Graduate Thesis

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RELATING MEASURES OF EXECUTIVE FUNCTIONING

THE RELATIONSHIP BETWEEN THE P3NoGo EVENT-RELATED POTENTIAL AND THE BEHAVIOR RATING INVENTORY OF EXECUTIVE FUNCTIONING FOR ADULTS

Acknowledgements

Abstract

The objective assessment of executive functions (EFs) as they manifest themselves in everyday life has long been a challenge for neuropsychologists. So has understanding the relationship between different EF measures. A promising approach in the assessment of executive functioning is the method of event-related potentials (ERPs). In this study we investigate whether the P3NoGo ERP from a visual cued Go/NoGo paradigm relates to the Behavioral Rating Inventory of Executive Functioning (BRIEF-A), a self-report measure of peoples everyday executive functioning. The results show that the P3NoGo amplitude correlates strongly with the Global Executive Composite (GEC) score on the BRIEF-A. Post-hoc analyses revealed that the relation to the Metacognition Index (MI), one of three BRIEF-A indexes, could mainly explain the correlation. This index is thought to represent the ability to control attention and cognitively plan, solve problems and monitor performance. We conclude that there is a significant relationship between two relatively different EF-related measures, namely P3NoGo and self-reported everyday executive functioning measured with BRIEF-A. Furthermore we suggest that an important underlying factor in this relationship is metacogntive control processes.

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Understanding how the human brain works is essential for developing theories of human functioning. Within the field of neuropsychology this knowledge is central to diagnosing and treating brain dysfunctions in the best possible way. Executive functions (EFs) is a group of higher-order functions responsible for controlling and coordinating other cognitive processes. They are important for adaptive living, as they allow us to quickly shift our attention and change plans in an ever-changing environment and to inhibit or execute goal-directed behaviors. Whether EFs consist of one underlying or general *g* component (Duncan, Emslie, Williams, Johnson, & Freer, 1996) or involve a set of integrated yet separable processes (Miyake et al., 2000) is a matter of much debate. However there is an agreement that EFs involve widespread circuits and areas of the human brain, with the prefrontal cortex playing an essential role. Impairment in executive functioning is evident in a number of disorders such as Schizophrenia, ADHD, traumatic brain injury and major depressive disorder (Hestad & Egeland, 2010). Understanding EF processes will help us correctly assess the cognitive functioning of these patient groups, and perhaps most importantly detect the patient's resources and predict the challenges he or she is likely to meet, thereby guiding necessary interventions and treatment (Gioia & Isquith, 2004; Roth, Isquith, & Gioia, 2005).

1.1 Measuring executive functions

One challenge we face regarding the treatment of executive dysfunction is the lack of a straightforward way of accurately measuring it. Often practitioners rely upon several EF measures because these may capture different aspects of EFs. Also it is not well understood exactly how different EF measures relate to each other. Since EFs may consist of separable components, an accurate measurement capturing these components is dependent on measurement specificity. On the other hand, too much specificity may result in decreased

ecological validity, as real-life EF appliance is dependent upon cooperation between and coordination of numerous processes. Traditionally one has applied the method of neuropsychological (NP) testing, but this is found to relate only moderately or poorly to real-life functioning, measured by self-report and informant report questionnaires (Chaytor & Schmitter-Edgecombe, 2003; García-Molina, Tirapu-Ustárroz, & Roig-Rovira, 2007; Odhuba, van den Broek, & Johns, 2005; Payne, Hyman, Shores, & North, 2011). Another limitation with NP testing is the task impurity problem, referring to the challenge that all NP tests involve multiple abilities, including executive processes other than those you want to measure. It is therefore difficult to understand from a poor test result which EF problems the patient is struggling with, or whether the results are due to non-EF processes such as motor or other cognitive disabilities (Friedman et al., 2008; Hughes & Graham, 2002; Jurado & Rosselli, 2007). Also, as IQ and EF are found to be related (Arffa, 2007; Kalbfleisch & Loughan, 2012) results on NP tests may be caused by variance in IQ.

Another measure of EFs, frequently used in clinical settings, is that of self-report questionnaires (Egeland, 2010; Roth et al., 2005; Vaskinn & Egeland, 2012). An important advantage with these is that they contain valuable information on how patients experience their own everyday executive functioning. However one challenge with self-report measures is that their validity may be affected by a person's self-understanding and awareness, reading skills and cognitive abilities (Morey, 2007; Roth et al., 2005).

1.2 Event-related potentials as a measure of executive functioning

One measurement method that may overcome the above-mentioned problems is event-related potentials (ERPs). ERPs reflect the electrical activity of the human brain associated with specific sensory, cognitive and motor events, based on electroencephalography (EEG) recorded during a task or sensory stimulation. These potentials are sampled continuously

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throughout the execution of the task, yielding measurements with a temporal resolution of 1 ms under optimal conditions (Luck, 2005). Several different ERP waves have been identified, some of which are related to lower-order processes, such as the sensory components (Luck, 2005), while others are used for assessing and examining higher-order executive functioning (Stroth et al., 2009; Weisbrod, Kiefer, Marzinzik, & Spitzer, 2000). Some of these higher-order ERPs have been shown related to NP tests (Brunner et al., 2014) and there are indications of a relationship between higher-order ERP attributes, for example the amplitude, and psychological disorders with associated executive dysfunction (Howe, Bani-Fatemi, & De Luca, 2014; Roca et al., 2012; Weisbrod et al., 2000). In order to evoke these higher-order executive ERPs, certain cognitively demanding task paradigms must be applied. Examples of such tasks are Stroop tasks (shifting attention), continuous performance tests (sustaining attention) and NoGo/signal stop tasks (inhibiting responses).

The ERP method has several advantages. First, the high time resolution of ERPs (Luck, 2005) allows us to examine separate phases of neurocognitive processes, as they occur at different stages of a task. Second, the ERP parameters reflect individual differences in neurocognitive functioning without disturbance from variance in various motor abilities. These advantages may be steps towards solving the impurity problem. Third, the fact that the ERP method is a more direct and objective method of measuring neurocognitive processes may reduce some of the biases related to self-report measures, namely self-awareness and cognitive and reading skills issues. Finally, ERPs allow assessment of executive processes with no behavioral response, and thus make it possible to test EFs in patients with movement disabilities (Paulus et al., 2002).

