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Correlating measures of Executive Processes With P3 NoGo Components

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Abstract

Promising in exploring the functional significance of ERPs, ICA decomposition reveals information of what temporally independent activations compose the observed scalp recording. Exhaustive understanding of the ERP component itself still provide limited knowledge without a paralleling exhaustive understanding of the mental processes in question. The P3 NoGo is an ERP seen in NoGo trials in the Go/NoGo task, and has been related to inhibitory processes. The P3 NoGo was decomposed with ICA and correlated to measures of cognitive function. P3 NoGo did not correlate to measures of processing speed or crystallized IQ, but did correlate to the two executive processes energization and task setting.

Keywords: P3 NoGo, ICA, energization, task setting, executive function

The P3 NoGo and Mental Processes

The electroencephalogram (EEG) is defined as electrical activity of an alternating type recorded from the scalp surface after being picked up by metal electrodes and conductive media (Niedermeyer & Lopes da Silva, 2005). This gives an indication of electrical activity in the brain by recording alterations in electrical activity generated by summed postsynaptic graded potentials from pyramidal cells in the cerebral cortex (Teplan, 2002). As stimuli induce reactions in the brain, these reactions cannot be seen on the raw EEG because spontaneous raw EEG amplitude fluctuations are random relatively to the time point when the stimuli occurred. By averaging voltage fluctuations occurring in response to repeated occurrences of a stimulus however, the product called an event-related potential (ERP) reflect only the cortical activity which is consistently associated with the stimulus processing in a time-locked way. Measuring voltage fluctuations in the range of milliseconds (ms), speed is the greatest advantage of EEG when measuring of neural activity (Teplan, 2002), having the potential of registering activity representative of mental operations operating within this time range. All in all, the ERP reflects significant voltage fluctuation related only to the cortical activity which is consistently associated with a processing of a specific stimulus in a time-locked way. Being of a positive or negative amplitude value, measures of amplitude and latency of the ERP can be compared to and correlated with measures of cognitive ability, and hypotheses regarding what the ERP represents in terms of cognition can be tested. A common method for observing and relating ERPs to stimuli is by the use of continuous performance tasks (CPT) (e.g. Overtoom et al., 1998). Often modified to the Go/NoGo paradigm, it is one of the most extensively used models for studying processes related to inhibitory response. Typically, a subject is presented with two stimuli for a fixed and usually short time period with pre-defined inter-stimulus intervals, and the task of the subject is to respond to certain stimulus qualities (Go) and withhold response to others (NoGo). The response may be overt such as clicking a computer mouse or covert, such as counting silently. The stimuli may vary, but are often visual and presented on a computer screen analogous to a CPT. Duration and number of trials vary according to the purpose of the test, and various conditions may be constructed according what mental function that is intended to be assessed. Commonly seen in the Go condition in the Go/NoGo paradigm is a negative followed by a positive deflection in the ERP, the event-related negativity (ERN) and posterror positivity (Pe) respectively (Larson & Clayson, 2010). These are sometimes referred to as the N2/P3-complex, but they seem to have differential response patterns to variations to the task at hand, suggesting their functional segregation (Huster, Enriques-Geppert, Lavallee, Falkenstein, & Herrmann, in press). The Pe ERP is described as occurring between 200 and 400 ms following participant response and is commonly referred to as the P300, or P3. The P3 has larger amplitude in NoGo trials than in Go trials. The P3 is referred to as P3 Go in Go conditions and P3 NoGo in NoGo conditions. The P3 Go has been found to have a parietal focus, whereas the P3 NoGo has been found to be distributed more anteriorly (e.g. Bokura, Yamaguchi, & Kobayashi 2001). The P3 Go ERP has been found to be influenced by the arousal state of the subject (Polich & Kok, 1995) as well as the subject`s age (Walhold & Fjell, 2002) and the stimulus modality of the task has (Singhall & Fowler, 2005). Not least, Katsanis, Iacono, & McGue, (1997) reported genetic influence on P3 amplitude and P3 latency. No heritability was found for the latency of P3 whereas heritability for amplitude was found. This aside, as it is regarded to reflect “supramodal processing stages” (Huster et al., in press, p. 8), it is the covariance of P3 Go with aspects of cognitive functioning that seems to be the principal concern of many authors. The reason P3 Go is considered a cognitive neuroelectric phenomenon is due to its occurrence in psychological tasks when subjects attend and discriminate stimuli (Polich & Kok, 1995). For example, a negative correlation has been found between an intelligence measure and reduced P3 Go amplitudes (Jausovec, & Jausovec, 2000), whereas other more precisely has pointed to how P3 Go latency and peak amplitude correlated negatively with scores on the Wechsler Adult Intelligence Scale III (WAIS-III; Wechsler, 1997a) subtests Matrices, Block Design and Digit span (Walhovd & Fjell, 2002). In addition to being related to subtests on intelligence measures, authors have also tried to explain the cognitive and functional meaning of the P3 Go in general terms. Bruin & Wijers (2002) pointed to a negative relationship between a subject’s assessment of the probability of an event and the amplitude of P3 Go. This is consistent with observations in a line of reasoning where the P3 Go is regarded as “a manifestation of central nervous system activity when attention is engaged to update memory representations” (Walhovd & Fjell, 2002, p. 66), in other words the maintenance of working memory representations (Polich and Kok, 1995). Regarding working memory, the latter authors also referred to P3 Go amplitude as “proportional to the amount of attentional resources in terms of processing capacity that is employed in a given task” (p. 107). Whereas P3 Go amplitude has been suggested to correspond to attentional resources, P3 Go latency has been suggested as an indirect indication of the duration of the processes involved in stimulus discrimination (Hansenne, 2000). However, the relationship between cognitive abilities and P3 Go remains disputed as authors have failed to find a relationship to measures of executive function in certain paradigms (Larson & Clayson, 2010).

The P3 NoGo has been suggested a reflection of response-inhibitory related processes because of its larger amplitude in NoGo condition in the Go/NoGo task as compared to in the Go condition (Smith, Johnstone, & Robert, 2007). Occurring after the response made by subjects in Go-conditions however, the P3 NoGo cannot itself be considered as causative to the respondent's inhibition of response, leading to other inferences regarding its nature (e.g. Falkenstein, Hoorman, & Hohnsbein, 1999). Furthermore, as P3 Go has been found to be affected by the stimulus modality of the task has (Singhall & Fowler, 2005), the increased amplitude seen in P3 NoGo has been claimed to be unaffected by stimulus modality (Smith & Douglas, 2011). In longer tests, P3 NoGo amplitude – but not P3 Go amplitude – has been found to decrease with time spent on a task along with increased reaction time and number of errors, whilst the latencies of both P3 Go and P3 NoGo increase (Kato, Endo, & Kizuka, 2009). Gajewski and Falkenstein (in press) found that increased task complexity had a similar effect. In their study, increased task complexity decreased P3 NoGo amplitude but not P3 Go amplitude, and increased both P3 Go and P3 NoGo latency. It has been proposed that the difference in amplitude between P3 Go and P3 NoGo is due to different patterns of overlap between their subcomponents (Falkenstein, Koshlykova, Kiroj, Hoormann, & Hohnstein, 1995). Another proposal regarding the finding of the increased amplitude of P3 NoGo is that it may overlap with a positive movement related potentials occurring specifically in conditions where overt motor responses must be inhibited (Smith, Johnstone, & Barry, 2008). Lacking however is describing the P3 Go and P3 NoGo within a theoretical model explaining how exactly if at all P3 NoGo relates to inhibition, and further why P3 Go measures has been found to correlate with other measures of cognitive functioning.

