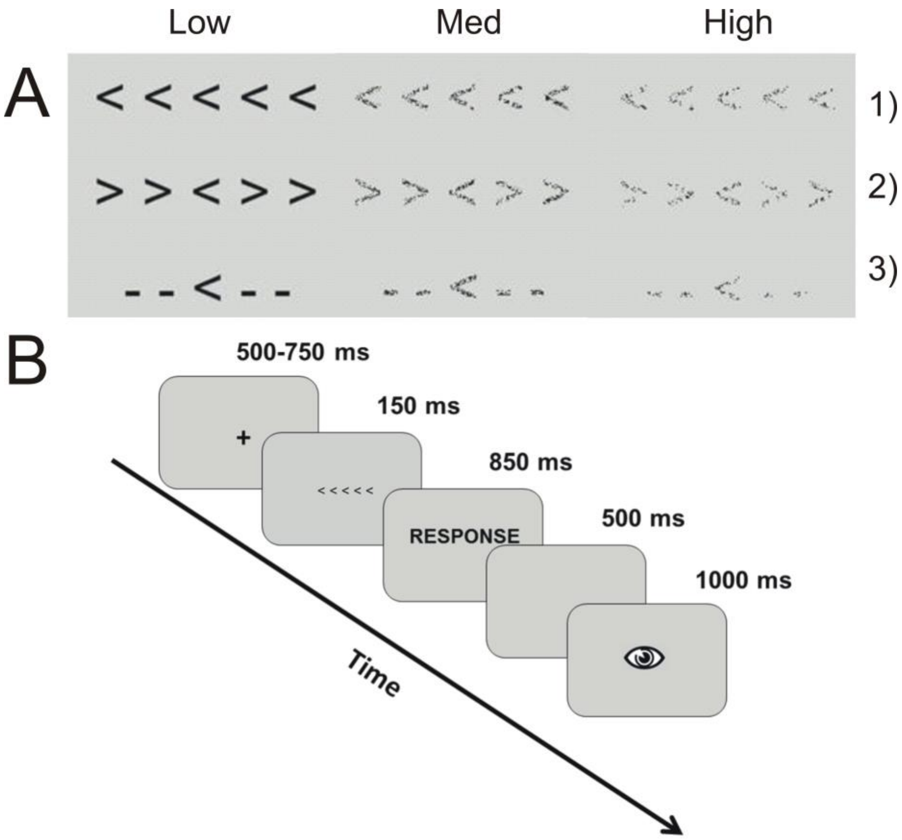

Figure 1: Congruent (1), incongruent (2), and neutral (3) flankers with three levels (Low – low task difficulty, Med – medium task difficulty, High – high task difficulty) of stimulus degradation (A) and trial structure (B).

The present study used a modified flanker task with three levels of task difficulty manipulated by visual degradation (Figure 1). In the three difficulty conditions, 0%, 60% and 80% of the pixels were randomly removed from the stimulus array, similar to the method used by Johnstone et al. (2010). Third of the trials were congruent, third were incongruent, and third of them were neutral. Participants were requested to press “A” for left facing targets and “L” for right facing targets on a standard QWERTY keyboard with a USB connection. They sat in front of a 19’’ CRT screen with 75 Hz of refresh rate. First, a fixation cross was presented for a random interval between 500 – 750 ms, which was followed by the flanker stimulus for 150 ms. After the flanker was showed, a blank screen was displayed for 850 ms or until the participant’s response. It was followed by a delay for 500 ms (with a blank screen again), and after that an image of an eye was presented for 1000 ms. Participants were free to blink during this period. They performed 18 practice trials, and then 12 blocks of 144 trials in each. Trials with different difficulty levels were divided into 3 blocks, and the order of their presentation was counterbalanced between participants and across groups. Stimuli were presented by using Presentation software (v. 12.2; Neurobehavioral Systems). Additionally, participants were asked to fill short screening questionnaires in the laboratory: for measuring depression the Hungarian Beck Depression Inventory short version (BDI, Rózsa, Szádóczky, & Füredi, 2001) was used, and for trait anxiety the Hungarian State-Trait Anxiety Inventory (STAI, Sipos & Sipos, 1983) was administered (see Table 1). The two groups did not differ in those questionnaires (all *p*s $> .05$).

Table 1: Measurements in the two groups: questionnaires, behavioral, and ERP data.