Since the ERP method may overcome some of the limitations of other EF measures, it is a promising method for assessing EFs. In order for it to become a more useful tool in a clinical setting, however, it would be advantageous to relate specific ERPs to actual

functioning in everyday situations (Chang, Davies, & Gavin, 2009). In this way practitioners would gain more knowledge as to what real life outcome individual differences in ERP parameters reflect. Current research suggests a relationship between specific ERPs and questionnaire measures of everyday-life functioning (Chang et al., 2009; Dywan & Segalowitz, 1996; Miller, Watson, & Strayer, 2012; Roca et al., 2012). As far as we know, however, only a few studies have investigated this relationship and only a few ERPs have been investigated, implying the need for further research on this topic. In order to further investigate the relationship between specific ERPs and assessment measures related to people's everyday executive challenges, a suitable ERP and measure of real-life functioning must be identified.

1.3 The ERPs in the cued Go/NoGo paradigm

A much applied paradigm for studying ERPs is the cued Go/NoGo paradigm. This paradigm may be applied in order to examine response selection abilities and it evokes several ERPs. The Go/NoGo task consists of a cue followed by either a Go target requiring a response (Go condition) or a NoGo target which should not be responded to (NoGo condition). In the intervals between the cue and target stimuli a negative ERP known as the contingent negative variation (CNV) is evoked. Around 200-260 ms after the presentation of a NoGo target stimuli (Kropotov, 2009) the N2 component, thought to reflect conflict processing, can be recognized (Huster, Enriquez-Geppert, Lavallee, Falkenstein, & Herrmann, 2013).

In the case of a correct response in a Go condition the P3 ERP is elicited. This is a positive wave occurring around 300-400 ms after presentation of the target stimulus. A related ERP, the P3NoGo, is evoked in the NoGo condition, namely when there is a need to suppress and override an already prepared response. Several studies have found a link between

P3NoGo and inhibition (Bruin, Wijers, & van Staveren, 2001; Kropotov, Ponomarev, Hollup, & Mueller, 2011; J. L. Smith, Johnstone, & Barry, 2006). However, Huster et al. (2013) argue that the P3NoGo appears too late to correspond to the actual motor inhibition and Bruin et al. (2001) suggest that the P3NoGo may instead be associated with the monitoring of the inhibitory response. Both the P3Go and the P3NoGo are associated with the investment of effort, as trials with shorter reaction times evoke larger ERPs than do longer reaction times (Dimoska, Johnstone, & Barry, 2006; Gajewski & Falkenstein, 2013; J. L. Smith et al., 2006). A P3-like response is also elicited in other modalities and test paradigms, an important one being the auditive oddball paradigm. This P3 ERP is related to uncertainty and probability (Johnson, 1986), and a suggested role for this P3 wave is the transfer of information to consciousness (Picton, 1992). Regardless of its exact functional meaning the P3NoGo is an interesting ERP for our purpose because it is evoked in a situation that requires executive functioning, such as an ability to change plans and being flexible in a changing environment. Furthermore a number of neuropsychological disorders are associated with decreased P3NoGo amplitude, such as alcoholism (Colrain et al., 2011), Attention Deficit Hyperactivity Disorder (Fallgatter et al., 2004) and Schizophrenia (Olbrich, Maes, Valerius, Langosch, & Feige, 2005), implicating that this ERP can be clinically relevant. The P3NoGo amplitude has been related to NP test results (Brunner et.al, 2014) but as far as we know no studies have been conducted on the relationship between the P3NoGo and executive functioning in everyday life, making this ERP an interesting candidate for such research.

1.4 Behavior Rating Inventory of Executive Functioning for Adults (BRIEF-A)

The BRIEF-A is a standardized questionnaire measuring people`s experience of their executive functioning in everyday life (Roth et al., 2005) and is widely used in psychological clinical practice (Egeland, 2010; Vaskinn & Egeland, 2012). There are several versions of

BRIEF, according to age groups (preschool, school, adult) and type of respondents (parent, teacher and self-report) (Roth et al., 2005).

The BRIEF- A scores consist of a summary score, the Global Executive Composite (GEC), and nine subscales clustered into broader indexes. Both factor and content analysis were applied in order to divide the single items into meaningful scales and indexes (Roth et al., 2005). Traditionally, the subscales have been clustered into the two indexes, the Behavioral Regulation Index (BRI) and the Metacognition Index (MI). However, there is growing support for a three-factor model, consisting of the BRI, the MI and the Emotional Regulation Index (ERI) (Roth, Lance, Isquith, Fischer, & Giancola, 2013). The BRI is composed of the subscales Inhibit and Self-Monitor and represents the ability to regulate behavior, control impulses and understand the effect one's behavior has on others. The MI contains the subscales Task Monitor, Initiate, Working Memory, Plan/Organize and Organization of Materials, reflecting the ability to control attention and cognitively plan, solve problems and monitor performance. Finally the ERI consists of the subscales Emotional Control and Shift related to emotional regulation as well as cognitive and behavioral flexibility (Roth et al., 2005).

A number of studies support the validity of BRIEF (Kalbfleisch & Loughan, 2012; Mahone et al., 2002; Sesma, Slomine, Ding, & McCarthy, 2008) and BRIEF-A (Olsen et al., 2014; Roth et al., 2005) as EF measures, and the self-report version tends to be moderately to highly correlated with informant versions (Ciszewski, Francis, Mendella, Bissada, & Tasca, 2014; Roth et al., 2005). However as described in the next section only a few studies have related BRIEF and BRIEF-A to specific neural correlates like ERPs.