The above descriptions give an indication of what proposals has been given regarding the functional significance of P3 Go and P3 NoGo. Even still, a framework of cognitive processes and functioning seems lacking when explaining the characteristics of P3 Go and P3 NoGo findings. Other researchers have taken steps to decompose the P3 in search for a deeper understanding. The research mentioned above has described the P3 as a unitary event, but just as the P3 by some authors have been referred to as part of a larger N2/P3-complex that is now commonly treated as separate entities, the P3 itself has become the object of decomposition. Snyder and Hillyard (1976) described the P3a and P3b where the P3a appears earlier and particularly to alerting stimuli. The P3a and P3b have been examined as to whether they represent different functions. For instance, Holcomb, Ackerman and Dykman (1986) found that P3b amplitude was smaller in clinical than in control groups. Other authors have claimed P3b amplitude as the best predictor of mental ability (Pascalis, Varriale & Matteoli, 2008). Although this represents scientific progress, authors like Polic and Kok (1995) and Larson and Clayson (2010) reminded readers that the question of whether P3 Go and P3 NoGo are unitary phenomenon as opposed to a summation of several distinct processes remains unsettled.

Representing a breakthrough in ERP research is the decomposition of the ERP by independent component analysis (ICA). Mueller, Candrian, Kropotov, Ponomarev, and Baschera (2010) used a modified two-stimulus Go/NoGo test in order to record ERPs and subsequently analyze the relevant P3. The authors used ICA to decompose ERPs into a set of independent components. ICA is a computational method that separates a set of mixed potentials measured at the scalp into a corresponding set of statistically independent source signals that can be applied to recordings from a single individual, on the following assumptions: 1) summation of currents produced by separate generators is linear at the scalp electrodes; 2) spatial distribution of components` generators remains fixed over time and; 3) generators of spatially separated components are temporally independent from each other (Makeig, Bell, Jung, & Sejnowski, 1996). The resulting ERP component cannot be further decomposed into independently activated sources (Kropotov, & Ponomarev, 2009), and gives information of what temporally independent activations compose the observed scalp recording, but not where in the cortex they originate from (Makeig, et al., 1996). ICA can also be applied to P3 NoGo. ICA has revealed that P3 NoGo consist of two waves (Kropotov, Pronina, Ponomarev & Murashev, 2011), in the current paper referred to as P3 NoGo Early and P3 NoGo Late. Potentially promising, ICA decomposition in search for the functional meaning of ERPs should have a corresponding exhaustive understanding of the cognitive processes, functions and abilities in question. These are commonly observed with neuropsychological tests. However, a theoretical perspective should be applied in order for clear communication of which mental abilities are presumed to be measured, because definitions of cognitive abilities and how to observe and measure them is a debated issue (e.g. Neisser et al., 1996; Croizet, & Dutrévis, 2004). Hence, conclusions regarding the functional meaning of the P3 phenomenon when tests of cognitive function are taken at face value without a theoretical framework may compromise a thorough understanding. Walhovd and Fjell (2002) note that the underlying mechanisms responsible for generating the P3, as well as those responsible for attentional resource allocation must be at least “partly independent” (p. 69). This calls for clarifications. Attention is sometimes discussed as a unitary construct.

However applied measures of attentional resource allocation are diverse. This has been demonstrated by Engle (2002), who showed that a Stroop-test of attention can be marginally changed and thereby reveal conceptually different functions. Furthermore, different aspects of attention are recognized (Sturm & Willmes, 2001). An understanding of the P3 NoGo as authentically mirroring attentional resource allocation is perhaps altogether a too optimistic finding to hope for. Nevertheless, an organized conceptual framework is essential when examining cognitive processes. A search for the mediators and moderators of the relation between P3 Go and NoGo and their nuances of measurement may reveal more convincing arguments and portray a more accurate image of their nature, but this requires an acceptance of the complexity of mental functions and its assessment.

Intelligence Quotient

Different approaches to intelligence can be found in the scientific literature, ranging from theoretical discussions on its nature to discussions regarding how it is best measured in practical terms. Spearman (1904) proposed a general intelligence factor (G) claiming different mental abilities are correlated due to a general underlying factor. Adding to this, Cattel (e.g. 1943) proposed a distinction between fluid (Gf) and crystallized intelligence (Gc), the former more apparent in tests requiring adaption to new situations whereas the latter was described as a function of time and interest invested in the use of Gf. (Cattel, 1963) - simplified the result of the learning process. In a more recent inquiry regarding the nature of intelligence, Hawkins and Blackesee (2001) stated that humans are more intelligent because they can make predictions about longer and more abstract kinds of patterns, and further claimed that intelligence tests are tests of prediction. In a separate discussion on how intelligence has evolved, otherwise disagreeing on how to define it, both Chiappe and MacDonald (2005) and Kanazawa (2004) agreed that intelligence relates to the ability to solve novel or nonrecurrent problems. Since the pioneering work of Spearman (1904) and Cattel (1943), intelligence research has added several refinements and proposed modifications. For example have authors suggested a differentiation between fast and slow intelligence (Partchev & Boeck, 2012). Despite this, current theoretical accounts can be seen to have salient parallels to the original proposals - although the terminology is often altered - recognizable in the form of a proposed general intelligence on the top of a hierarchy of abilities that is argued should be the main focus of interest in research on mental abilities (Lubinsky, 2004).

Intelligence as measured by intelligence tests such as the WAIS-III (Wechsler, 1997a) represents a more pragmatic approach intended to give an indication of abilities. Here, a range of abilities from verbal capabilities to long term memory functions, reasoning ability, attention and general knowledge are measured. These measures are converted to standardized scores and summed up in order to create a composite intelligence score, commonly referred to as IQ. Scores from a test can be compared to a norm, as their results are constructed to be normally distributed in the population. One person`s scores on different subscales vary on how close they are to the composite IQ score (Wechsler, 1997a); an individual might have a high composite score on WAIS-III intelligence due to high scores on most of the subscales without having a correspondingly high short-term memory as measured by the Digit Span test. The tests can thus be said to consist of a compilation of subtests revealing composite scores – somewhat fragmented abilities understood to work in harmony, revealing general intelligence. However, dispersions in scores occur, leaving the individual researcher and practitioner with the challenge of interpretation, as no single interpretation of intelligence testing data is widely accepted (Ardilla, 1999). It is important to note about these theories of intelligence that the concept is defined and measured as one or several abilities, without reference to processes that make these abilities possible.

The Central Executive

As noted above, a theoretically derived concept of intelligence themes prediction as well as the resolution of novel problems. At the same time, the psychometric approach estimates intelligence as the sum of somewhat fractionated measured abilities. This intuitively invites to a consideration of the orchestration components into a capability of solving novel problems. Baddeley and Hitch (1974) proposed a model of cognition in which two subcomponents – the phonological loop and the visou-spatial sketchpad – was proposed to be controlled by a central executive. The original concept has later been admitted by Baddeley (1996) as so unclear as to serve as little more than a “ragbag” (p. 6), and has even been claimed “nonexistent” by other authors (Parkin, 1998, p. 518) due to amongst other causes the lack of studies demonstrating its anatomical localization. Nevertheless, the legacy of the original idea continues its life and has gone through refinement in the process of scientific scrutiny. Presently, the concept of executive function (EF) has been referred to “as set of abilities” necessary for the intentional guidance of behavior toward goals particularly in nonroutine situations (Banich, 2009, p 89). This is reminiscent of the account of Gf (Cattel, 1943), and also similar to the psychometric approach to measuring intelligence in that EF is described as a set of abilities, specifying more than one control function. Suggestions of components of this set of abilities are vast, ranging from abilities of directing and controlling attention (Engle, Tuholski, Laughlin & Conway, 1999; Miyake et al., 2000; Stuss & Alexander, 2007), conscious control (Chiappe & McDonald, 2005) and intentionality (Burgess, Alderman, Evans, Emslie & Wilson, 1998) to perhaps more intricate abilities such as analogical reasoning, decontextualization and insight (Arffa, 2007).