	Low impulsive	High impulsive	
	Mean (SD)		
Age	20.0 (2.1)	21.2 (2.1)	n.s
BDI total score	12.1. (2.8)	13.1 (2.7)	n.s.
BIS total score	57.0 (0.7)	77.3 (4.0)	***
STAI total score	36.4 (8.0)	41.4 (7.4)	n.s.
Correct RT at Low (con)	387 (17)	416 (26)	n.s.
Correct RT at Med (con)	396 (19)	428 (28)	*
Correct RT at High (con)	419 (19)	473 (47)	**
Correct RT at Low (neu)	393 (17)	422 (27)	n.s.
Correct RT at Med (neu)	409 (21)	440 (30)	*
Correct RT at High (neu)	431 (20)	477 (48)	**
Correct RT at Low (inc)	473 (11)	504 (13)	n.s
Correct RT at Med (inc)	471 (9)	501 (9)	n.s.
Correct RT at High (inc)	511 (10)	554 (15)	*
Incorrect RT at Low (inc)	386 (22)	392 (15)	n.s.
Incorrect RT at Med (inc)	379 (12)	396 (15)	n.s.
Incorrect RT at High (inc)	404 (8)	447 (21)	n.s.
Error ratio at Low (inc)	9% (2%)	9% (1%)	n.s
Error ratio at Med (inc)	7% (2%)	9% (2%)	n.s.
Error ratio at High (inc)	11% (3%)	16% (5%)	n.s.
Ne at Low (A)	-8.89 (1.13)	-7.27 (1.31)	n.s.
Ne at Low (lat)	38.2 (11.46)	38.2 (3.66)	n.s.
Ne at Med (A)	-11.32 (1.38)	-6.51 (1.15)	*
Ne at Med (lat)	29.0 (4.10)	27.4 (3.07)	n.s.
Ne at High (A)	-9.85 (1.13)	-5.16 (1.32)	*
Ne at High (lat)	31.6 (8.12)	34.2 (7.41)	n.s.

Note. BDI TS: Beck Depression Inventory short version total score; BIS TS: Barratt Impulsiveness Scale total score; STAI-T: T-Anxiety score. A – amplitude, lat – latency, Low – low task difficulty, Med – medium task difficulty, High – high task difficulty, inc:

incongruent. RT data are in ms. We used LSD tests for pair-wise comparisons, except for age and total scores of questionnaires, on which independent samples t-tests and Mann-Whitney tests were performed. $*p < .05$; $**p < .01$; $***p < .001$

2.3. EEG recording and pre-processing

EEG activity was registered with a 32 channel recording system (BrainAmp amplifier and BrainVision Recorder software, BrainProducts GmbH). EEG was acquired at 500 Hz sampling frequency. Cz channel was used as a reference. Data analysis was conducted by using BrainVision Analyzer (BVA) software. A band-pass filter (0.01 – 30 Hz, 12 dB/oct), and a 50 Hz notch filter was applied. Independent component analysis was used to correct eye-movement and heartbeat artifacts. The EEG data was re-referenced to the average activity of all electrodes. Response-locked ERPs were calculated for error trials in the incongruent condition. The Ne peak was determined as the most negative deflection in a 0 – 100 ms time range relative to response onset at Cz. The Pe peak was measured as the most positive value between 150 and 350 ms after the response at Cz[1]. A 100 ms time window before the response was used as baseline. We used an automatic artifact rejection algorithm implemented in BVA with a criteria that segments with activity above or below +/- 100 μV were excluded. The average number of kept epochs for error trials was 18.9 (ranging from 5 to 114).

2.4. Data analysis

Fast responses with RTs lower than 200 ms were excluded, and we did not analyze omission errors. Ex-Gaussian parameters mu (μ), sigma (σ), and tau (τ) were estimated in each congruency and task difficulty condition separately using the *simple egfit* function in MATLAB provided by Lacouture & Cousineau (2008). Correct reaction time, and the three ex-Gaussian parameters of correct raw RTs were analyzed by three-way mixed ANOVAs with Congruency (congruent, incongruent, neutral) and Task difficulty level (low, medium, high) as within-subjects factors, and Group (low impulsive, high impulsive) as a between-subjects factor. As a target of interest, incongruent reaction time (correct and incorrect), incongruent error ratio (ratio of incorrect responses), and ERP peak amplitudes and latencies were analyzed by two-way mixed ANOVAs with Task difficulty level (low, medium, high) as a within-subjects factor, and Group (low impulsive, high impulsive) as a between-subjects factor. In these analyses, we used the incongruent trials only, where the error percentage was sufficiently high (for low Task difficulty $M = 9.11$, $SD = 0.05$; medium $M = 7.92$, $SD = 0.05$; high $M = 13.59$, $SD = 0.13$). To calculate post-error slowing, only the incorrectly responded incongruent trials were treated as errors in order to remain consistent with the error-related ERP analysis. We averaged the RTs given on trials directly preceding the error (error-1), and averaged the RTs given on trials directly following the error (error+1) for each individual (these trials could be either correct or incorrect). Post-error slowing was analyzed by a three-way mixed ANOVA with Task difficulty level and Response order (error-subsequent, preceding) as within-subjects factors, and Group as a between-subjects factor. In all analysis, the Greenhouse-Geisser epsilon (ε) was used for necessary corrections. We used LSD tests for pair-wise comparisons.