1.5 The relationship between ERPs and everyday-life executive functioning

As mentioned, a few studies have investigated the relationship between specific ERPs and self-report measures of everyday executive functioning. Dywan and Segalowitz (1996) found a relationship between the CNV wave and initiation and planning domains of the Brock Adaptive Functioning Questionnaire (BAFQ) in a population with traumatic brain injury. There are indications that the error-related ERN and Pe ERPs are related to the subscales of task monitoring and working memory of the BRIEF-A (Chang et al., 2009; Miller et al., 2012) and that P3 in an oddball paradigm is associated with a number of subscales on the parent-reported BRIEF in children with ADHD (Roca et al., 2012). These studies suggest a relationship between certain ERPs and everyday executive functioning as measured with questionnaires on clinical populations.

1.6 Research hypothesis

The goal of this study is to investigate whether two EF- related measures, namely the P3NoGo ERP with parameters acquired from brain activity and the BRIEF-A self-report measuring how people experience their everyday executive functioning, correlate with each other. Since the P3NoGo has been suggested to reflect aspects of both behavioral regulation (inhibition) and metacognition (controlled attention, monitoring), and since some theories argue for EFs as a unitary construct (see for example "The Supervisory attentional System's theory" of Norman & Shallice, 1986), we first want to investigate whether the P3NoGo is related to self-reported EFs in general, as reflected by the GEC. Since both the GEC score on the BRIEF-A and the P3NoGo amplitude are thought to reflect underlying EFs, we would expect them to measure the same underlying g factor and thus be related.

Accordingly, we hypothesize that there is a negative relationship between the P3NoGo amplitude and the overall GEC score on the BRIEF-A.

The reason we expect a negative relationship is that a larger P3NoGo amplitude is associated with better executive functioning (Brunner et al., 2014; Kamarajan et al., 2005) and so is a lower score on BRIEF-A.

However, GEC is a very general measure. According to Miyake et al. (2000) and the theory of "unity - yet separability" of the EF construct, it would be meaningful not to treat EF solely as a unitary construct. In line with this theory is research showing that the P3NoGo represents some but not all aspects of EFs (Bruin et al., 2001; Brunner et al., 2014; Smith et al., 2006). Relating it to the GEC provides little information as to what kind of everyday executive problems a relationship between them would indicate. The results on the BRIEF- A can be divided into scores on different levels, and Roth et al. (2005) recommend using the indexes rather than the GEC score when applying the BRIEF-A clinically. Thus *if* we find a relationship between P3NoGo and GEC, we want to examine the relationship between P3NoGo and the three separate BRIEF-A indexes. This may tell us whether some of the indexes MI, BRI or ERI, can explain a P3NoGo-GEC relationship more than others. Gaining more specificity as to which problems the patient is struggling with could make the tool more useful in the clinic.

As IQ is suggested to be related to everyday executive functioning (Kalbfleisch & Loughan, 2012) and the results on NP tests (Arffa, 2007), the present study should control for a possible effect of Full Scale (FS) IQ on the relationship between the P3NoGo and the BRIEF indexes. Duncan et al. (1996) suggest that fluid intelligence aspects of IQ, also described as novel problem solving, is closely related to an underlying *g* factor explaining general frontal lobe and executive processes. Thus one should control for the fluid

intelligence variable in addition to FS IQ. Also, energization is a factor found to affect executive functions. Energization can be described as a facilitating process that is necessary for initiating and maintaining any effortful process, and reaction time (RT) is found to be a sensitive indicator of this variable (Stuss & Alexander, 2007). RT is shown to affect the P3NoGo amplitude (Dimoska et al., 2006; Gajewski & Falkenstein, 2013; Smith et al., 2006) and we would expect that the mechanisms behind variance in RT would also affect peoples executive functioning in everyday situations. As energization, measured by RT may be a moderating factor in the P3NoGo-BRIEF relationship this variable should also be controlled for.

Method

2.1 Participants

ERP data were collected from 28 healthy adult subjects doing a cued Go/NoGo task. Participants were recruited through ongoing projects on mild traumatic brain injury and young adults born with very low birth weight related to "Hodeskadeprosjektet". The participants underwent intelligence testing (WAIS-III) and filled out forms on BRIEF-A, data that was included in the further analysis. All of the participants gave their written consent to be included in the study, and the project was approved by the Regional Committee for Medical Research Ethics.

2.2 Cued Go/NoGo task

The 28 participants performed a visual cued Go/NoGo task (see Figure 1). The visual cued Go/NoGo task consisted of 400 (4*100) stimulus pairs, presented with three second intervals between the pairs, and one second interval between the paired stimuli. The stimulus presentation had a duration of 100 ms. The group of stimuli included 20 plants (P), 20 animals (A) and pictures of humans in 20 different occupations (H) presented together with an intrusive sound. There were four different and equiprobable stimulus pair compositions, namely A-A (Go condition), A-P (No-Go condition) P-P (Ignore-condotion) and P-H (Ignore/distractor condition). In the A-A condition the two animal pictures were identical and in the P-P conditions the two plant pictures were identical. The subjects were instructed to push a button with their right hand as quickly as possible upon detecting an A-A pair, and not to push the button after any of the other pairs. Only data recorded during successful NoGo trials, namely when not pushing the button in a No-Go condition, was included in the final data analysis.