In accordance with a view of EF consisting of more than one component, Stuss & Alexander (2007) argued that a singular central executive is not supported by present data of deficits in abilities seen in frontal lobe patients. Instead, they proposed that anatomically as well as functionally independent though interrelated control processes gives a better fit to current knowledge. These processes were described to be domain general in that they are necessary for different cognitive and sensory modalities in addition to basic tasks such as reaction time. In the framework of Stuss (e.g. Stuss & Alexander, 2007) three executive processes were proposed: *energization*, *task setting* and *monitoring*. The energization concept refers to a process of initiation and sustaining of any response that allows maintenance of concentration on any task. Energization corresponds to phasic attention in the neurological literature and to effort in and information processing literature. Task Setting on the other hand entails the ability to establish a relationship between a stimulus and a response and is necessary in the initial stages of learning. Finally, the Monitoring process is the checking of the task at hand over time, allowing adjustment of behavior when needed. Harmonious as the approach of aligning localized anatomical areas with specific processes may sound, it has not been endorsed by all, as Davis and Pierson (2012) contend that the difficulty related to a clear agreement of defining EFs will deepen as they claim the localization-of-deficits approach as not applicable. This debate is likely to continue. Regardless of the outcome of the debate, the concept of EF is a functional one (Baddeley, 1996), implying its existence genuine as a scientific idea despite lack of simple mapping to underlying neuroanatomical structures. Having this in mind, other authors have taken a different tactic to disentangling EF. Miyake, et al. (2000) used a latent variable approach on the results of tests of executive function performed on a group of normal subjects, resulting in a three factor model consisting of the components *shifting* back and forth between multiple tasks, operations or mental sets, *updating* and monitoring of working memory representations, and last the capacity to deliberately inhibit dominant, automatic, or prepotent responses called *inhibition*. These three proposed functions were found to be separable yet moderately correlated, leading to their portrayal of the “unity and diversity” of EFs (p. 49). Regarding the unity, the authors suggest that all the tasks applied in their study share a requirement for maintenance of goal as well as context information in working memory. Interestingly, this proposed explanation by Miyake et al. (2000) regarding the unity of their three proposed components seems to resemble Stuss and Alexanders (2007) description of the energization process, which according to them is required for maintenance of concentration. Not contradictory to this, in a latent variable analysis of the relation between executive functions and intelligence Friedman et al. (2006) argued that it is the process of Updating working memory representations that mediates the relationship between IQ and EFs. The latter authors reasoned that this is due to the fact that working memory tests involve updating and maintaining relevant information in the presence of interference. What makes these two studies similar is that the proposed EFs both concern an ability to maintain focus – to hold relevant information in awareness or present for conscious scrutiny - despite interference. McCabe, Roediger, McDaniel, Balota and Hambrick (2010) remark that working memory capacity appears treated somewhat different than abilities of EF in the scientific literature, in that unlike the debate regarding the unity or diversity of EFs, working memory capacity usually has been conceptualized as a unitary executive attentional construct. An ability strongly related to that of maintaining concentration stands in the center of Engle`s (2002) thinking, arguing the concept “executive attention” (p. 19) to be vital to understanding intelligence, in that it is necessary for upholding the activation of memory units, controlling attention towards one task or several as well as reducing automatic activation through inhibitory processes. Using attention as an explaining factor has also been done by other authors. In the view of Anderson (2002), “attentional control” (p. 73) comprises the capability to selectively attend to specific stimuli over prolonged periods and inhibit prepotent responses. He further claimed that this ability influences the functioning of other executive domains, whereas other EFs such as information processing and cognitive flexibility are inter-dependent and inter-related. Echoing a view similar to that of Engle (e.g. Engle et al. 1999; Engle, 2002), Lepine & Barcoulliet (2005) suggest that working memory tasks are involved in both elementary and complex cognitive processing, placing their view of executive attention in line with models that regard cognitive resources as mental energy required to produce activation.

An affiliation between EFs and IQ

The concept of EF seem clearly related to the concept of intelligence, as solving problems, successful planning and insight certainly correspond to concepts of intelligent behavior. (Arffa, 2007). Also, from an evolutionary perspective, Chiappe & MacDonald (2005) proposed that the EFs of working memory have been essential in attaining evolutionary goals for the reason that they allow for the solution of nonrecurrent problems. Interestingly, Friedman et al. (2008) reported findings indicating heritability as responsible for correlations between executive measures, placing EFs among the most heritable psychological traits. Perhaps surprisingly is that the WAIS-III (Wechsler, 1997a), one of the most common measures of intelligence, does not explicitly include EF in any of its indexes or tests. This might be due to the difficulties related to an agreed-upon framework of definition and measurement mentioned above. Difficulty in definition may also be a reason to the inconsistencies in studies examining the relationship between intelligence as measured by psychometric intelligence scales and measures of EF (Arffa, 2007; Davis, Pierson & Holmes Finch, 2011). However, as the concepts of intelligence and EFs evidently relate, in addition to studies demonstrating an association (Engle et al., 1999; Davis et al., 2011; Friedman et al., 2006; Kane, Bleckley, Conway, & Engle, 2001), some explanations for the reported inconsistencies in can be proposed. One reason may be the use to too few measures – or too unreliable measures of EF in small samples. Another reason is that measures of intelligence like the WAIS-III contain tests like the Digit-Symbol Coding test (DSCT) that have been shown to load onto and display covariance with EF and attention to as large an extent as general intelligence or processing speed (Davis & Pierson, 2012; Ardila; 2007; Dickenson, Ramsey & Gold; 2007; Drowe et al., 1999). Furthermore, in the view of McCabe et al. (2010), administering test corresponding to different EFs permits inspection of the relation between EFs and outcome measures, but has the shortcoming of overlooking variance common to all EF tasks. The authors proposed the reverse will be the case when administering several EF tasks in order to create a single executive factor; this allows examination of the variance common to multiple executive tasks but fails to recognize the variance specific to each task. An example of this comes from a study by Davis et al. (2011), in which an expected relationship between DSCT from WAIS-III and a canonical executive measure constructed by scores on the Delis Kaplan Executive Function System (D-KEFS) (Delis, Kaplan, & Kramer, 2001) was not found (Davis et al., 2011). However, in a later study (Davis & Pierson, 2012), it was demonstrated that DSCT did correlate strongly to more precisely defined cognitive set shifting variable, explicatory to how in the earlier study the expected relationship was masked by the canonical executive measure.

A different question to if EFs and intelligence relates is how it is related. Although it has been proposed that the training of EFs and attention may result in improvements in intelligence (Buschkeuhl & Jaeggi, 2010), measures of EFs seem less susceptible to practice effects, as demonstrated in a study by Basso, Carona, Lowery, and Axelrod (2002) who found significant practice effects on most subscales of the WAIS-III with the exception of the working memory scale. A tempting streamlined conclusion from this, indeed reached by some (e.g. Salthouse, Atkinson & Berish, 2003), is that declines in executive measures and attention are what forecasts decline in other abilities and furthermore that EFs are prerequisites for obtaining Gc (Davis et al., 2011). Additionally, executive and attentional abilities also seem to reach a plateau earlier and stabilize differently in the form of gradual decline in the course of normal living (e.g. Ryan & Ward, 1999, Wechsler, 1997a; Ardila, 2007) as opposed to obtained knowledge such as vocabulary more commonly seen as prototypical measure of Gc (e.g. Ryan, Sattler, & Lopez, 2000; Engle et al., 1999). It should be noted that not all authors agree with this exact view of the relationship between EF and IQ. It has been argued that short term memory together with mental speed is what predicts intelligence (Colom, Abad, Quiroga, Shis & Flores-Mendoza, 2008), as they account for the relationship between working memory and intelligence. These authors gave the largest credit to short term memory for predicting intelligence, claiming that executive updating and the control of attention are not “genuinely” (p. 600) related to intelligence. Additionally, the oscillation rate of neurons have also been discussed as a limiting factor in elementary information processing with consequences for psychometric intelligence, with suggestions that the temporal coordination of mental operations become apparent when for handling information are limited on a particular level of processing (Troche & Rammsayer, 2009). The subject of speed and EF has been explored by Friedman et al. (2008) by means of latent variable analysis in a study where it was found that processing speed was related to a common executive factor they found, and furthermore that processing speed is slightly more related to the EF of inhibition due to the fact that inhibition was somewhat more related to the common EF factor they found. Mental speed or oscillation rate of neurons may (or may not) represent good predictors of intelligence or EFs, but the issue regarding the establishment of informative functional models that includes concepts of intention, attention, conscious control and so on remains vital, as these have an appearance of relevancy to any study of the mind. In order to complete this, incorporating current knowledge from every perspective is essential.

