ELECTROPHYSIOLOGICAL IDENTIFICATION OF MALINGERED EXECUTIVE DYSFUNCTION

by

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Abstract

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Traditional evaluation of cognitive functioning is based on the assumption that the individual being assessed is responding to the best of his or her abilities. However, when individuals have external incentives to appear more impaired, such as those involved in civil or criminal litigation, the results of these evaluations may be questionable. Therefore, measures designed to assess malingering have become an integral part of many neuropsychological evaluations, particularly in forensic settings. However, these malingering measures have been demonstrated to be vulnerable to both manipulation and coaching. Consequently, recent research has attempted to identify physiological indices of cognitive functioning that are less susceptible to overt manipulation. Previous physiological studies have focused on assessing the validity of an individual’s memory impairment, however, this study evaluates the effectiveness of a physiological measure of frontal lobe executive functioning.

This study used EEG recording in conjunction with a three stimulus oddball design to compare differences in neural responses in simulated malingerers and controls. The experimental group was tasked with simulating the cognitive deficits associated with traumatic brain injury (TBI). Specifically, the study was designed to compare an event-related potential (ERP) known as the P3a, which is elicited by irrelevant distracter stimuli, and to investigate its resilience to intentional manipulation. The P3a is believed to be an index of frontal lobe executive processes, specifically the attentional orienting response.

The results of this study demonstrated that simulated malingerers did not produce a physiological P3a response that was significantly different from control participants. Furthermore, the P3a in simulated malingerers did not demonstrate any of the physiological indicators demonstrated to be present in prior studies with mTBI patients. Not only were malingerers unable to produce a significant change in their basic orienting response, but the very process of attempting to employ additional strategies to appear impaired produced other physiological markers of deceptive responses. Therefore, the P3a component appeared to be unaffected by an individual’s motivation or overt performance, thus making it an excellent candidate for measures differentiating between malingerers and patients with genuine TBI.

The results are discussed in comparison to traditional behavioral measures of malingered executive deficits, and serve as a pilot study for future development of physiological measures of cognitive functioning that span multiple cognitive domains.

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CHAPTER 1: INTRODUCTION

Many neurological conditions, especially in their early stages, present without physical manifestations that can be verified through laboratory tests or imaging techniques (Lezak, Howieson & Loring, 2004). This issue is particularly salient in cases of traumatic brain injury (TBI). TBI is often characterized by both verifiable focal injuries, which do not necessarily directly correlate with specific functional impairments, *and* diffuse axonal injury caused by the stretching of brain tissue (Levin, 1990), which cannot be detected using brain imaging techniques such as computed tomography (CT) scans, single-photon emission computed tomography (SPECT), or magnetic resonance imaging (MRI) (Ichise, Chung, Wang, Wortzman, Gray & Franks, 1994). Therefore, the onus of assessing the cognitive deficits associated with brain injuries chiefly relies on traditional behavioral measures of neurocognitive functioning (for a review, see Lezak et al., 2004). However, standard measures of cognitive functioning are often grounded in the assumption that an individual is putting forth their best effort, and therefore have been demonstrated to be susceptible to both careless responding (low effort) and the intentional exaggeration of symptoms (malingering; Larrabee, 2007; Vagnini, Berry, Clark & Jiang, 2008). Traditionally, the task of determining whether the test results are an accurate representation of a person’s abilities has been left purely to a clinician’s judgment, based on impressions formed during testing. However, a significant risk remains that individuals who are careless in their responses may be misidentified as cognitively impaired. These problems are compounded in forensic settings when assessing populations who have an external incentive to appear impaired, such as those involved in legal proceedings.

For the past decade, clinical neuropsychology has increasingly moved into the private sector, and the majority of private practice referrals now have forensic applications (Sweet, Moberg & Suchy, 2000). Other than divorce actions, personal injury cases represent approximately half of all remaining civil cases litigated within the American court system (Modlin, 1983), the majority of which involve reports of TBI (Miller, 1993). General damages awarded to personal injury claimants are intended to correlate with the degree of impairment, pain and suffering, and future repercussions associated with their injuries (Greenberg, 2003). This provides substantial motivation for a plaintiff to intentionally exaggerate the degree of their impairment in order to receive higher compensation.