Figure 1 The cued Go/NoGo task
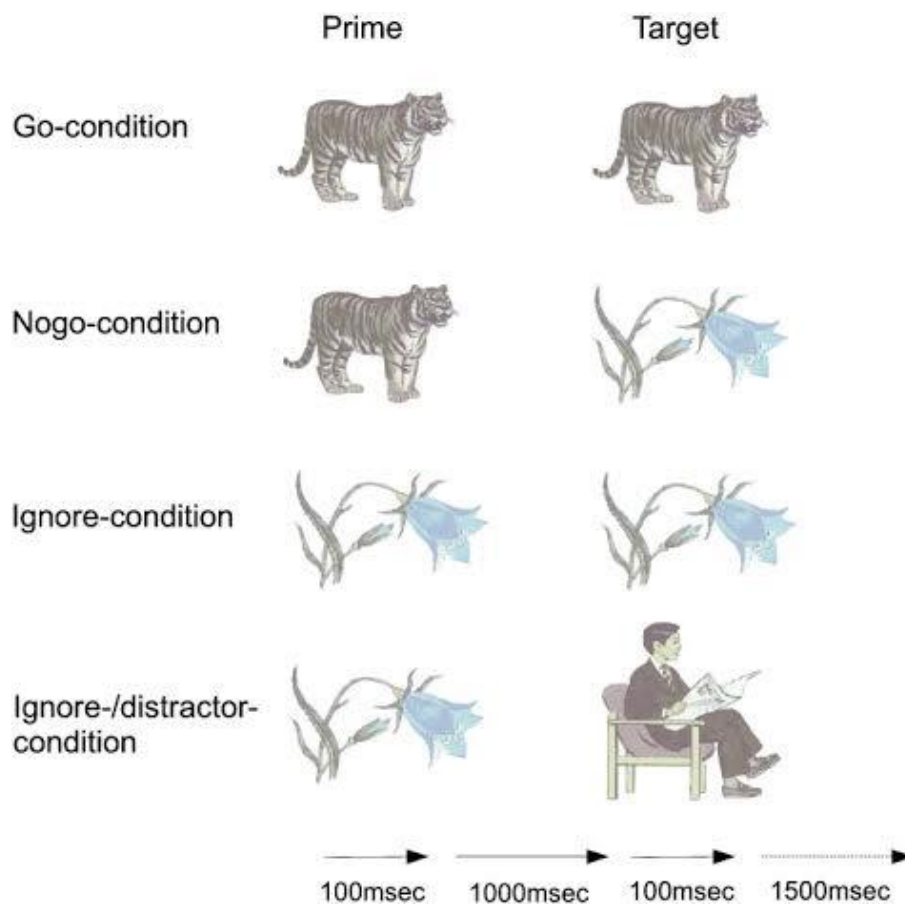
Figure 1. The cued Go/NoGo task. The left column shows the first stimulus (prime) and the right column shows the second stimulus (target), separated by the time interval. The four rows show the four task conditions.

2.3 EEG recording

The EEG system used for this study was bought from Mitsar (bandpass 0.3 Hz-50 Hz, sampling rate 250 Hz) and includes an electron cap with 19 electrodes. The placement of electrodes on the scalp was done in conjunction with the 10-20 system. The electron resistance was kept beneath 5 k Ohm.

During the EEG task participants were sitting in a comfortable chair, looking at a 17" screen 1,5 meters away. ERP waveforms were computed from filtering and averaging EEG data from the trials. The ERP waveforms were computed offline in the common average

montage. For the purpose of this study the P3NoGo amplitude was computed from the average of all successful NoGo trials. Consequently, commission and omission error trials were not included in the average.

2.4 Measurement of ERP parameters

The P3NoGo amplitude and latency were estimated using the fractional area (FA) approach. As explained in Brunner et al. (2013) the FA is the area between onset and offset (marked by the grey area in Figure 2b). The onset is set to where the amplitude exceeds 50 % of the max - min amplitude and the offset where the amplitude reaches the same level as onset. For the P3NoGo wave the estimation of the max-min amplitude was limited to 280-480 ms post stimulus. The mean amplitude used in the analysis was the mean FA amplitude, calculated individually for the 28 participants. The latency was the FA median.

2.5 Correction of artifacts

Independent component analysis (ICA) was used to remove eye blinks from the EEG recordings. EEG-data with exaggerated amplitude and very slow frequency was also excluded from further analysis. The exclusion treshold was as follows: (1) 100 microvolt (µV) for non-filtered EEG (2) 50 microvolt for slow waves i 0-1 Hz band and (3) 35 microvolt for fast waves in 20-35 Hz band.

2.6 Self-report questionnaire on executive functioning (BRIEF-A)

The participants completed BRIEF-A (Roth et al., 2005), a self-report questionnaire consisting of 75 statements concerning executive problems of various nature. They were asked to indicate, on a 3- point Likert scale, the frequency of each statement, 1 indicating *never*, 2 indicating *sometimes* and 3 indicating *often*. A high score indicated a high level of experienced problems whereas a low score indicated a low level of experienced problems.

The Global Composite Score (GEC) and the three indexes Behavioral Regulation index (BRI), Metacognition index (MI) and Emotional Regulation index (ERI) were calculated for each of the participants (Roth et al., 2013). BRI was calculated from the subscales Inhibition and Self-Monitor, MI from the subscales Initiate, Working Memory, Plan/Organize, Task Monitor and Organization of Materials and ERI from the subscales Emotional Control and Shift. The indexes are highly inter-related (Roth et al., 2013).

2.7 Data analysis

We analysed the data using IBM SPSS Statistics 21.0. The relationship between BRIEF-A GEC and index scores was investigated with correlational analyses. So was the relationship between BRIEF-A data and the P3NoGo amplitude. The BRIEF-A statements were distributed along an ordinal scale and were summed up to an index score. When the sum score was normally distributed and thus a parametric variable, Pearson`s r was used. Spearman`s rho was used when the sum score was not normally distributed. The assumption of normality was tested with Shapiro Wilks test and the coefficient of determination (r^2) was calculated for the BRIEF-P3NoGo correlations. The strength of the correlations was evaluated according to Jacobsen (2005). To control for the possible effect of Full Scale IQ and reaction time on the P3NoGo-BRIEF relationship partial correlation was conducted. In order to control for fluid intelligence we applied the Perceptual Organization Index (POI) of WAIS-III, an index comprising novel problem solving aspects of intelligence. Consequently partial correlation was conducted controlling for the POI variable.

<center>**Results**</center>

This section first presents the descriptive statistics, the P3NoGo ERP peak amplitude for succesfull NoGo trials and correlations between P3NoGo and BRIEF-A. Finally IQ and RT were controlled for.

3.1 Descriptive statistics

The descriptive statistics for the participants are presented in Table 1. FS IQ, cued RT, GEC and MI were normally distributed, as found with Shapiro Wilks test. Also note the low number of commission and omission errors in the cued Go/NoGo task and the small variance in age between the participants SD = 0.6 years. For GEC, T= 45, compared with norm data for the same age group (Roth et al., 2005).