Categorizing specific tasks of EFs according to theory as well as separating Gc from them in psychometrics

Regarding what the most correct measurement of EF, McCabe et al. (2010) briefly states “there is no correct approach to measuring EF” (p. 225). Hardly any more cheerful, Jurado and Rosselli (2007) echo Banich (2009) in claiming that “there is yet no clear agreement about what EFs are” (p. 215), leaving accurate assessment of EFs as a seemingly “impossible task” (p. 218). The challenge seems to lie in the lack of clear definition – in the sense of a theoretically operationalized measure. This continued debate is reportedly one of the reasons one of the most common used test batteries of executive function - the D-KEFS - was developed according to an atheoretical perspective (Davis and Pierson, 2012; Homack, Lee, & Riccio, 2005; Delis, Kaplan, & Kramer, 2001). Banich (2009) remind readers that EFs covers a wide domain of skills, leaving current practitioners and researchers with no single agreed-upon gold standard test of EF. Despite differing perspectives on how to operationalize them, a consensus that EF relate to higher level organization of thoughts and behavior and supervisory cognitive processes seem to exist (Alvarez & Emory, 2006). Yet still to an extended degree vague, this general guideline in conjunction with theoretical accounts is what the practitioner and researcher must use as a compass when making judgments in psychometrics.

Irrespective of this general framework, acknowledging a specific challenge concerning the validity of tests of EFs is required. As noted above, one of the proposed purposes – or at least consequences – of an operative EF is successful strategy selection as well as the ability to solve novel problems (Banich, 2009), capabilities assumed to be linked to insight (Arffa, 2007) as opposed to trial-and-error learning. Consequently, the test-retest reliability of some executive measures has been argued to be self-contradictory, as the task in a measurement of the ability to cope with a novel problem no longer will present a novel problem to the subject during the time of the second testing (e.g. Salthouse, et al., 2003). An example of this practice effect has been found on the Wisconsin Card Sorting Test (WCST) (Basso, Bornstein & Lang, 1999). Although the WCST has been proposed to rely on the EFs of mental set shifting (Rubinstein, Meyer, & Evans, 2001) or inhibition (Ozonoff & Strayer, 1997), performance on the task itself is dependent on subjects` ability to correctly identify the correct sorting strategy through hypothesis testing which may not be apparent until the test is over. Hence, the second testing may not measure ability to generate solutions to a novel problem (Basso et al., 1999). In fact, even among the normal population, subjects taking the WCST may fail because they consider too many sorting rules (Dehaene, & Changeux, 1991), possibly a contributing factor to low correlations found between tests of EF such as the WCST and the Tower of Hanoi Test (TOH) (Jurado and Rosselli, 2007) and to the conclusion reached by some authors that the WCST may not be considered as either valid or specific marker of prefrontal EF (Nyhus & Barceló, 2009). Contrary to findings relating the WCST, no practice effects were found by Basso et al. (1999) on the F-A-S Verbal Fluency Test (FAS) and Trail Making Test (TMT) switching condition. This discrepancy is perhaps due to the differing abilities these tests tap and also to the nature of the tasks. In contrast to the WCST as well at the TOH, the strategies required for the FAS and TMT are relatively simple and thus less susceptible to strategy failure.

The measurement of strategy and novel problem solving is not the only challenge encountered by those endeavoring to measure EFs. Following an assumption of multiple EFs is the consequence that tests of EFs tap differentially onto separable parts of the system. These tests tapping exclusively onto specific EFs has proven challenging to find. First, increasing task complexity will lead to increasing cooperation between different functions in order to complete the task, with the confounding of results as a consequence. In addition, EFs by definition operate on other cognitive processes. Hence, a share of their variance in any one task is necessarily measuring other processes than the assumed executive process, often referred to as the “task impurity problem” (e.g. Friedman et al., 2008, p. 202; Jurado, & Rosselli, 2007, p. 218). For example, Testa, Bennet and Ponsford (2012), who proposed six different but correlated EFs, explained correlation between the tests as commonality in non-executive skills required. Consequently, practitioners as well as researchers have to settle for approximations - using those measures expected have closest relationship to different corresponding EFs. Regarding the approach of aligning specific tasks with specific EFs, McCabe et al. (2010) claimed that this is an oversimplification stating that “no EF tasks appear to be process pure” (p. 223). Furthermore, as different EFs are described as having some degree of unity (Miyake et al., 2000) in addition to the association found between measures of EF and IQ scores (Davis & Pierson, 2012; Davis et al., 2011), attempts to assess assumed discrete functions may nevertheless reveal a degree of overlap.

Not least, it should be clear that tests intended to load on EFs are heterogeneous. This is the case not only regarding what they intend to measure but also with regards to what level their defined measure refers to. An example of this is a minor but noteworthy departure in language that can be found in Stuss` descriptions (e.g. 2011). He described executive *processes* as opposed to the term *abilities* used by others (e.g. Banich, 2009). As some tests pursues to tap abilities relating to strategy or insight, conclusions regarding the task demands required to successfully perform the task may logically be drawn, given that the abilities required are the ones the test claim to be dependent on. Stuss (2011) commented that, “tasks however, are not processes” (p. 760), meaning that identifying task demands is not the same as identifying underlying processes required, and that abilities may be the result of multiple executive processes. This should prescribe cautiousness regarding interpretation of results on executive tests as equivalent to the existence of a singular underlying executive processes or the function it serves, as opposed to executive ability or task requirements. For example, discussing the Stroop (1935) test, authors describe this test as requiring cognitive control (Derrfuss, Brass, Neumann, & Yves von Cramon, 2005) or inhibition (e.g. MacLeod, 1991) without particular reference to the executive processes that make cognitive control or inhibition possible. Another example comes from Prigatano (1978) in a review of the Wechsler Memory Scale (WMS; Wechsler, 1997b) where he refers to the Mental Control (MC) subtest as falling within a “freedom from distractibility-factor” (p. 820), without further explanation of what process or processes enables a person to be free from distractibility. This is not to say that cognitive control or freedom of distractibility are useless concepts regarding understanding EFs. Rather, it is to remind the reader that a task may require abilities that consist of more than one process, and that selection of tests according to what processes they are assumed to be based on will at best be an estimate. An estimation approach may also be applied when measuring IQ as a contrast to other cognitive processes and functions. As indicated above, a relationship exists between EFs and measures of IQ, and a clear separation may hence prove challenging. In the face of this often demonstrated relationship between EF and IQ, authors have applied scores from WAIS-III as a contrast to measures of EF, such as Friedman et al. (2006) who used the Information subtest from WAIS-III in order to observe Gc in subjects in order to avoid the confounding influence of EF. The Information subtest (Wechsler, 1997a) is intended to give a measure of general information acquired from one`s culture, and can thus be viewed as a rather classical example of Gc (Cattel, 1963). Verbal abilities and especially acquired vocabulary is another example of what is viewed as Gc (Ryan et al., 2000) that has been used as a contrast to executive measures. For example, Brown, Reichel and Quinlan (2009) pointed to the discrepancy between scores on intelligence tests and deficient abilities revealed during the course of normal living in some elderly and in patients being diagnosed with ADHD but having superior intelligence. In order to separate patients with high IQ from the rest of their patient group, these authors used WAIS-III index scores for either Verbal Comprehension Index (VCI) or Perceptual Organization Index (POI) with a cut-off of 120, arguing these to be less sensitive to cognitive impairments associated with EF. In the study of Brown et al. (2009), the aim of applying these measures was the selection of patients with high abilities. However, the use of the VCI scores when the purpose is to avoid measuring abilities that share variance with EFs must be done with caution as authors have found EFs to share variance with verbal abilities in general (Ardila, Pineda & Roselli, 2000; Arffa, 2007; Ardila, Galeno & Rosselli, 1998.), with verbal learning and memory specifically (Duff, Schoenberg, Scott & Adams, 2005) and even with vocabulary (Davis et al., 2011). Moreover, in the study of practice effects on the WAIS-III described above, Basso et al. (2002) did find practice effects Verbal IQ and VCI. Nevertheless, among the significant improvements, the lowest reported increases were verbal scales, with Verbal IQ and VCI with increases of respectively three and four points.