Precise base rates of malingering are difficult to determine since, by definition, malingerers do not admit their deception (Greiffenstein, Baker & Gola, 1994). However, a recent survey of American Board of Neuropsychology diplomats in forensic practice estimated that as many as 30% of disability cases, 29% of personal injury cases, and 19% of criminal cases were suspected of exaggerating or fabricating their symptoms (Mittenberg, Patton, Canyock, and Condit, 2002). This survey placed particular emphasis on the high proportions (38%) of malingered neurocognitive deficits suspected in personal injury claims of mild head injuries. This estimate was later confirmed by Larrabee (2003) in a meta-analysis of 11 studies investigating malingering in mild TBI (mTBI). Using cutoff scores on established measures of both cognitive functioning and malingering, they estimated that 40% of mTBI patients who were seeking compensation were identified as having performance deficits suggestive of malingering. Prevalence estimates from individual studies within this meta-analysis ranged from 15% (Trueblood

& Schmidt, 1993) to as high as 64% (Heaton, Smith, Lehman & Vogt, 1978). Similarly, a high prevalence of exaggeration of cognitive complaints has also been reported in a sample of whiplash patients who did not appear to have significant injuries; 61% of them complained of cognitive symptoms with severity scores comparable to those with major closed head injuries (Schmand et al., 1998).

Despite the apparently high base rate of symptom exaggeration in forensic cases, little is known about the abilities of clinicians to reliably identify malingerers. A survey of neuropsychologists revealed that when they were presented with a comprehensive battery of test data from an individual feigning cognitive deficit, they were unable to identify the results as "fake" (Faust, Hart, Guilmette & Arkes, 1988). Given these findings, it is not surprising that clinicians are continually exploring new methods to assess the veracity of an individual's reports of cognitive deficit, particularly when assessing populations without quantifiable injury, such as those with mild to moderate TBI.

Traditional Behavioral Measures of Malingering

To date, clinicians have relied on behavioral measures of effort to assist them in making a determination of malingering. In a recent survey, 84% of neuropsychologists reported including malingering measures in their assessment batteries (Sharland & Gfeller, 2007). Typical tests used in clinical practice to detect malingering or suboptimal effort on neuropsychological measures frequently employ a paradigm referred to as Symptom Validity Testing (Sharland & Gfeller, 2007). Symptom Validity Testing (SVT) is based around the idea that when faced with a forced-choice task, even those with severe cognitive impairment should not score significantly below chance. The primary appeal of such tests lies in their ability to quantify the probability of poor performance on a particular measure since the cutoff scores for determining malingering are based on statistical confidence intervals. Below chance performance on this type of test suggests an intentional effort to avoid what is known to be the correct response. This type of behavior meets one of the diagnostic criteria for Malingered Neurocognitive Dysfunction proposed by Slick and colleagues, as evidence of a “definitive negative response bias” (Slick, Sherman & Iverson, 1999). Several variations of SVTs are used in clinical practice and are considered by many clinicians to be the most valid indicators of malingering currently available (Sharland & Gfeller, 2007). The most frequently encountered SVTs in clinical practice (and those believed to be the most reliable) are the Test of Memory Malingering (TOMM; Tombaugh, 1996), the Word Memory Test (WMT; Green, 2005) and the Validity Indicator Profile (VIP; Frederick, 1997) (Sharland & Gfeller, 2007).

The TOMM is a memory task that was designed to produce high accuracy performance even in neurologically impaired populations (Larrabee, 2007). After viewing a series of line drawings, participants are presented with an old and a new item and have to identify which one they saw previously. Individuals suffering from documented aphasia, TBI, and cognitive impairment are typically able to provide correct responses on over 97% of the items, when responding to the best of their abilities. Even those suffering from dementia are able to achieve 92% accuracy on this measure (Tombaugh, 1996).

The TOMM remains the most commonly used instrument to assess malingering, with regular use by 75.3% of neuropsychologists surveyed (Sharland & Gfeller, 2007).

Its popularity, however, makes the TOMM a very recognizable instrument and has raised concerns that this measure may be too easy to identify and manipulate. It has also been criticized for being too simple, with a lower hit rate than other measures of malingering (Larrabee, 2007).