Table 1 Descriptive statistics

	n	Mean	SD	Range
Demographic statistics				
Age (years)	28	22.7	0.6	21.6-22.7
Education (years)	28	12.1	1.2	11-15
IQ				
Full scale IQ (WAIS-III)	28	102.0	11.8	84-127
Perceptual organization index	28	110.1	13.0	88-130
Behavioral parameters				
Cued RT (ms)	28	345.9	37.7	283-411
Omissions	28	1.5	1.7	0-6
Commissions	28	0.5	0.9	0-4
SE RT (ms)	28	7.4	2.1	4.2-14
ERP parameters				
P3NoGo amplitude (μV)	28	9.5	4.6	0.5-19.8
P3NoGo latency (ms)	28	354.0	20.8	328-406
BRIEF-A scores				
GEC	28	93.0	16.0	70-125
BRI	28	18.0	4.4	14-31
ERI	28	20.6	5.6	16-36
MI	28	55.0	10.3	40-75

Note. Descriptive statistics for the group of 28 participants. n= number of participants;SD= Standard deviation; WAIS-III = Wechsler Adult Intelligence Scale – Third Edition; Cued RT = Reaction time after target stimulus; SE RT = Standard error of the reaction time; ERP=Event-Related Potentials; BRIEF-A = Behavior Rating Inventory of Executive Functioning for Adults; GEC = Global Executive Composite; BRI = Behavioral Regulation Index; ERI = Emotional Regulation Index; MI = Metacognition Index.

3.2 The P3NoGo ERP

Presentation of the target stimuli in the NoGo condition evoked a strong P3 NoGo wave with a mean latency of 354 ms and a mean amplitude of 9.5 µV as measured in Cz. As is visible in Figure 2 this ERP had a fronto-central distribution.

Figure 2 The P3NoGo wave in the cued Go/NoGo task
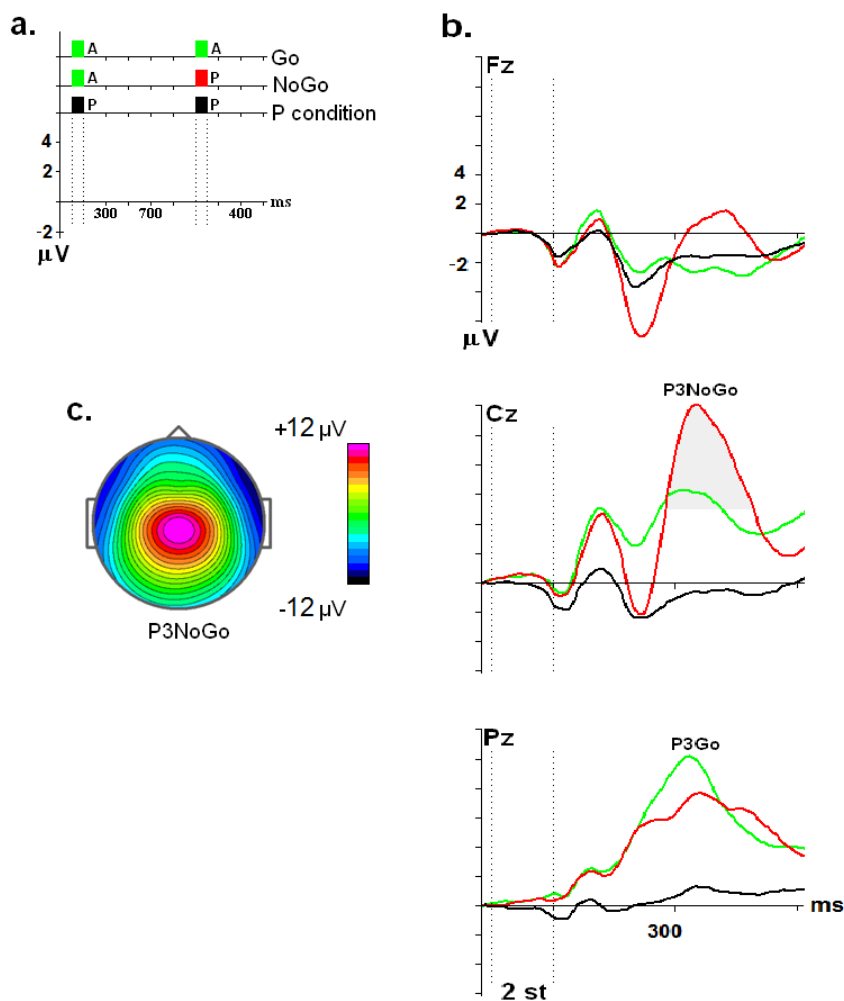
Figure 2. The P3NoGo wave average in the cued Go/NoGo task (n=28). (a) A representation of the cued Go/NoGo task. A=animal image, P=plant image. The participant is instructed to press a button in the Go condition, to withold the response in the NoGo condition and to not respond in the P condition. Time (ms) at x-axis (b) ERP waves at Fz, Cz and Pz for the Go condition (green), NoGo condition (red) and P condition (black). Time (ms) at x-axis and amplitude (µV) at y-axis. The fractional area is marked by the grey area at Cz. (c) Map of P3NoGo activity at Cz as indicated by the grey area.

3.3 Correlations between BRIEF-A and ERP data

The correlations between BRIEF-A scores (GEC, BRI, ERI and MI) and the P3NoGo

amplitude are presented in Table 2. It should be noted that the correlations remained after

controlling for FS IQ.

Table 2 Correlations between P3NoGo amplitude and BRIEF-A scores

	n	P3NoGo amplitude (µV)
GEC	28	-.556** *(-.442*)*
BRI	28	-.295 (.010)
ERI	28	-. 331 (-.189)
MI	28	-.611** (-.565**)

Note. Correlations between the P3NoGo amplitude and the BRIEF –A scores Global Executive Composite
(GEC), Behavioral Regulation Index (BRI), Emotional Regulation Index (ERI) and Metacognition Index (MCI).
The partial correlations, after controlling for full scale IQ (FSIQ), are presented in parenthesis. Pearson`s r is
used for parametric variables and Spearmans`s rho for non-parametric variables.
* $p < .05$ level (two-tailed)
** $p < .001$ level (two-tailed)

There were significant negative correlations between P3NoGo amplitude and GEC (r

= -.556, p<.01, r^2 = .31) and between P3NoGo amplitude and MI (r = -.611, p<.01, r^2= .37).