3. Results

3.1. Behavioral results in all trial

In correct trials, LI participants responded significantly faster than HI participants, $F(1, 18) = 10.81$, $p < .01$, $\eta_p^2 = .38$. The main effect of Task difficulty was also significant, $F(2, 36) = 40.18$, $\varepsilon = .63$, $p < .001$, $\eta_p^2 = .69$., as well as Congruency, $F(2, 36) = 178.66$, $\varepsilon = .53$, $p < .001$, $\eta_p^2 = .91$. These were overridden by a Task difficulty * Congruency interaction, $F(2, 36) = 11.64$, $\varepsilon = .56$, $p < .001$, $\eta_p^2 = .39$. To sum up, RTs in incongruent trials were higher in every Task difficulty conditions (all $p < .001$). Furthermore, responses at high difficulty level were slower than at medium difficulty level (all $p < .001$), and they were also slower at medium difficulty level than at low difficulty level (all $p < .001$), except for the difference between incongruent trials at low difficulty level and incongruent trials at medium difficulty level, which was not significant ($p = .31$).

Visual inspection of the RT distributions (see Figure 2.) suggested that fitting an ex-Gaussian distribution may provide a better representation of the data than the normal distribution. Shapiro-Wilk tests showed that raw RTs deviated significantly from the normal distribution in both groups in all conditions (all *ps* < .001). The ex-Gaussian parameter of mean RT (μ) was larger in the HI than in the LI group, $F(1, 18) = 7.68$, $p < .05$, $\eta_p^2 = .30$ The main effect of Task difficulty was significant, $F(2, 36) = 62.61$, $\varepsilon = .60$, $p < .001$, $\eta_p^2 = .78$. Congruency was also significant, $F(2, 36) = 283.05$, $\varepsilon = .56$, $p < .001$, $\eta_p^2 = .94$. These were overridden by a Task difficulty * Congruency significant interaction, $F(2, 36) = 7.25$, $\varepsilon = .64$, $p < .001$, $\eta_p^2 = .29$. In every Congruency condition, μ at high difficulty was higher than at low and at medium difficulty ($p < .001$). In every Task difficulty condition, incongruent μ was higher than congruent or neutral values. In every Congruency condition, μ was higher at high difficulty than at medium difficulty ($p < .001$). In congruent and neutral conditions, μ was higher at medium difficulty than at low difficulty ($p < .001$). HI participants had larger σ value than LI participants, $F(1, 18) = 5.06$, $p < .05$, $\eta_p^2 = .22$. The main effects of Task difficulty, $F(2, 36) = 6.83$, $p < .01$, $\eta_p^2 = .28$, and Congruency, $F(2, 36) = 37.59$, $\varepsilon = .69$, $p < .001$, $\eta_p^2 = .68$, were significant. The σ was larger for incongruent trials than for congruent ($p < .001$) or neutral ones ($p < .001$). The σ was larger at high than at low ($p < .01$) or at medium difficulty level ($p < .01$). The τ tended to be larger in the HI than in the LI group, $F(1, 18) = 3.66$, $p = .072$, $\eta_p^2 = .17$. The main effect of Congruency was significant, $F(2, 36) = 6.49$, $\varepsilon = .69$, $p < .001$, $\eta_p^2 = .27$. Incongruent trials had larger τ than congruent ($p < .05$) and neutral ones ($p <$

.05). The interaction between Task difficulty and Congruency was only marginally significant, $F(2, 36) = 2.84$, $\varepsilon = .69$, $p = .052$, $\eta_p^2 = .27$.