The Word Memory Test (WMT) is also a direct measure of malingering that is frequently used in clinical settings, which is similar to the TOMM but uses words instead of pictures. Like the TOMM, even patients with severe cognitive impairment produce relatively high accuracy scores on this measure (Sharland & Gfeller, 2007). When the WMT was administered to a population of TBI patients with identifiable brain injury, accuracy scores still exceeded 90% (Sharland & Gfeller, 2007). However, despite the relative simplicity of this measure, patients with mild traumatic brain injuries actually scored significantly worse than those with more severe injuries (Green, Iverson & Allen, 1999). In a sample of patients referred for personal injury or disability evaluations, the WMT was shown to make determinations of malingering in 32% of the sample, in comparison to 11% who were identified as “faking” by the TOMM (Gervais, Rohling, Green & Ford, 2004). This draws attention to the possible simplicity of the TOMM, and its tendency to underestimate the presence of more subtle malingering. However, a concern that the WMT may have a tendency to produce false positives is particularly troubling for forensic application.

In contrast, the Validity Indicator Profile (VIP) offers a more sophisticated measure of malingering than either the TOMM or the WMT, but is also based on a two alternative, forced-choice design. In contrast to many other methods, which test either verbal or visual memory, the VIP assesses both vocabulary knowledge and nonverbal problem solving abilities. Administering both verbal and non-verbal subtests therefore improves the chances of detecting malingering by testing multiple domains of cognitive functioning, because a sophisticated malingerer will only feign on those measures that appear consistent with their reported deficits. The VIP subtests can be administered separately, or as companion measures. The VIP has been reported to have greater incremental validity and sensitivity than another popular measure of malingering, the Rey 15-Item Test (Frederick & Crosby, 2000). When used alone, the VIP-V reportedly correctly classifies 75.5% of malingerers. While the ability of this measure to positively identify malingerers is relatively weak (only 67% sensitivity), it has the advantage of producing a relatively low number of false positives (83% specificity). The VIP-NV has shown slightly better classification accuracy (79.8%), with 74% sensitivity and 86% specificity (Frederick, 1997). The results of the two VIP subtests can also be combined in one of two different ways. First, protocols indicative of malingering are identified if performance on either one of the two subtests is invalid. This approach results in an overall classification rate of 77.7% (78% sensitivity and 77.5% specificity) (Frederick, 1997). In order to achieve increased specificity, which is particularly crucial for forensic application, the second approach requires both subtests to be invalidated to make a determination of malingering. Doing this maintains the overall classification rate (77.7%), while increasing specificity to 91.9% (sensitivity of 62.7%; Frederick, 1997). While the ability of the VIP to differentiate between malingerers and honest responders is slightly less effective than some measures like the TOMM (with a reported specificity of 100% and sensitivity of 82%; Tombaugh, 1996), the advantage of the VIP over either the TOMM or the WMT lies in its structure and complicated analysis. This makes it very difficult for participants to either be coached in advance or to successfully manipulate their performance to appear impaired.

Although forced-choice SVTs are by far the most common malingering measures used by clinicians (Larrabee, 2007; Sharland & Gfeller, 2007), numerous criticisms of these measures have been voiced. Larrabee (2007) points out that given the similarity among test formats, and the fact that often the same ability (memory) is being assessed, forced choice measures are increasingly likely to correlate with each other. In addition, the tendency of these measures to focus on malingered memory impairments limits their application, as they will likely be ineffective for cases where no memory deficits are reported. Furthermore, while the majority of test developers report the relative sensitivities and specificities of their various measures, very few report positive and negative predictive accuracies. This is probably due to the uncertainty regarding the precise base rates of malingering in different populations (Rosenfeld, Sands, & van Gorp, 2000). While instrument sensitivity quantifies the proportion of malingerers in a sample, positive predictive accuracy may be a more clinically relevant measure since it estimates the proportion that is truly malingering (Rosenfeld et al., 2000). This figure, however useful, remains somewhat unreliable until accurate base rates for malingering can be determined.

The relatively limited pool of malingering instruments and their commonality also makes them easy to anticipate and subsequently identify. Information regarding these tests is readily available to the general public. Bauer and McCaffrey (2006), by scouring the internet, were able to locate information about the most commonly used tests including their purpose and format, how malingerers and non-malingerers typically react during the test, who should be able to perform well on these tests and, perhaps most damaging, exact cut-off scores indicative of questionable effort. Attorneys may also provide similar information to their clients. Victor and Abeles (2004) reported that 75% of attorneys who were members of the National Academy of Neuropsychology (NAN) and the Association of Trial Lawyers, spent 25-60 minutes with their clients discussing details of the evaluation process, including providing information about specific tests and suggesting how best to respond. Furthermore, 44% of these attorneys requested to know exactly which instruments would be administered to their client, and the majority of them were provided with this information prior to the assessment.