Further description of two proposed executive processes and test outcomes fundamentally dependent on them.

Assuming that performance on a task most likely is at best an estimate of the executive process is required for it, two specific executive processes will be described further, largely based on the concepts of Stuss (e.g. Stuss, 2011; Stuss, Shallice, Alexander & Picton, 1995) described above. However, as some degree of overlap with other concepts of EF is impossible to avoid, similar concepts and processes will be cited when informative. With this, energization (also called energizing) refers to facilitation of the neural systems that are needed to initiate and maintenance of consistent activation of the intended response of any task, the absence of which would become apparent in a general deficit of activation. The proposal of an energization process was largely based on observations that neural activity halts when lacking input. Kane & Engle (2003) describe performance on the Stroop (1935) task as an attentional process that is dependent on the resolution of response competition between the dimensions in the task, which only will be engaged when the task goal is sufficiently activated in memory. The activation of the goal, or the maintenance of task or mental set, has also been described as having to be “enforced” in order to inhibit the prepotent response (Derrfuss et al., 2005, p 23), requiring mental “effort” (Lippa, & Davis, 2010, p. 147). In line with this, the energization concept corresponds to the effort system in information processing literature and to phasic attention in the neurological literature according to Stuss and Alexander (2007). Mental effort has been described as being related to the “energy” required in information processing

(Howells, Stein, & Russel, 2010, p. 3) whereas phasic attention refers to the ability to increase response readiness subsequent to external cueing (Sturm & Willmes, 2001).

Compatible with the descriptions given by other authors, increased slowness in the incongruent condition in the Stroop task therefore would be interpreted as failing to uphold consistent activation of the neural systems needed for an intended response within an energization framework (Stuss, 2011). This is not to say that variations in results in the inhibition condition of the Stroop task is unaffected by other cognitive and executive processes. Rather, it is a hypothesis that the concept of an energization process offers a better explanation regarding the variations in the results of the inhibition condition in the Stroop task than other processes. This may also be the case regarding the variations in results on other tests of EFs, as the energization function should be applicable to any task (Stuss & Alexander, 2007). For example, according to the D-KEFS examiners manual (Delis et al., 2001), the FAS test taps initiation, simultaneous processing, as well as retrieval of phonetically similar items and speed of processing. However, variations in results on this task within an energization framework would be explained as related to the process of sustaining and maintaining preparation to respond (Stuss & Alexander, 2007). Other authors have also given similar descriptions to the capabilities needed in a verbal fluency task, as Reverberi, Laiacona, and Capitani (2006) who attributed a lower number of words produced within a given timeframe to a deficit of activation. As with the inhibition condition of the Stroop test, other executive processes have been proposed as influential in the FAS test. For example hypothesized Robinson, Shallice, Bozzali and Cipolotti, (2012) that performance on fluency task involve at least two additional sets of cognitive processes in addition to sustained activation (or energization), namely selection and creation of novel processes. As verbal fluency tests may depend on these other processes (and probably do), performance on tests of verbal fluency where the dependent measure is the number of words of a given category produced within a given timeframe will depend on the executive energization process.

Another executive process proposed by Stuss (e.g. 2011) is the task setting process. This process becomes apparent under conditions where continuous refreshing and suppression of more salient responses are needed, such as in the initial stages of learning. It involves the establishment of the connection between a stimulus and a response, requiring the establishment of a criterion used to respond to a defined and specific target as well as the organization of the schemata necessary to complete a particular task. This concept is similar to the shifting process described by Miyake et al. (2000), involving disengagement of irrelevant task sets and subsequent activation of a relevant task set, resulting in the ability to perform an operation in the face of proactive interference. Subtle disagreements of definitions of this ability may be found, but the fundamental theme of the task setting process reverberating is the organization of schemata, and task setting will here be used as equivalent to set shifting or shifting with respect to tests heavily reliant on this process. For example, the Color Word Interference (CWI) test of D-KEFS is to be regarded as equivalent to the Stroop (1935) test. In addition to the regular word reading and inhibition condition (CWI inhibition), the CWI test includes a condition in which the task is to switch between reading the word and naming of the color of the letters (CWI switching). This switching condition captures an additional aspect of EF that the inhibition condition alone does not (Lippa, & Davis, 2010) and has been applied as a measure of Set Shifting (Kalkut, Han, Lansing, Holdnack, & Delis, 2009). A possibly more common measure of the task setting executive process is condition four of the TMT (TMT switching), which requires that subjects draw a line between numbers and letters, alternating between them, and is to be considered equivalent to condition B in the Trail Making Test of the Halstead–Reitan test battery (Reitan, & Wolfson, 1993). According to the D-KEFS examiners manual (Delis et al., 2001) this switching condition is “the primary executive-function task”, measuring “flexibility of thinking” (p. 23). As this test battery was constructed on an atheoretical basis however, the task setting concept offers a more precise and illuminating description of the process underlying this test condition. Task setting can be seen as the executive process commonly regarded to have the largest effect on variations in this this condition (Sánches-Cubuillo et al., 2009) in addition to actually having been applied as a test measuring this function (Arbuthnott, & Frank, 2000; Kalkut, Han, Lansing, Holdnack., & Delis, 2009; Zinn, Stein & Swartzwelder 2004). Task Setting may also be seen in other test batteries with inspection of specific processes as opposed to general EF. For example, the WMS (Wechsler, 1997b) offers detailed inspection of memory functions. The MC subtest of this battery has been used to measure “freedom from distractibility” (Prigatano, 1978, p. 820) and has been applied as a measure of EF in several studies e.g. (Baudic et al., 2006; Insel, Morrow, Brewer, & Figueredo, 2006; Libon, Malamut, Swenson, Sands, & Cloud, 1996). In an even more specific description though, the MC subtest has been found to rely on maintenance of task setting (Lamar et al., 2004). Similarly, the WAIS-III (Wechsler, 1997a) contains the DSCT that has been found to correlate highly with a general executive or attention measure (Ardila, 2007; Drowe, et al., 1999) as well as being one of the most robust executive deficiencies of schizophrenia (Dickenson et al., 2007; Leeson et al., 2008). As with the MC subtest of WMS however, with closer inspection variations specifically in task setting ability has been concluded to be the best explaining factor of variations in results of the DSCT of the WAIS-III as opposed to general intelligence or mental speed (Davis, 2012).

The Present Study

Several authors have proposed a positive relationship between the latency and amplitude of the P3 Go and measures of cognitive ability. The findings thus far are however not placed within a theoretical framework of cognitive function. Often, inhibitory-related processes or conflict of responses are central themes in discussions about the functional significance of P3 NoGo, without reference to the mental processes in question within a theoretical framework.

Measures of cognitive ability are heterogeneous, yet it is both in theory and practical accounts possible to understand these measures within of a theoretical framework. What is of essence is a clarification of what is meant by mental processes and mental functions. For example, the term inhibition may refer to an overt response, a process between neurons or other. Within the current framework largely adapted from Stuss (e.g. 2007) the aim of the present study is to shed light on what cognitive process or processes the P3 NoGo can be said to represent and which it does not represent. As indicated above, the P3 NoGo can be decomposed and demonstrated to consist of two waveforms. These components will in the current study referred to as P3 NoGo Early and P3 NoGo Late. Definitions and observation of ERPs are also subject to discussion and refinements. The aim of the current study is however to investigate in detail the mental processes underlying the P3 NoGo Early and P3 NoGo Late components.