When controlling for FS IQ the correlation between P3NoGo amplitude and GEC was (r = -

.442, p<.05) and between P3NoGo amplitude and MI (r = -.565, p<.01). The other

correlations were not significant. When controlling for WAIS POI the P3 NoGo GEC

relationship (r= -.529, p<.01) and the P3NoGo-MI relationship (r= .616, p<.01) were still the

only significant correlations.

Figure 3 Scatter-plots of GEC and P3NoGo amplitude
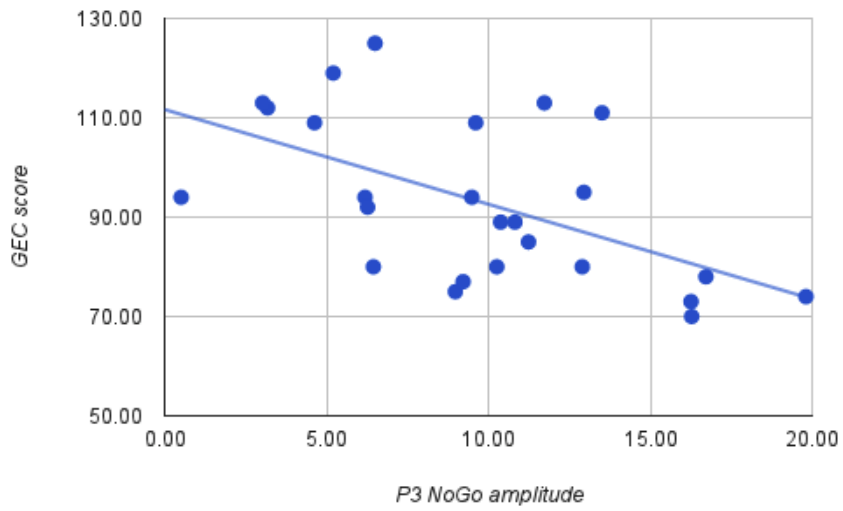
Figure 3. Scatter-plot of GEC scores and P3 NoGo amplitude. Each circle corresponds to one test subject. GEC= Global Executive Composite.

Figure 4 Scatter-plots of MI and P3NoGo amplitude

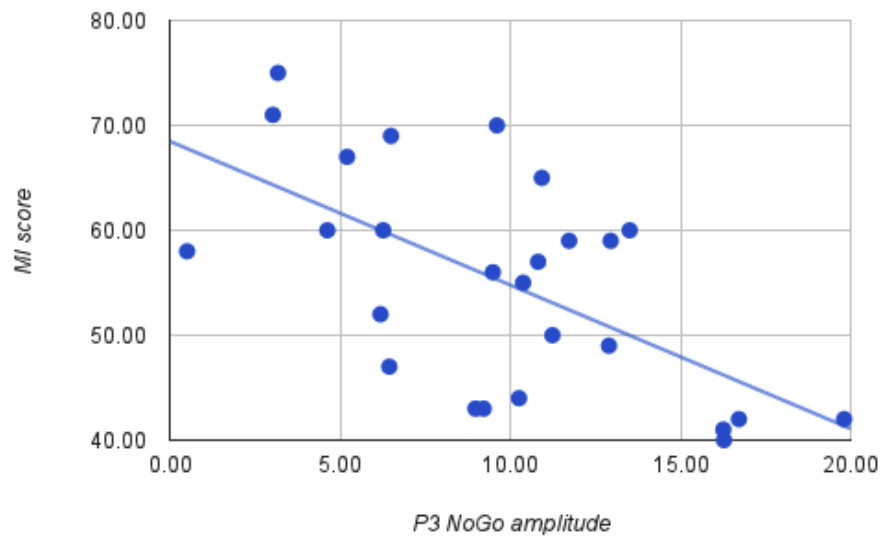*Figure 4.* Scatter-plot of MI scores and P3 NoGo amplitude. Each circle corresponds to one test subject. MI= Metacognition Index.

3.4 Reaction time

       After controlling for reaction time (RT) the correlation between the P3NoGo amplitude and MI remained significant (-.529, p<.01). None of the other correlations were significant after controlling for RT.

Discussion

The goal of this study was to investigate the relationship between the two EF-related measures, the P3NoGo amplitude and the BRIEF-A overall score (GEC). It was also examined whether some of the BRIEF-A indexes, the MI, BRI or ERI, explained this relationship more than others. As was expected a significant relationship between the GEC score and the P3NoGo amplitude was found. The correlation was strong and around 31% of the variance in one factor can be explained by the variance in the other. This indicates that to some degree the two measures are overlapping, which is in line with earlier research on the relationship between other ERPs and self-report measures (Dywan & Segalowitz, 1996; Miller et al., 2012; Roca et al., 2012).

4.1 The relationship between P3NoGo and the BRIEF-A indexes

GEC reflects answers to questions about a wide range of behaviors and is therefore not very specific as to what kind of everyday executive difficulties it relates to. As mentioned in the introduction we wanted to specify the relationship between a measure of everyday-life executive functioning and the P3NoGo by exploring whether this ERP relates to some everyday EF difficulties more than others. When we investigated the relationship between the P3NoGo amplitude and the three BRIEF-A indexes a strong relationship between the P3NoGo amplitude and the MI of BRIEF-A was found. The variance in P3NoGo amplitude explained 37% of the variance in the MI score. The MI was the variable that explained most of the relationship between the P3NoGo and the GEC and this was also the only significant relationship between the P3NoGo amplitude and the three indexes. As mentioned in the introduction MI refers to the ability to control attention, cognitively plan, solve problems and monitor performance, and examples demonstrating the behavioral problems associated with a high MI score are statements such as "I have a short attention span", "I have problems getting

started on my own" and "I don`t check my work for mistakes" (Roth et al., 2005). The

P3NoGo –BRI and P3NoGo – ERI relationships, on the other hand, were non-significant.