Behavioral Assessment of Malingered Executive Deficits

To help address some of the concerns about traditional malingering measures, malingering has also been assessed using atypical response patterns of performance on standard measures of cognitive functioning (e.g., intelligence tests). Malingering measures have been developed using popular cognitive measures such as the Digit Span subtest of the Wechsler intelligence tests (Axelrod, Fichtenberg, Millis & Wertheimer, 2006; Greiffenstein, Baker & Gola, 1994; Iverson and Tulsky, 2003), the California Verbal Learning Test (CVLT-II; Delis, Kramer, Kaplan, & Ober, 2000; Millis, Putnam, Adams, & Ricker, 1995), and the Wisconsin Card Sorting Test (WCST) (Heaton, Chelune, Talley, Kay & Curtiss, 1993; Bernard, McGrath, & Houston, 1996; Greve et al., 2002; Suhr and Boyer, 1999).

Of particular relevance to the current study are the malingering instruments proposed to detect malingered executive dysfunction. A recent survey of clinicians reported that the most frequently used measure to assess malingered executive deficits was the WCST (Sharland & Gfeller, 2007). However, when considering all measures of malingering, these same clinicians rated its accuracy in identifying malingering as relatively poor, ranking it 25th of the 29 instruments evaluated. This suggests that despite the fact that the measure shows poor discrimination ability, its popularity remains, likely due to a lack of more reliable measures.

For the standard administration of the WCST, individuals are presented with four “target” cards, and each card has a different number of shapes in various colors (i.e., one red triangle, two green stars, three yellow crosses, four blue circles). Participants are then presented with a succession of test cards (e.g., one green triangle), which they have to match with one of the target cards. Therefore, cards can be matched along one of three different dimensions, color, shape, or number of symbols. The participant is not told about the sorting rule, but after each response, individuals are told whether their response was correct or incorrect, and have to figure out the sorting criterion through trial and error. Once 10 correct responses are made, the category is considered complete and the sorting criterion changes. The WCST therefore requires adaptability and mental flexibility; cognitive functions that have been reliably associated with frontal lobe executive functioning.

In general, multivariate analysis of WCST results has been used to identify malingerers; however, there has been some debate as to which variables provide the best sensitivity and specificity. Bernard and colleagues (1996) administered the WCST to a sample of college students (21 responding honestly and 24 simulating cognitive impairments), and compared the results to those obtained with neurological patients with TBI with no other evidence of neuropathology (*n*=70), and those with mixed neurological deficits not caused by TBI (*n*=89). They subsequently developed a series of discriminant function equations to identify which indices would differentiate between simulated malingerers and those with genuine impairments in each of these categories. Their results showed that the best variables to use were the number of categories completed and the number of perseverative errors. This supported their hypothesis that while a malingerer may be aware of relatively obvious indicators of brain injury, such as the total number of categories completed, they are unlikely to be aware that those with cognitive deficits frequently perseverate or repeated the same types of errors. Bernard et al. created a series of discriminant equations that could be used to classify participants as honest responders, malingerers, or neurological patients, either with or without genuine head injury (the coefficients for these equations and directions for their usage can be seen in Table 1). The formulae were found to yield an overall hit rate of 91% (sensitivity = 86%, specificity = 94%) when attempting to distinguish between malingerers, and those with genuine TBI.

Suhr and Boyer also attempted to refine the WCST indicators used to distinguish between groups, by using logistic regression analyses to compare WCST performance in four groups of participants: simulated malingerers (*n*=41), honest responders (*n*=31), patients with TBI (*n*=16), and a sample of workers compensation litigants with additional indicators of malingering (*n*=17). Subsequently, Suhr and Boyer developed two regression equations, the first was used to discriminate between simulated malingerers and honest responders in an experimental setting, and the second was used to identify suspected malingerers in a clinical setting.