The P3 NoGo Early and P3 NoGo Late components will be correlated to measures of cognitive abilities. Several considerations have been taken in the categorization of these measures. One is the distinction between the measurements of Gc on the one hand, versus EFs on the other. As tests of Gc are chosen on a basis of high risk aversion to the confounding influence of executive measures, measures of verbal ability will not be applied in the measurement of IQ. The other group of measures will be used as measures of EF. The executive measures will be compartmentalized in two according to leading current accounts of EF consistent with the two executive processes described above. One group of measures will fall into what is described as energization process measures (the mental effort system). The other group of tests will be considered as corresponding to a task setting process. In addition to having to tap EFs, only tests with time-dependent scores were included. In this fashion, the tests used can be said to load on EFs in a time accuracy trade-off paradigm. The motive of this is to attempt to avoid the confounding variable of differential and perhaps at times random or at least uncontrolled effects of strategy selection that can be seen for example when subjects taking their time on a task when time is unlimited will perform better than somebody not taking their time. It may be argued that this characteristic also is a reflection of executive processes or function or maybe a characteristic of personality with relevance to the understanding of EF. This discussion is however, not a part of this paper. Furthermore, as applying a time restraint on the tests offers the risk of confounding speed of processing with the executive measures, the Grooved Pegboard and Symbol Search will be applied as measures of speed and correlated with P3 NoGo Early and Late components.

The three measures will be correlated with the latency and the amplitude of P3 NoGo Early and Late components. It is the hypothesis of this study that measures of estimated IQ or speed of processing show no correlation with P3 NoGo parameters (Hypothesis 1), whereas measures of executive processes will show correlation to P3 NoGo components (Hypothesis 2).

Method

Written consent was obtained from the subjects in the study before testing as part of a larger study on prematurely born which was approved by the Regional Committee for Medical Research Ethics and the Norwegian Social Science Data Services (NDS) approved the study.

Participants and neuropsychological testing

Data were collected from 28 healthy adults (15 men, 13 women) that participated as a control group in a larger study on prematurely born. All subjects were right-handed. All testing of subjects was performed by authorized psychologists at Centre of Rehabilitation, Lian, St. Olavs hospital. They were on average 19 years (range 18-21) at time of neuropsychological testing with the exception of electroencephalogram (EEG) recording and its pertaining Go/NoGo task that was recorded when the participants were on average 22.2 years of age.

Speed of Processing and Gc

The Symbol search and Grooved Pegboard test were used as measures of speed of processing. In the Symbol search subtest from WAIS-III (Wechsler, 1997a) the subject visually scans two groups of symbols. One is a target group of two symbols and the other is a search group composed of five symbols. The subject’s task is to indicate whether either of the target symbols matches any of the symbols in the search group as fast as possible. Time used to determine this by the subject is the measure of the test. The Grooved Pegboard test (e.g. Bornstein, 1986) consists of a matrix of five times five keyhole-shaped holes varying in their orientation, and the subject’s task is to place pegs into these as fast as possible.

The Information subtest and the POI scores from the WAIS-III were applied as measure of estimated Gc. The Information subtest is intended to give a measure of general information acquired from one`s culture. The POI is an index constructed on the basis of scores on three subtests in the WAIS-III, namely Picture Completion, Block Design and Matrix Reasoning.

Energization

The FAS and Category Fluency Test and the CWI inhibition condition from D-KEFS (Delis et al., 2001) were applied as measures of energization. In the FAS the subject generates words that begin with the letters F, A and S as quickly as possible during 60 seconds. In the Category Fluency condition, the subject generate words that belong to a designated semantic category – Animals and Boy`s names - as quickly as possible during 60 seconds. The CWI from D-KEFS is based on and equivalent the Stroop (1935) procedure, where the subject has to name the color of the letters of a word spelling another color.

Task Setting

The MC from WMS (Wechsler, 1997b), the DSCT from WAIS-III (Wechsler, 1997a) and the TMT switching condition and CWI switching condition from the D-KEFS (Delis et al., 2001) were applied as measures of the task setting process. In MC from WMS (Wechsler, 1997b), the subject is to count from one to twenty, say the alphabet, name the days of the week from Monday to Sunday, and the months of the year from starting with January. After completing this, the examinee will do the same tasks in the opposite direction, counting from twenty down to one, saying the alphabet backwards, the days of the week starting with Sunday, and last the months in reverse order starting with December. DSCT from WAIS-III (Wechsler, 1997a) requires the subject to copy symbols that are linked pairwise to numbers. With the use of a key, each symbol is to be written under its corresponding number. The score indicates the number of symbols that is correctly written under its corresponding number, with a time limit of 120 seconds. In the TMT switching condition from D-KEFS (Delis et al., 2001) the subject has to draw a line from the number 1 to the letter A to the number 2 to the letter B and so on until the letter P. The time the subject uses as well as the errors made contribute to the score on this test. In the CWI switching condition from D-KEFS the subject is asked to switch between naming the ink and reading the words.

Go/NoGo Task

Subjects performed a modified vCPT, a two-stimulus Go/NoGo task used in earlier studies on the P3 NoGo (for a more detailed description of the paradigm, see Mueller, Candrian, Kropotov, Ponomarev, & Baschera, 2010, and Kropotov, Ponomarev, Hollup, & Mueller, 2011) whilst seated upright 1.5 meters in front of a 17 inch LCD screen. This test lasted 22 minutes and consisted of 400 trials. Here, two images were presented for 100 milliseconds with inter-stimulus presentation of 1 second every 3 seconds. The visual stimuli used in the trials were of three categories; animals, people and plants, each of which consisted of 20 different images. During presentations of humans a sound was also presented. These stimuli were presented pairwise in four conditions: Go (animal-animal), NoGo (animal-plant), Ignore (plant-plant) and novelty (plant-human). In Go as well as Ignore conditions, the images presented were identical. The 400 trials were presented in four sessions consisting of 100 trials each, in between which participants could rest for a few minutes. In each session stimuli were presented pseudo-randomly with equal probability for each category and condition.

Participants were instructed to respond as fast as possible during Go-trials by pressing a button on a computer mouse.

EEG

All EEG analyses including ICA were done by a specialist in clinical neuropsychology at Centre of Rehabilitation, Lian, St. Olavs hospital. Participants` EEG was recorded in a 3 minutes eyes open as well as 3 minutes closed resting state condition before the modified vCPT described above. EEG was recorded by specialist in clinical neuropsychology Jan Brunner at Centre of Rehabilitation, Lian, St. Olavs hospital with a Mitsar 21-channel EEG system, using a 19-channel standardized electrode cap with tin electrodes (Fz, Cz, Pz, Fp1, Fp2, F3, F4, F7, F8, T3, T4, T5, T6, C3, C4, P3, P4, O1, O2) that was placed according to the 10-20 system (Jurac, Tsuzuki, & Dan, 2007). Signals were referenced to both earlobes (off-line), and ground electrode was placed on the forehead. Impedance was under 5 kΩ and signals between 0.5-30 Hz were sampled at 250 Hz. Periods of EEG recording with signals exceeding 100 µV for non-filtered EEG, signals exceeding 50 µV for waves from 0-1 Hz as well as signals exceeding 35 µV for waves between 20-25 Hz were excluded from analysis. EEG recordings were manually inspected for verification of artifact removal. Trials with omissions and commissions were excluded when ERPs were averaged and computed in accordance with the fractionated area (FA) approach (Hansen, & Hillyard, 1980; Kiesel, Miller, Jolicoeur, & Brisson, 2008) in order to minimize measurement error.

Statistical Analysis

ICA of P3 NoGo revealed two components in line with previous studies. Assumptions of normality for the P3 NoGo Early and P3 NoGo Late components was assesses with the preferred Shapiro-Wilk test (Razali & Wah, 2001) (alpha set to 0.05). The relationship of EEG measures to psychometric measures was assessed with Spearmans correlation coefficient when distributions did not meet the assumptions of normality, whereas Pearsons correlation coefficient was applied otherwise. Two-tailed tests of significance were applied to correlations. Only scaled scores of neuropsychological tests were used. Due to restricted sample size, potential outliers were not removed.

Results

Assessment of the assumptions of linearity, normality, and homoscedasticity revealed that P3 Early and Late components` latencies were normally distributed in the sample ($p>0.05$) whereas P3 components` amplitude were not ($p<0.05$). Descriptive statistics for P3 NoGo Early and P3 NoGo Late amplitudes and latencies are seen in Table 1.