Accordingly this study does not indicate that P3NoGo is related to the functions assessed by

the BRI and ERI. These indexes involve behavioral and emotional regulation and include

statements such as "I have troubles sitting still" and "I overreact emotionally" (Roth et al.,

2005). When summarized the results can indicate that there is a relationship between the

P3NoGo amplitude and self-reported metacognitive control functions, whereas a relationship

between the P3NoGo amplitude and behavioral and emotional regulation functions was not

found.

4.2 Neural networks for the P3NoGo and BRIEF-A MI

To further understand the results, a central question is why P3NoGo is related to MI

and not to the other two indexes. One possible explanation is that the P3NoGo amplitude and

the processes underlying BRIEF-MI are related to the same neural networks. The P3NoGo

component is thought to be generated in the posterior midcingulate cortex (pMCC), dorsal

Anterior Cingulate Cortex (dACC), medial frontal regions (including preSMA), precentral

and middle frontal cortices (overlapping with Dorsolateral Prefrontal areas) as well as the

insulae (Huster, Westerhausen, Pantev, & Konrad, 2010; Karch et al., 2008; Schmajuk, Liotti,

Busse, & Woldorff, 2006). These regions are thought to be related to various neurocognitive

processes, some to response selection and selective attention (Nee, Wager, & Jonides, 2007)

and others to response inhibition (McNab et al., 2008; Swick, Ashley, & Turken, 2011)

monitoring of performance and conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001;

Kropotov et al., 2011) or energization, also described as cognitive effort (Stuss & Alexander,

2007). Response selection, selective attention, energization and monitoring can all be

described as relating to attentional control processes. Thus one can argue that the P3NoGo

component seems to be related to attentional control processes as these mechanisms supposedly originate in the same neural networks.

In addition, Alexander (1994) and Alexander et al. (1990) describe the segregation of prefrontal functions in the form of parallell frontro-subcortical circuits. One of these circuits is overlapping with the generator constellation of the P3NoGo component. This is the dorsolateral circuit which is related to executive functions such as attentional control processes, planning, goal selection and generating hypotheses (Bonelli & Cummings, 2007). The functions thought to be assessed by MI closely resemble many of the mentioned functions related to P3NoGo generator areas. This may in turn indicate that both the P3NoGo amplitude and self-reported MI reflect attentional control processes, which fits well with the findings in the current study of a strong relationship between P3NoGo and MI of BRIEF-A. This is also in line with a study by Brunner et al. (2014), relating P3NoGo to attentional control processes measured with neuropsychological task parameters.

Response inhibition is one of the processes suggested to be related to the P3NoGo generator areas, and some studies relate P3NoGo to reponse inhibition/suppression processeses (Bruin et al., 2001; Kropotov et al., 2011; Smith et al., 2006). However Huster et al. (2013) argue that there is little empirical support for this hypothesis, a notion that fits well with our results which do not show a relationship between the P3 NoGo amplitude and BRI, the index which includes behavioral inhibition. According to the parallell basal ganglia-prefrontal circuits theory, response inhibition is related to a circuit involving orbifrontal prefrontal cortex (OFC) (Starkstein & Kremer, 2001). If response inhibition is indeed related to another neural network than MI and P3NoGo, this can explain the findings of the current study. Some authors suggest there to be a difference between behavioral and cognitive inhibition (Follmer, 2014; Janette L. Smith, Johnstone, & Barry, 2008). Thus it may be that these processes are related to different neural circuits and that P3NoGo is related to cognitive

inhibition processes, which are not well assessed by BRIEF-A, and not related to behavioral inhibition processes. Furthermore, the orbitofrontal- basal ganglia circuit described in Bonelli and Cummings (2007) is also supposedly related to emotional lability, which is one of the processes BRIEF ERI aim to measure. Because of the resemblance between the BRI and ERI processes and the orbitofrontal circuit processes we suggest these to be related. Summarized, it can be proposed that P3NoGo is a measure of MI and dorsolateral processes rather than ERI, BRI and orbitofrontal circuits.

There are, however, contradictory findings of the link between MI and dorsolateral processes. In a study by Løvstad et al. (2012) they found that patients with orbitofrontal lesions had a higher MI score than controls did, which unexpectedly was not the case for patients with dorsolateral lesions. This discrepancy indicates that more research is needed on the link between P3NoGo generator areas, dorsolateral processes and experienced metacognitive executive functioning in everyday life.

4.3 Can IQ explain the results?

Accordning to Duncan et al. (1996) there should exist a common underlying *g* factor for intelligence functions and other EFs. Accordingly one would expect the relationship between BRIEF-A scores and the P3NoGo amplitude to cease when controlling for fullscale IQ as that would involve isolation of a possible underlying factor. This however is not the case in our data as both of the significant relationships, namely P3NoGo - GEC and P3NoGo - MI, still stand despite the FS IQ variable being kept constant. These relationships are still significant also after controlling for POI, the index in WAIS-III comprising novel problem solving and resembling the fluid intelligence term. In other words the IQ variable alone, neither FS IQ nor POI, can explain the relationships we have found.

4.4 Can reaction time explain the results?

After controlling for reaction time, the relationship between P3NoGo and GEC was no longer significant. From this we infer that RT seems to be a central third variable for explaining the relationship between them. As earlier research has found that reaction time has an impact on the P3NoGo amplitude (Dimoska et al., 2006; Gajewski & Falkenstein, 2013; Smith et al., 2006) our results are not surprising. When it comes to the mechanisms underlying RT, it is shown to be affected by the degree of cognitive effort invested in a task, also known as energization (Stuss & Alexander, 2007). Participants who have slower reaction times also seem to have more problems in everyday life situations, which is evident in a lower score on various executive behavioral outcome (GEC). This tendency could be explained by reduced energization in both the test situation and in everyday situations.

Contrary to the relationship between P3NoGo and GEC, the relationship between P3NoGo and MI remains statistically significant after controlling for RT. This indicates that there are factors other than energization that explain this relationship.