While Bernard and colleagues used categories completed and perseverative errors as the critical variables to classify participants, Suhr and Boyer found that these two indicators were highly correlated and, as a result, proposed "failure to maintain set" as a different index of "subtle" cognitive impairment. The number of failures to maintain set is defined as the number of times participants lose track of the current sorting principle (i.e., they make several consecutive correct responses, but make an error before they are able to make the 10 correct responses needed to complete the category). Using the two equations outlined in Table 1, Suhr and Boyer accurately classified 77.8% of their undergraduate sample (controls versus simulated malingerers), with 70.7% sensitivity and 87.1% specificity. The authors reported comparable accuracy within the patient sample (TBI versus suspected malingerers), with a classification rate of 87.5% (sensitivity = 82.4%, specificity = 93.3%). A list of cutoff scores to achieve varying levels of sensitivity and specificity can be found in Table 2.

More recently, Greve and colleagues (2002) attempted to further refine earlier efforts to use the WCST as a malingering measure by adding a third factor. Using a population of TBI patients, participants were classified as either honestly responding or malingering using the Slick et al. (1999) criteria for Malingered Neurocognitive Dysfunction (MND). These criteria require the presence of external incentive for malingering, and atypical or inconsistent response patterns on either neuropsychological tests, and/or inconsistency in behavior or self-reported symptoms (and not fully accounted for by other psychiatric, medical, or developmental factors) (Slick et al., 1999). Accordingly, participants were classified as controls (did not meet the criteria for MND) (*n*=17), "probable" malingering (had external incentive with multiple indicators of atypical or inconsistent testing and/or self-report inconsistencies) (*n*=32), "suspect" malingering (had external incentive and one indicator of testing or self-report inconsistency) (*n*=30), and “incentive-only” (had external incentive with no other indicators) (*n*=10). This method of utilizing actual clinical samples and speculating about the presence of malingering is similar to the patient comparison made by Suhr and Boyer (1999). However, in addition to analyzing the number of categories completed and either the number of perseverative errors (Bernard et al., 1996) or failures to maintain set (Suhr and Boyer, 1999), Greve et al. also included the number of “unique responses” as a variable. A unique response was considered to occur when a participant failed to match a test card with its identical target card. Greve et al. compared the relative accuracy of the various methods, in conjunction with various combinations of the two equations and the number of unique responses, in accurately classifying patients as malingerers. They also explored the classification accuracy of their measures using two cutoff levels. The first threshold (cutoff #1) was determined by calculating the cutoff values needed to produce a specificity of at least 90%. In an attempt to improve the measure’s sensitivity and decrease the number of false positives, the authors also calculated the cutoff values needed (cutoff #2) to improve the sensitivity to above 90%. Multiple comparisons were made using these different criteria, and the relative sensitivity and specificity of the different combinations varied significantly (see Table 3 for complete results). The authors did not attempt to make determinations regarding which combination of indicators would be best due to the inherent trade-off between sensitivity and specificity (an area of particular concern for forensic application). However, from their results it appears that the most effective measure for identifying the highest number of malingerers was the requirement of an individual to meet criteria (using cutoff #1) for either unique responses OR Suhr and Boyer's criterion (sensitivity = 66%). However, it should be noted that in order to achieve this moderate level of sensitivity, there were a high number of false positive errors (specificity = 82%). The same results were also obtained by requiring patients to meet criteria for either unique responses OR Suhr and Boyer's equation OR Bernard et al.'s equation, suggesting that the use of the Bernard et al. equation did not add anything beyond what was obtained with the Suhr and Boyer equation.

Physiological Measures of Malingering

The possible fallibility and limitations of behavioral methods has resulted in the exploration of physiological markers for detecting the malingering of cognitive deficits. These provide a more objective approach to identifying malingering that may be less susceptible to the effects of coaching and overt manipulation, and can be used to supplement traditional behavioral assessments for cases in which accurate determinations of symptom validity are particularly crucial. However, the question still remains as to whether there are reliable neural correlates of neurocognitive functioning that are unaffected by malingering, or actual physiological markers of deception that that can aid in the detection of malingering. In addition, attempts to identify the neurological correlates of malingered responses have only focused on a single domain of cognitive functioning: identifying malingering in cases of feigned memory impairment (Abe et al., 2006; Browndyke et al., 2008; Farwell & Donchin, 1991; Lee et al., 2002; Rosenfeld et al., 1987, 1995, 1998, 1999; Tardiff et al., 2000, 2002).