Table 1. *Descriptive statistics of P3 NoGo Early and P3 NoGo Late amplitudes and latencies*

	Early		Late	
	Mean	SD/IQR	Mean	SD/IQR
P3 NoGo Latency (ms)	329.75	19.73	391.36	23.79
P3 NoGo amplitude (µV)	8.05	6.51	4.23	2.21

Scores on tests of executive processes, Gc and processing speed fell within normal ranges. Scaled scores are reported in Table 2.

Table 2. *Mean and standard deviations of scaled scores on neuropsychological tests*

Executive processes			Gc and processing speed		
	Mean	SD		Mean	SD
Energization			Processing speed		
FAS	11.7	3.79	Symbol search	11	2.8
Category Fluency	13.56	3.94	Grooved pegboard	69.81	12
CWI Inhibition	10.7	2.48	Gc		
Task setting			POI	109.89	13.13
CWI switching	10.7	1.84	Information	10.85	2.8
TMT switching	9.81	2.17			
DSCT	9.15	2.28			
MC	10.67	2.67			

Correlational analysis

Tests that showed significant correlation to measures of P3 NoGo Early and P3 NoGo Late are summarized in Table 3. All correlations between tests of task setting and P3 NoGo Late latency were large. Two moderate correlations were seen between measures of P3 NoGo Early latency and tests of task setting, namely CWI switching and DSCT. Correlations between measures of energization and measures of P3 NoGo amplitude were moderate to large.

Table 3. *Correlation coefficients between P3 NoGo components and EF measures*

	Latency (Pearson`s)		Amplitude (Spearman`s)	
	P3 NoGo Early	P3 NoGo Late	P3 NoGo Early	P3 NoGo Late
Tests of energization				
FAS	-0,2	-0,37	0,58**	0,13
Category Fluency	-0,19	-0,27	0,48*	0,19
CWI Inhibition	-0,22	-0,26	0,36	0,53**
Tests of task setting				
CWI switching	-0,44*	-0,63**	-0,04	0,14
TMT switching	-0,3	-0,60**	0,28	0,1
DSCT	-0,41*	-0,53**	0,29	0,19
MC	-0,37	-0,55**	0,42*	0,55**

Note: * is significant at p<0.05. ** is significant at p<0.01.

Discussion

Measures found to correlate with P3 NoGo components' amplitudes and latencies were performed at average over two years prior to EEG recording. The measures of executive processes were derived on a theoretical basis from different test batteries in this study. Results support the hypotheses that P3 NoGo components` amplitudes and latencies do not correlate with measures of IQ or mental speed (Hypothesis 1) but do correlate with measures of executive processes (Hypothesis 2). Measures of executive processes differentially show correlation to amplitude and latency measures of the P3 NoGo Early and Late components. By large, measures of the task setting process correlate with P3 NoGo latency measures, and furthermore measures of the energization process correlated with P3 NoGo amplitude. Specifically, decomposition with ICA revealed that P3 NoGo Late latencies showed the strongest and most consistent relationship to measures of the task setting process. The Category and Verbal fluency tasks here applied as measures of energization correlated with P3 NoGo Early amplitude, whereas the inhibition condition of the CWI task correlated with P3 NoGo Late amplitude, indicating a possible difference between the fluency tasks and the inhibitory task. MC scaled scores departed from the findings on other measures in that it correlated with both P3 NoGo Late latency as well as P3 NoGo Early and Late amplitudes.

MC scaled scores were departed from the findings on other measures in that it correlated with both P3 NoGo Late latency as well as P3 NoGo Early and Late amplitudes, indicating that variance in both the energization and Task setting executive processes are determining for performance on this test. The MC scaled score is a composite score based on subjects` ability to say numbers up to twenty, weekdays and months of the year forwards and backwards. Furthermore, it contains a condition in which the subject has to switch between naming the days of the week and multiply numbers with six, starting with zero. In contrast to the fluency tasks, the subject already has knowledge of the correct answers in the MC backwards conditions as represented by a sequence opposite to that of the task demands. This task demand is reminiscent of the Stroop inhibition condition where the subject is aware of the task objective but has to enforce the correct answer. Accordingly, it may be proposed that variance in the MC test is significantly related to both variance in the task setting and the energization processes, and that this is why it correlates with measures of both P3 NoGo amplitudes and latency. Furthermore, variation was found amongst the correlations between P3 NoGo components and measures of energization. One explanation can be proposed with respect to a difference that can be found in the task demands. Whereas the Verbal and Category fluency conditions depend solely on production of novel responses without prominent competing response tendencies, successful performance in the CWI inhibition condition is dependent on resolving two competing response tendencies. The same can be said about the MC test from D-KEFS. Accordingly it can be proposed that the resolution of competing response tendencies is a process that occurs in a later stage that mere production of responses without any established competing response tendencies, and that this is why P3 NoGo Late amplitude has correlation to CWI inhibition condition and MC.

P3 NoGo has been proposed as to reflect processes related to inhibition. Inhibition is regarded as an executive function. In line with this, the present study has found P3 NoGo to correlate specifically with measures of two different executive processes. However, as opposed to an inhibition-account, a more specific description is available when P3 NoGo is correlated to specific measures of executive processes. Even though P3 NoGo has been found to occur after the response made in the Go/NoGo task and hence cannot be said to be causative to the subject`s response inhibition, the current study bypass this particular problem of explanation by correlating measures of P3 NoGo components to neuropsychological tests. Furthermore somewhat different roles of the P3 NoGo Early and P3 NoGo Late components are proposed. In addition to the functional role of amplitude and latency measures are specified. Previous findings have found on correlations between measures of cognitive ability and P3 Go. A comprehensive review of the relation between P3 Go and P3 NoGo is beyond the scope of the current study. However, findings of relation between P3 Go and P3 NoGo and interpretations of the functional significance of P3 Go and P3 NoGo will be cited when relevant.

P3 Go amplitude has been described as corresponding to the amount of attentional resources employed in a task (Polich and Kok, 1995). In the present study, P3 NoGo has been found to index energization. Energization does indeed have correspondence to the amount of attentional resources employed in a task. Nevertheless, it should be noted that energization is a specific characteristic of the attention system. Energization corresponds to phasic attention (Stuss & Alexander, 2007), the ability to respond to a stimulus that is preceded by another (Sturm & Wilmes, 2001) as is the case in the Go condition of the Go/NoGo task. However, this does not imply that there are no other features of attention. For example, "intrinsic alertness" is assessed by measuring the ability to respond to a stimulus without a preceding warning (Sturm & Wilmes, 2001), referring to the cognitive control of wakefulness and arousal. Accordingly, an apparent similarity in the descriptions given by P3 Go amplitudes and P3 NoGo component amplitudes in the present study is seen. In the present study it is however specified that P3 NoGo component amplitudes have been found to index energization of attentional resources. Furthermore, it has been suggested that P3 NoGo amplitudes are larger in conditions where overt motor responses must be inhibited due to positive movement related potentials (Smith et al., 2008). This does not stand in contrast to the current interpretation of findings, as the energization process refers to facilitation of the neural systems needed for initiation and maintenance of the intended response of any task, including motor schemata (Stuss, 2007).