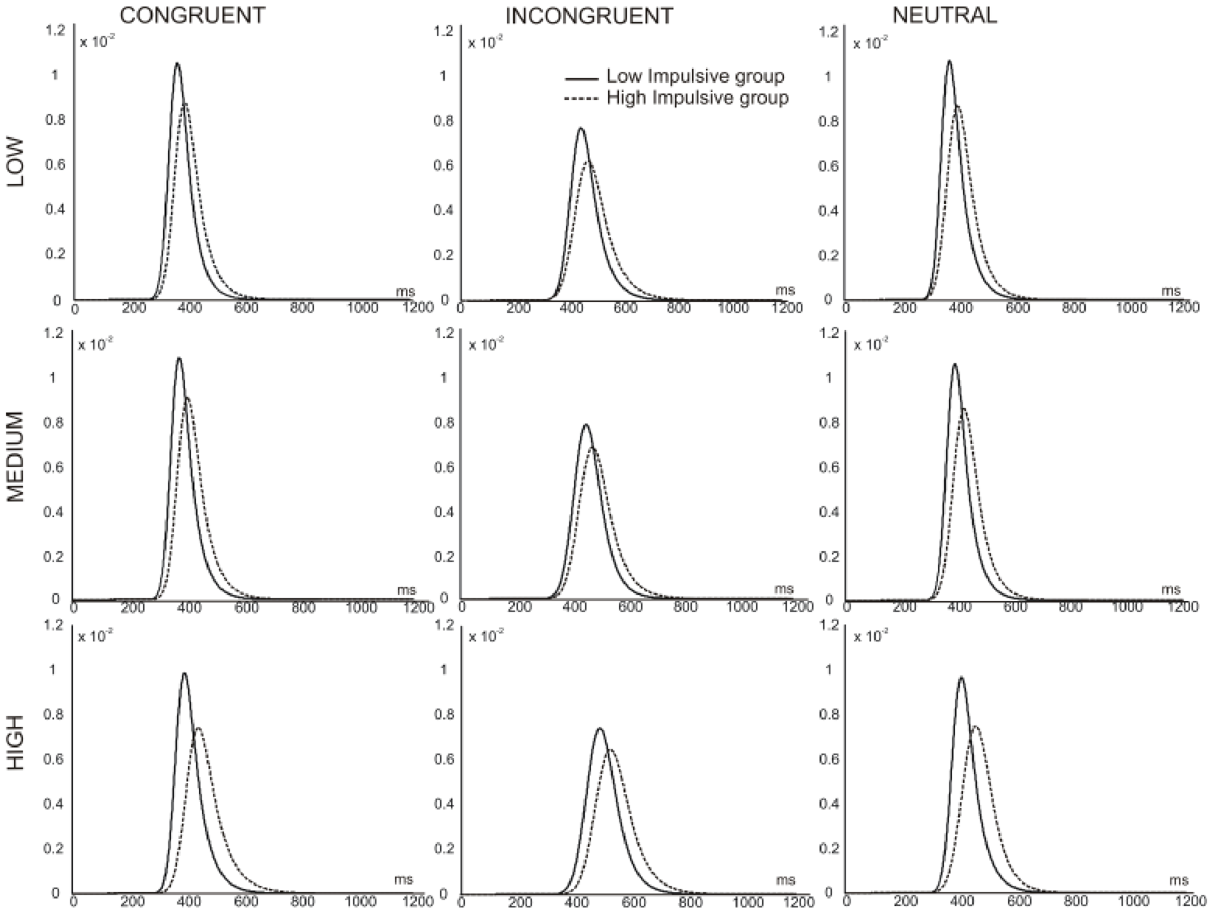

Figure 2: Ex-Gaussian distributions fitted to RTs in congruent, incongruent and neutral conditions. Ex-Gaussian distributions are expressed as probability densities.

3.2. Responses in incongruent trials

In correct incongruent trials, LI participants responded significantly faster than HI participants, $F(1, 18) = 5.89$, $p < .05$, $\eta_p^2 = .25$. The main effect of Task difficulty was also significant, $F(2, 36) = 32.55$, $\varepsilon = .69$, $p < .001$, $\eta_p^2 = .64$, showing that trials with high difficulty level were responded slower than trials with medium ($p < .001$) or with low difficulty level ($p < .001$). On RTs of incorrect trials, only the effect of Task difficulty was significant, $F(2, 36) = 32.55$, $p < .001$, $\eta_p^2 = .41$. Participants responded slower at high difficulty than at medium (p < .001) or at low (p < .001) Task difficulty. Considering error ratio, Task difficulty revealed a marginally significant main effect, $F(2, 36) = 3.93$, $\varepsilon = .54$, $p = .059$ $\eta_p^2 = .18$, indicating that all participants erred more in the high difficulty condition than in the medium ($p < .001$) or in the low difficulty ($p < .001$) conditions. The analysis of post-error slowing yielded a significant main effect of Group, $F(1, 18) = 9.62$, $p < .01$,$\eta_p^2 = .05$, showing that high impulsive participants responded slower before and also after the incongruent incorrect response than those with low impulsivity. The main effect of Task difficulty was also significant, $F(2, 36) = 39.37$, $p < .001$, $\varepsilon = .77$, $\eta_p^2 = .03$, in line with the general RT findings described above. Responses on the error-subsequent trials were generally slower than on error preceding trials, $F(2, 36) = 60.28$, $p < .001$, $\varepsilon = 1.0$, $\eta_p^2 = .77$, irrespective of the effect of impulsivity. Mean RTs to incongruent trials split by condition and a summary of ERP findings are presented in Table 1.