While previous research has attempted to utilize numerous different imaging techniques in order to identify malingered impairments (e.g. Abe et al., 2006; Browndyke et al., 2008; Lee et al., 2002), electroencephalography (EEG) techniques and, more specifically, event-related potential (ERP) recording, have been used most frequently (e.g. Farwell & Donchin, 1991; Rosenfeld et al., 1987, 1995, 1998, 1999; Tardiff et al., 2000, 2002), and have shown the most potential for future development.

Event-Related Brain Potential (ERP)

ERPs represent the summed post-synaptic electrical activity of pyramidal neurons, measured at the scalp, in response to a stimulus or event (Luck, 2005). Changes in electrical activity in the brain that are associated with cognitive processing occur on the order of milliseconds, while the resultant regional hemodynamic changes occur much slower, on the order of seconds (Langleben, 2008). ERPs, therefore, provide a direct measure of voltage change associated with neural activity, while fMRI and PET are indirect measures in which neural function is implied by changes in blood oxygenation levels in different brain areas. This makes ERP recording a more appropriate method for evaluating both information processing and other underlying cognitive processes involved in the production of a feigned response, as physiological data is seen in 'real-time.' This technique also allows for determinations to be made on a case-by-case basis by comparing an individual's profile to that of both a malingerer, as well as someone with genuine impairments. This feature is particularly crucial for applicability to a clinical setting (Andreassi, 2000).

While there are competing theories regarding the underlying mechanisms of ERP generation (e.g., the phase-shift model proposed by Sayers, Beagley, and Henshall, 1974), the predominant theory states that the EEG consists of both the stimulus-related ERP waveform, as well as random noise generated from other biological and cognitive processes unrelated to the task or stimulus. A reliable ERP component remains consistent in its timing in relation to a stimulus or event across numerous trials, while background EEG noise is random with respect to the time-locked event (Luck, 2005). In order to isolate an ERP waveform, numerous trials are averaged together. If background noise is in fact random, when averaged over multiple trials the net effect of the noise will be gradually reduced, leaving only the ERP (Luck, 2005). The components in the ERP waveforms are typically labeled as either positive (P) or negative (N) based on the direction of the deflection, and by the timing at which the peak occurs (e.g. P300 is a positive peak occurring approximately 300 milliseconds after the stimulus or response).

Physiological Identification of Malingered Memory Deficits Using ERP

Prior research using ERPs to detect malingering has focused on the identification of feigned memory impairment, frequently using the P300 paradigm. The brain is particularly adept at the detection of different classes of stimuli that occur rarely in a series. Therefore, the presence of an infrequent but meaningful stimulus against the background of frequent but meaningless stimuli results in the generation of a P300 ERP component. Rosenfeld and colleagues (1995) used a P300 paradigm to assess the veracity of an individual’s autobiographical memory. Within this study, P300 amplitudes over midline electrodes were analyzed in a sample of undergraduates simulating amnesia. Using an oddball paradigm, autobiographical information (i.e., their own phone number, birthday, or mother’s maiden name) was presented infrequently among frequent but irrelevant similar stimuli (other meaningless phone numbers, dates, or names, respectively). Group analysis showed that the P300 could be used to detect 77% of malingerers when the stimuli included the participant’s mother’s maiden name, and 92%

of those simulating memory impairment for their own birthdates or phone numbers. The authors attribute this discrepancy between stimuli as a reflection in the difference between the over-learned nature of the birth date and phone number items in comparison to less frequently retrieved information (mother's maiden name). This suggests a possible limitation of this procedure. Since P300 amplitude is potentially influenced by the relative degrees of familiarity with the "known" information, malingering for less well-memorized stimuli might be more difficult to detect (Rosenfeld et al., 1995).

While Rosenfeld et al. (1995) did not collect the single sweep data necessary to conduct a within-subject analysis; the authors later conducted a follow-up study in order to make such a distinction (Ellwanger et al., 1996). In this study they also explored the possible utility of the procedure to assess malingering memory deficits for newly acquired information. Validation of these paradigms with anterograde stimuli is particularly crucial for clinicians, as the majority of patients in clinical practice report deficits in their ability to learn and remember new information, but not amnesia for autobiographical details (Lezak et al., 2004). The stimuli included autobiographical details (birthday), as well as knowledge of the experimenter's name and a learned list of 14 words. Participants were given various degrees of instruction regarding *how* to malinger, "sophisticated" simulators were provided with specific information regarding what deficits would be anticipated following a head injury. Comparable to the results of Rosenfeld et al. (1995), identification of malingering was most accurate for the most salient items (birthdates; 86% of sophisticated malingerers were identified), with the more novel and less automatically remembered stimuli (list-learning, 53% of sophisticated malingerers) providing the weakest discrimination between malingerers and honest respondents. However, since the majority of memory deficits involve difficulties in learning and remembering new information, a 53% hit rate achieved with the list-learning task significantly limits the practical applications of such a measure. Additionally, this rate is substantially below many of the behavioral measures of malingering.