Some authors have proposed P3 Go as relevant for memory updating. In the current view, P3 NoGo amplitude is viewed as to index energization and would be considered critical in memory updating as energization refers to the activation of relevant neural systems. However, memory updating is not equivalent to the energization process. In the current view, energization as indexed by P3 NoGo amplitude is of relevance to memory updating functions, but it is also claimed that energization is relevant for other functions. Conversely, memory updating is also dependent on other processes, executive processes included. Hence, both amplitude and latency of P3 NoGo components would be considered relevant when considering memory updating in general. In a related vein, Walhovd & Fjell (2002) suggested that the P3 Go latency indexes the relative timing of the stimulus evaluation process. In the present study, the P3 NoGo Early has been found to correlate with measures of the task setting process. A possible interpretation of the findings in the current study is that P3 NoGo indexes the timing stages in the task setting process. This would implicate that the efficiency of the task setting process correlates with the P3 NoGo latency because P3 NoGo latency provides a measure of the time used to finish the processing of one mental set and switch to another mental set. Provided that this is correct, ICA decomposition indicates that it is the latency of P3 NoGo Late component where this is most evident. Concluding that it is the P3 NoGo Early latency is of little importance would be a premature conclusion however. Two of the measures of the task setting process, the CWI Switching condition and the DSCT do correlate with P3 NoGo Early latency. The correlation of P3 NoGo Early latency to measures of task setting might be interpreted as to mean that the latency of the P3 NoGo early component reflect a time component in earlier stages of the task setting process. Assuming that this is correct would lead to concluding that successful performance in the CWI Switching condition and the DSCT require processing from the earlier stages of the task setting process in addition to later stages.

The current results provide some direction in ICA of the P3 NoGo phenomenon. It is not so much the findings themselves but rather their interpretation within a theoretical framework which makes the current study different from earlier ones. The primary advantage ICA decomposition of the P3 NoGo in this study has been the identification of component waves as possibly having different roles in stages of executive processing of information. Results show that P3 NoGo Late latency has the strongest relationship to the task setting process, possibly indicating it as an index of how long it takes to complete a change in mental set. Furthermore, the P3 NoGo Early latency is a candidate for indexing earlier stages in the task setting process. P3 NoGo Early amplitude is proposed to be of importance as an index of energization early in the processing stage when no competing response tendencies are present.

The relevance of energization as indexed by P3 NoGo amplitude can be described in several ways. First, it is of general relevance to tasks requiring energization of neural systems especially during performance of non-automated tasks. Second, P3 NoGo Early amplitude has in the current study been assumed to index energization in the initiation of information processing, whereas P3 NoGo Late amplitude has been interpreted as relevant in energization processes occurring at later stages when response tendencies must be resolved. A possible interpretation of this is that the energization process is of relevance to the task setting process. This interpretation is based on several assumptions. The first one is that EFs are domain general, meaning that executive processes not only exert influence on lower lever processes, but also each other. Secondly, a limitation in the resources available for any given process is assumed. Thirdly, even though tests load on specific executive processes more than others as seen when variance in specific outcome variables are more associated with variance in specific executive processes does not exclude other executive processes from being involved. Therefore, several executive processes are assumed to be a requisite, even though variance in outcomes in one test is best explained as variance in one particular process capability. As an example, behavioral performance on the CWI inhibition condition as measured by variation in reaction time is in the current framework interpreted dependent on sufficient energizing of neural systems as reflected in P3 NoGo amplitude. Successful inhibitory behavioral performance would nevertheless still be dependent on the task setting process for maintaining the correct mental set. Hence, unsuccessful inhibition represented by reading errors would in according to this interpretation be predicted to be caused by a deficit in task setting. Accordingly, variations in failures in the CWI inhibition condition would be predicted to be associated with the task setting process, reflected in P3 NoGo latency measures. The reason why this interpretation must assume both a limitation in the resources available as well the interdependence of executive processes is that behavioral task failure would be explained by a sequence of executive process failures. An exceeding of threshold for maximum capacity would be defined as the moment where an executive process no longer utilizes its resources on other executive processes resulting in their failure and consequently its own collapse due to itself no longer being under proper executive control by the other executive processes which itself controls. Such an exceeding of threshold for maximum processing capacity in the CWI inhibition condition would result in the halt of covariance of measures of the energization executive process with measures of reaction time, paralleling the start of covariance of measures of failure with measures of the task setting executive process. This interpretation does appear rather speculative and is lacking of current empirical support. However, it would provide explanation to the inherent correlation between P3 NoGo amplitude and latency and be a reflection of proposed the “unity and diversity” (Miyake et al., 2000) of executive function. Furthermore, it would provide an explanation of why P3 NoGo amplitudes are larger than P3 Go amplitudes, as the task setting process would require more from the energization process in order to maintain correct mental set in NoGo conditions. Finally, this interpretation implies that P3 NoGo does not index inhibition. Rather, P3 NoGo would be seen to index the energization and task setting processes which in turn, make behavioral inhibition possible by energizing of the neural circuits required to maintain the correct mental set.

The mechanisms responsible for generating attention and those responsible for generating the P3 Go have been suggested to be partly independent. The correlations between tests measuring executive processes and P3 NoGo Early and P3 NoGo Late amplitude and latencies were in the current study moderate to large, but far from perfect. This might be due to task impurity and the possibility that other aspects of the attention system such as intrinsic alertness (Sturm & Wilmes, 2001) are relevant when performing the tasks. Furthermore, even though the current study provides some indication to the functional significance of P3 NoGo, a more detailed description is still lacking. Furthermore, the relation between P3 Go and P3 NoGo and the question to whether they can be ascribed to the same or fundamentally different processes remains without explanation. If they are in fact found to be based on the same process, findings of correlation between P3 Go and intelligence measures would in the current study be interpreted as to be due to the confounding influence of executive processes. If the P3 Go and P3 NoGo are found to be based on largely different processes, then their difference each would provide explaining value. It would be preferable however that a theoretical framework of executive functioning would be applied in understanding and relating them both as opposed to fragmented suggestions, for example in explaining why increased P3 Go and P3 latencies increase while at the same time NoGo amplitude but not P3 Go amplitude has been found to decrease as a consequence of increased test duration (Kato et al., 2009) or increased stimulus complexity (Gajewski & Falkenstein, in press).

Limitations of the current study

The restricted sample size of a young population is a strong limitation of the results and their interpretation in the current study. Furthermore, only two measures of executive functioning were studied, and these were not specifically designed for studying the processes in question. Optimally, tests of executive function, Gc and speed of processing would have to be constructed according to theory in order to reduce task impurity. Lastly, the current study did not correct for multiple comparisons as would optimally be the case with a larger sample size.

Conclusion

Decomposing of ERPs through ICA is promising in revealing new knowledge about the nature of the mental processes that underlie them. P3 NoGo does not correlate with IQ or processing speed, but with measures of executive processes. Despite not being causal to the response made in the Go/NoGo test because it occurs after the response usually have been made, the P3 NoGo index executive processes. P3 NoGo latency is associated with the task setting executive process. Specifically, P3 NoGo Early latency is suggested to be associated with earlier stages of the task setting process, whereas P3 NoGo Late latency is suggested to be associated with later stages where response competition is resolved. P3 NoGo amplitude is associated with the energization executive process. P3 NoGo Early amplitude is seen to be more important in tasks where competing responses are absent, whereas P3 NoGo Late amplitude is important in tasks inducing competing response tendencies in the subject. In addition to ICA decomposition, the current study emphasizes the necessity of a thorough theoretical framework of cognitive functioning when explaining the functional significance of P3 NoGo. Having representations available for scrutiny in working memory is equivalent to having them available for attention and consciousness. Abilities described as attentional control or executive attention is often placed at the top of a hierarchy predominantly influencing and less influenced by, other processes. Within a scientific framework however, referring to this ability of inhibiting prepotent responses and selective attention over prolonged periods as depending on and explained by attentional control or similar has a seemingly circular sound to it. A more rewarding approach is an enquiring into the constituents of this ability of attention. This is not to say that cognitive or attentional control as a functional concept is important to understand a central executive. What it does say is that different levels of conceptual understanding must be kept on their respective level in order to enable comprehensive understanding, and consequently that any ability and function can be seen as supported by multiple processes. In the current view, both the energization and task setting Process are assumed to be important processes required for proper attention.

Additionally, the proposal that the influence of general intelligence needs to be understood before the psychological import of specific cognitive abilities can reveal themselves (Lubinsky, 2004) seems in line for revision. This is because general functions and abilities appear largely carried by specific processes. The central executive itself does not exist in an anatomical position or as a singular process. Rather, it can be comprehended as the proper coordination of different processes into a coherent functional whole. It is this coherent whole, represented by the control functions it is capable of performing that is the central executive. Hence, in order to understand general abilities, specific executive processes must be understood.

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