3.3. ERP results

Considering the Ne amplitude, we obtained a significant group difference, $F(1, 18) = 5.56$, $p < .05$, $\eta_p^2 = .24$, which was overwritten by a Group * Task difficulty interaction, $F(2, 36) = 3.61$, $p < .05$,$\eta_p^2 = .17$. The HI group showed an attenuated Ne compared to LI group in the medium ($p < .05$), and in the high difficulty ($p < .05$) conditions, but not in the low difficulty condition. For LI participants, the Ne was enhanced in medium difficulty level compared to the low level ($p < .05$). In the HI group, the amplitude of Ne was lower in the high difficulty than in the low condition ($p < .05$). We did not find any group difference or experimental effect on Ne latency and on the Pe amplitude and latency. Grand average ERP waveforms and ERP results at electrode Cz are summarized in Figure 3.

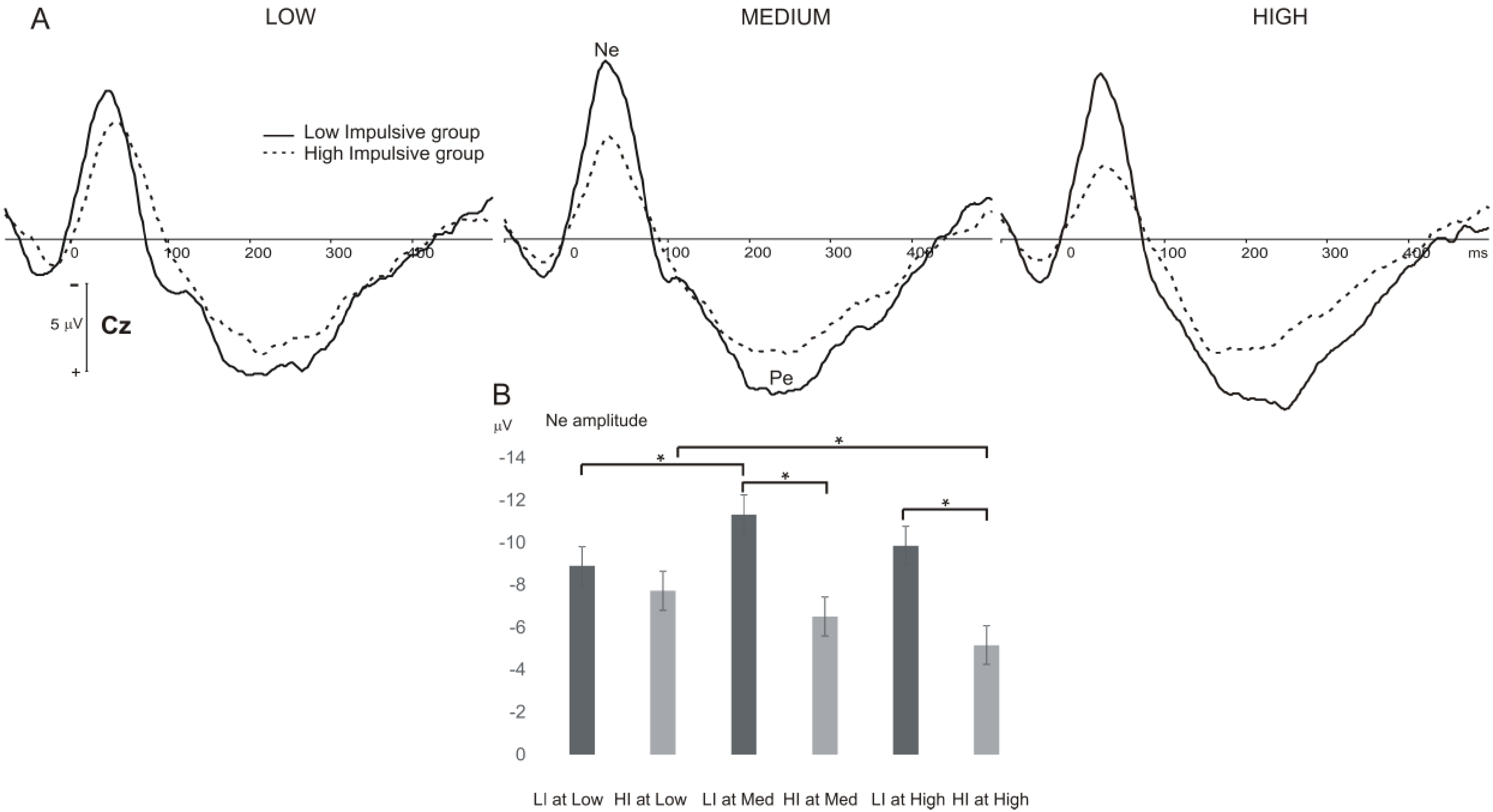
A
LOW
MEDIUM
HIGH
Low Impulsive group
High Impulsive group
Ne
Pe
0
100
200
300
400
ms
5 μV
Cz
B
μV
Ne amplitude
-14
-12
-10
-8
-6
-4
-2
0
*
LI at Low
HI at Low
LI at Med
HI at Med
LI at High
HI at High