4.5 The validity of BRIEF-A

There is no golden standard for assessing EF, and also BRIEF-A has it's strenghts and limitations. Several findings point in the direction of BRIEF being a valid measure of everyday executive functioning. First, clinical populations with executive function difficulties report more executive difficulties measured with BRIEF and BRIEF-A (Kalbfleisch & Loughan, 2012; Mahone et al., 2002; Olsen et al., 2014; Roth et al., 2005; Sesma et al., 2008) and it may be used to differentiate between ADHD subgroups (McCandless & L, 2007). Second, the BRIEF-A self-report and informant report show moderate to high correlations (Ciszewski et al., 2014; Roth et al., 2005), findings that may compensate for the limitations related to possible lack of self-awareness that applies to some patient groups.

Third BRIEF shows moderate to strong convergent validity, as it relates to other measures of executive functioning, such as the Dysexecutive Questionnaire (DEX) and the executive dysfunction domain in the Frontal Systems Behavior Scale (FrSBe) (Roth et al., 2005). The correlations between BRIEF and NP test results, on the other hand, are found to be weak (Løvstad et al., 2012; Payne et al., 2011). This implies that although BRIEF-A has strong convergent validity when it comes to other similar measures of EF, there is little support in the litterature for a relationship between BRIEF-A and specific neurocognitive processes. However the current study found that the BRIEF-A GEC and MI are indeed related to a specific neurophysiological correlate, strengthening the convergent validity of BRIEF.

Regarding the possible limitations of BRIEF it should be mentioned that since BRIEF is a self-report measure several other factors than actual neurocognitive functions may affect how people respond on the questionnaire. Jonge and Sleats (2005) found a relationship between neurotisicm and extraversion and reponse tendency on a self-report questionnaire. Also personality factors are found to be related to how people perceive their health (Kesavayuth, 2013) and consequently it could be reasonable to assume that it affects how they perceive their executive functioning. Furthermore the findings of Løvstad et al. (2012) suggest there to be a strong association between BRIEF-A and emotional distress. As mentioned, also self-understanding and reading skills may affect the validity of self-report measures (Morey, 2007; Roth et al., 2005). All this points to the possbility that a BRIEF score is not selectively related to executive functioning, but is also affected by several other factors.

Taken together, current research on BRIEF-A suggests it to be related to EFs although several other factors than neurocognitive ones may affect the way people respond. The results of the current study strengthens the convergent validity of BRIEF-A, as the findings indicate a link to a neural correlate of attentional control processes.

4.6 Strengths and limitations of the study

A strength with our study is that data on reaction time and IQ was collected, which made it possible to control for these variables. Also the mean and SD IQ scores in our sample correspond to those of a normal population, and both IQ and RT are normally distributed. The fact that our sample consists of healthy subjects allowed us to investigate everyday executive function without the possible biases of reduced self-awareness, language and cognitive impairment that could affect results in a patient population.

There are two main limitations in this study. The first relates to this being a correlational study, which implies that we can only speculate as to what mechanisms explain the relationships. We have already discussed the possibility of third variables explaining the relationships, pointing to RT as a possible underlying mechanism for the relationship between P3NoGo and overall executive functioning and attentional control processes for the P3NoGo-MI relationship. However, experimental studies will be needed to further investigate these relationships. It would also be useful to know whether experienced change in EF is detectable in the P3NoGo amplitude, for example whether cognitive training and associated EF improvement leads to P3NoGo amplitude change. The second limitation relates to the external validity of this study. As executive functioning is influenced by age (Zelazo, Craik, & Booth, 2004) and there is little age variance in our population, the generalizability of our findings is limited. Another factor influencing the generalizability is the relatively small number of participants. More research is needed in order to replicate our findings both in healthy populations and in populations with EF impairment.

4.7 Relating EF measures

Our results indicate that there is a relationship between two EF-related measures of relatively different nature. The P3NoGo amplitude is aquired from brain activity and is elicited in an executive task with clear instructions supposedly measuring optimal performance. BRIEF-A is on the other hand a self-report measure assessing behaviors related to executive functioning in unstructured everyday-life situations, where clear instructions are not common. Despite these differences the two EF measures seemingly assess a common underlying factor or factors. As mentioned, earlier findings suggest a relationship between the P3NoGo amplitude and NP test parameters (Brunner et al., 2014). On the other hand, the relationship between NP tests and self-report are often found to be only weak or moderate (Chaytor & Schmitter-Edgecombe, 2003; García-Molina, Tirapu-Ustárroz, & Roig-Rovira, 2007; Odhuba, van den Broek, & Johns, 2005; Payne, Hyman, Shores, & North, 2011). Accordingly, the results in the present study, of a relationship between the P3NoGo amplitude and BRIEF-A, may indicate that the P3NoGo amplitude assesses some aspects of EF that NP tests do not.

Conclusions

The goal of this study was to investigate whether two EF-related measures, namely the P3NoGo ERP and the BRIEF-A self-report measure of experienced executive functioning in everyday situations, relate to each other.

We found a relationship between the P3NoGo amplitude and the overall score on BRIEF-A. Post-hoc analyses revealed that this correlation could mainly be explained by the relation to the Metacognition Index (MI), an index assessing the ability to control attention and cognitively plan, solve problems and monitor performance. The findings could not be explained by IQ alone. It is suggested that the P3NoGo amplitude and the MI share a common neural network which differs from neural networks related to behavioral and emotional regulation.

The finding of a P3NoGo-BRIEF relationship could have important implications for future appliance of ERPs as an EF assessment method in the clinic, as we are closer to an understanding of its relation to everyday-life executive functioning. As the relationship between NP tests and self-report is often found to be weak, the relationship in the present study may indicate that the P3NoGo assesses some aspects of EF that NP tests do not. Also the validity of BRIEF-A as an EF measure is strengthened by its relationship with a parameter aquired from brain activity. Finally our results indicate that there is a relationship between two EF measures of relatively different nature, which in turn brings us closer to understanding the nature of the EF construct and finding a more accurate way of measuring it.

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