Figure 3: Grand average ERP waveforms (Ne and Pe) at electrode Cz for each group (A). Negativity is plotted upwards. Ne amplitude data (B) divided by Group (LI, colored with dark grey, HI, colored with brighter grey) and condition (Low – low task difficulty, Med – medium task difficulty, High – high task difficulty). Error bars present +/- 1 SD. *$p < .05$

3.4. Correlational results

We found significant correlations between Ne amplitude and RTs only at high Task difficulty level for incongruent trials: for correct responses $r(18) = .55$, $p < .05$, and for incorrect responses $r(18) = .67$, $p < .01$. These indicated that faster responding was associated with enhanced Ne. At the same time, Ne latencies and Pe data did not correlate with incongruent RTs. Furthermore, we did not find significant correlations between the amplitude and latency data of Ne and Pe, and the index of post-error slowing.

4. Discussion

In the present study we compared Ne and Pe components as psychophysiological markers of error processing between HI and LI adults to investigate the flexible adaptation in trait impulsivity. Overall, the Ne amplitude was smaller in HI than in LI, in line with our hypothesis and with the previous studies (Martin & Potts, 2009; Potts et al., 2006), including an alternative approach where impulsivity was measured by a faster response style instead of self-reports (Ruchsow, Spitzer, Gron, Grothe, & Kiefer, 2005). However, the group difference obtained in our study appeared only in high and medium task difficulty, indicating that performance monitoring is only impaired in impulsivity when more effort is needed to fulfill the task requirements. We may conclude that adjustment to task difficulty is altered in impulsivity, in line with the above described self-monitoring impairment (Martin & Potts, 2009). The Ne increased with task difficulty from low to medium levels in the LI group. In contrary, the Ne decreased between low and high difficulty levels in the HI group. Without significant differences between task difficulty levels in error ratio, we cannot confirm that our experimental manipulation affected the perceived level of uncertainty, which could have decreased the Ne amplitude (Endrass et al., 2012). However, it is possible that LI participants were less sensitive to the difficulty manipulation, enabling to focus only on the cognitive conflict, and to solve the task with faster responses than participants from the HI group. The decreasing effect on Ne was obtained only in the HI group. To clarify the functional significance of this finding, further studies should be conducted. We should point out that despite the attenuated performance monitoring at a neural level, HI participants did not differ from the LI group in error ratio. The same discrepancy between the ERP and the accuracy results appeared in a study with externalizing participants (Hall et al., 2007). Hall et al. (2007) suggests that successful performance in a flanker task does not need complex processing, but an increase in task difficulty could sharpen problems in cognitive control and monitoring leading to group differences at the behavioral level. However, in our study, the interacting effect between task difficulty and impulsivity was present only at the neural level. Contrary to our assumption and the appearance of grand average ERP waveforms (see Fig. 2), the two groups did not differ either in the amplitude or in the latency of Pe. The lack of this difference could have been caused by a power issue. To clarify the relationship between impulsivity and later stages of error processing, further studies are needed with larger sample size.

Slower responding in HI than in LI participants could be counterintuitive, and this finding also contradicts some previous results (e.g., Burnett Heyes et al., 2012, Pailing et al., 2002, Ruchsow et al., 2005). However, Russo et al. (2008) also reported slower responses in high impulsivity than in low impulsivity. The authors suggested that while impulsivity is characterized by rapid decisions, a rather long and monotonous task with demanding sustained attention could lead to slower task solving. In the same study, we analyzed the correct responses in a larger sample (Kóbor et al., 2014), where the RT difference between the two groups was in line with the ERP findings. Namely, P3 was delayed in HI participants, and the Lateralized Readiness Potential (LRP) peaked later in the HI group than in the LI group, as well, irrespective of other experimental effects. It was previously shown (Bari & Robbins, 2013) that impulsive individuals were faster than non-impulsive individuals in situations where decisions should be quick and the task was easy (e.g., visual categorization). However, we introduced a rather long task with different levels of difficulty.

Longer responses were reported in relation to higher BIS scores in other EF tasks, as well (Gorlyn et al., 2005, Pietrzak et al., 2008). Furthermore, the ex-Gaussian τ and σ parameters were also larger in the HI than in the LI group. These parameters could give insight to the slower responses. High σ could mean larger heterogeneity of RTs in the HI group compared to the LI group. The marginally larger τ value in the HI group may indicate more frequent attentional lapses. We may conclude that our results are in line with the impulsivity concept of Arce and Santisteban (2006), where impulsivity could represent a "lost chain between knowledge and action (pp. 215)."

Correlations between Ne amplitude and RTs suggest that error detection was more pronounced at high difficulty level when responses were faster. Slips in performance can occur more likely when participants are under stress, as the task difficulty is increased. The detection of an error has greater functional significance in this case, since an increased allocation of attention or cognitive control is necessary to meet the task's requirements (Simons, 2010).

Impulsivity was not related to Ne amplitude in the study of Amodio et al., 2008. They used the BIS-BAS approach to underpin the relationship between personality and error processing. The BAS corresponds to behavior regulation (Amodio et al., 2008), which is similar to the altered motivational system in impulsivity (Martin & Potts, 2009). However, the BAS suggests an adaptive response style, in contrast with the characteristics of impulsivity (Boy et al., 2011; Stanford et al., 2009). Our results are in line with previous studies using the BIS-11 (Martin & Potts, 2009; Potts et al., 2006). To understand the role of impulsive personality trait in error detection and self-monitoring, further studies are needed with other types of impulsivity questionnaires. As a limitation, we should note that this version of the flanker task was not developed to enhance the error level. Therefore, our result can be generalized only for situations where errors are rare.

In sum, the automatic error detection seems to be impaired in high trait impulsivity. The difference in self-monitoring between LI and HI groups only appeared when participants had to flexibly regulate their behavior to an increase in task difficulty. Impaired performance monitoring in case of impulsivity has a functional significance for learning from errors and avoiding maladaptive behavior, as it was previously shown in externalizing problems and impulsive antisocial behavior (Hall et al., 2007; Heritage & Benning, 2013). While impulsivity is a risk factor to develop ADHD or substance use disorders (Olvet & Hajcak, 2008), there is still a debate whether the presence of milder symptoms in the population is a subclinical part of the same dimension, or a distinct category (Boy et al., 2011; Kóbor, Takács, Urbán, & Csépe, 2012).

Previous studies emphasized the effect of altered motivation on error processing in impulsivity (Martin & Potts, 2009; Potts et al., 2006). Furthermore, our present results suggest that error sensitivity in impulsivity is generally decreased.

Footnote

1: If we measured Pe as the mean amplitude between 150 and 350 ms after an erroneous response, we obtained the same results as presented below.

References

Amodio, D. M., Master, S. L., Yee, C. M., & Taylor, S. E. (2008). Neurocognitive components of the behavioral inhibition and activation systems: Implications for theories of self-regulation. *Psychophysiology, 45*(1), 11-19.

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders, fourth edition, text revision (DSM-IV-TR)*. Arlington, VA: American Psychiatric Association.

Boy, F., Evans, C. J., Edden, R. A., Lawrence, A. D., Singh, K. D., Husain, M., & Sumner, P. (2011). Dorsolateral Prefrontal γ-Aminobutyric Acid in Men Predicts Individual Differences in Rash Impulsivity. *Biological Psychiatry, 70*(9), 866-872.

Burnett Heyes, S., Adam, R. J., Urner, M., van der Leer, L., Bahrami, B., Bays, P. M., & Husain, M. (2012). Impulsivity and rapid decision-making for reward. *Frontiers in Psychology, 3*, 153. doi:10.3389/fpsyg.2012.00153

Endrass, T., Klawohn, J., Gruetzmann, R., Ischebeck, M., & Kathmann, N. (2012). Response-related negativities following correct and incorrect responses: Evidence from a temporospatial principal component analysis. *Psychophysiology, 49*(6), 733-743.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components: II. Error processing in choice reaction tasks. *Electroencephalography & Clinical Neurophysiology, 78*(6), 447-455. doi: 10.1016/0013-4694(91)90062-9

Farr, O. M., Hu, S., Zhang, S., & Li, C.-S. R. (2012). Decreased saliency processing as a neural measure of Barratt impulsivity in healthy adults. *NeuroImage, 63*(3), 1070–7. doi:10.1016/j.neuroimage.2012.07.049

Gehring, W. J., Goss, B., Coles, M. G., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4*(6), 385-390.

Gorlyn, M., Keilp, J. G., Tryon, W. W., & Mann, J. J. (2005). Performance test correlates of component factors of impulsiveness. *Personality and Individual Differences, 38*(7), 1549–1559. doi:10.1016/j.paid.2004.09.014

Hall, J. R., Bernat, E. M., & Patrick, C. J. (2007). Externalizing psychopathology and the error-related negativity. *Psychological Science, 18*(4), 326-333. doi: 10.1111/j.1467-9280.2007.01899.x

Heritage, A. J., & Benning, S. D. (2013). Impulsivity and response modulation deficits in psychopathy: Evidence from the ERN and N1. *Journal of Abnormal Psychology, 122*(1), 215.

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review, 109*(4), 679–709. doi:10.1037//0033-295X.109.4.679

Johnstone, S. J., Watt, A. J., & Dimoska, A. (2010). Varying required effort during interference control in children with AD/HD: task performance and ERPs. *International Journal of Psychophysiology, 76*(3), 174-185. doi: 10.1016/j.ijpsycho.2010.03.010

Kóbor, A., Takács, Á., Urbán, R., & Csépe, V. (2012). The latent classes of subclinical ADHD symptoms: Convergences of multiple informant reports. *Research in Developmental Disabilities, 33*(5), 1677-1689.

Kóbor, A., Takács, A., Honbolygó, F., & Csépe, V. (2014). Generalized lapse of responding in trait impulsivity indicated by ERPs: the role of energetic factors in inhibitory control. *International Journal of Psychophysiology*. 92(1), 16-25. doi:10.1016/j.ijpsycho.2014.01.008

Lawrence, A. J., Luty, J., Bogdan, N. a, Sahakian, B. J., & Clark, L. (2009). Impulsivity and response inhibition in alcohol dependence and problem gambling. *Psychopharmacology, 207*(1), 163–72. doi:10.1007/s00213-009-1645-x

Li, C. R., Huang, C., Yan, P., Bhagwagar, Z., Milivojevic, V., & Sinha, R. (2008). Neural correlates of impulse control during stop signal inhibition in cocaine-dependent men. *Neuropsychopharmacology, 33*(8), 1798–806. doi:10.1038/sj.npp.1301568

Martin, L. E., & Potts, G. F. (2009). Impulsivity in Decision-Making: An Event-Related Potential Investigation. *Personality and Individual Differences, 46*(3), 303. doi: 10.1016/j.paid.2008.10.019

Meyer, A., Riesel, A., & Proudfit, G. H. (2013). Reliability of the ERN across multiple tasks as a function of increasing errors. *Psychophysiology*, n/a-n/a. doi: 10.1111/psyp.12132

Olvet, D. M., & Hajcak, G. (2008). The error-related negativity (ERN) and psychopathology: Toward an endophenotype. *Clinical Psychology Review, 28*(8), 1343-1354.

Olvet, D. M., & Hajcak, G. (2009). Reliability of error-related brain activity. *Brain Research, 1284*, 89-99. doi: 10.1016/j.brainres.2009.05.079

Pailing, P. E., Segalowitz, S. J., Dywan, J., & Davies, P. L. (2002). Error negativity and response control. *Psychophysiology, 39(2)*, 198–206. doi:10.1111/1469-8986.3920198

Pietrzak, R. H., Sprague, A., & Snyder, P. J. (2008). Trait impulsiveness and executive function in healthy young adults. *Journal of Research in Personality, 42*(5), 1347–1351. doi:10.1016/j.jrp.2008.03.004

Potts, G. F., George, M. R., Martin, L. E., & Barratt, E. S. (2006). Reduced punishment sensitivity in neural systems of behavior monitoring in impulsive individuals. *Neuroscience Letters, 397*(1-2), 130-134. doi: 10.1016/j.neulet.2005.12.003

Rózsa, S., Szádóczky, E., & Füredi, J. (2001). A Beck Depresszió Kérdőív rövidített változatának jellemzői hazai mintán. *Psychiatria Hungarica, 16*(4), 379-397.

Ruchsow, M., Spitzer, M., Gron, G., Grothe, J., & Kiefer, M. (2005). Error processing and impulsiveness in normals: evidence from event-related potentials. *Brain Research, Cognitive Brain Research, 24*(2), 317-325. doi: 10.1016/j.cogbrainres.2005.02.003

Russo, P. M., De Pascalis, V., Varriale, V., & Barratt, E. S. (2008). Impulsivity, intelligence and P300 wave: an empirical study. *International Journal of Psychophysiology, 69(2)*, 112–8. doi:10.1016/j.ijpsycho.2008.03.008

Simons, R. F. (2010). The way of our errors: Theme and variations. *Psychophysiology, 47*(1), 1-14.

Sipos, K., & Sipos, M. (1983). The development and validation of the Hungarian Form of the State-Trait Anxiety Inventory. *Series in Clinical & Community Psychology: Stress & Anxiety*.

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences, 47*(5), 385-395. doi: http://dx.doi.org/10.1016/j.paid.2009.04.008

Wiersema, J. R., van der Meere, J. J., & Roeyers, H. (2009). ERP correlates of error monitoring in adult ADHD. *Journal of Neural Transmission, 116*(3), 371–9. doi:10.1007/s00702-008-0165-x