Rosenfeld and colleagues (1998) also investigated how simulated malingering influences P300 using a match-to-sample task in which participants were presented with a three-digit number. The behavioral hit rate for malingerers was manipulated to simulate the different (and more sophisticated) strategies employed by actual malingerers. Not only did the malingering strategies of the different groups have an influence on the overall amplitude of P300, but the unrehearsed nature of this repetition task also resulted in hit rates that were somewhat lower than in previous studies. Accurate identification occurred for only 69% of those with the highest rate of malingering (those instructed to achieve a 75-80% hit rate). When the proportion of malingered responses decreased further (85-95% accuracy group), identification rates dropped to only 38%. These findings suggest that in order to make reliable distinctions, malingerers not only need to be relatively familiar with the encoded stimuli, but they must also feign memory deficits on a high proportion of the items.

Increasing concerns have been expressed regarding the application of P300 as a reliable method for identifying malingered memory deficits. As discussed previously, the relative amplitude of P300 and its subsequent reliability appears to be a function of the familiarity and accessibility of the information. The relative amplitude of the P300 component is also significantly influenced by the difficulty of the task or with the requirement to allocate resources to multiple tasks such as those required for malingering (Kok, 1997). When participants simulating memory impairment were presented with personal information, the additional requirement to malinger actually decreased P300 amplitude (Johnson, Barnhardt & Zhu, 2003; Johnson, Henkell, Simon & Zhu, 2008; Miller, Rosenfeld, Soskins & Jhee, 2002; Rosenfeld et al., 1999). This difference is often attributed to a dual task effect or an increase in workload that becomes necessary when being required to both monitor your natural response, as well as produce a false response (Miller et al., 2002).

Application of ERP Measures of Malingering to an mTBI Population

While modest gains have been achieved by exploring the use of memory paradigms to identify malingering within patients reporting brain injuries, additional development is necessary in order to improve the clinical utility of such techniques. Particularly, given the limitations of prior research, future attempts to explore the utility of a physiological measure of malingered cognitive dysfunction may need to focus on domains of cognitive function other than memory. While memory dysfunction is the single most common neurocognitive complaint among those being referred for neuropsychological assessment (Lezak et al., 2004), it is rarely the only cognitive symptom reported. Other frequently cited complaints include impairments in attention and concentration, verbal retrieval problems, sensory/perceptual and motor problems, as well as diminished processing speed (Lezak et al., 2004). In addition, impairments in attention and processing speed can actually impact an individual’s perceived memory function, drawing additional attention to these areas of functioning as primary contributors to overall cognitive dysfunction (Lezak et al., 2004). Therefore, it would be beneficial to establish whether ERPs can be used to assess performance validity in other domains of cognitive functioning, besides memory. This would not only allow for evaluation of cases in which memory impairments are not present, but would also provide additional information for individuals reporting multiple cognitive deficits.

TBI and Executive Dysfunction

The cognitive deficits associated with TBI typically depend on the type of injury. The physiological consequences associated with penetrating wounds are easily identified through imaging procedures such as magnetic resonance imaging (MRI) and computerized tomography (CT) (Lezak et al., 2004). However, the majority of TBIs occur as a result of closed head injuries in which no penetration has taken place (Lezak et al., 2004). Damage to the brain tissue is sustained either through direct impact between the brain and the interior of the skull, or by diffuse stretching and tearing as a result of the rapid acceleration-deceleration forces (Kaipio, Alho, Winkler, Escera, Surma-aho & Näätänen, 1999). Consequently, closed head injuries typically result in focal insult to the frontal poles, as well as diffuse axonal injury between frontal regions and their supporting networks (Kaipio et al., 1999; Levin, 1990). Subsequently, it is believed that the majority of TBI cases involve some level of disruption in frontal-subcortical systems (McDonald, Flashman & Saykin, 2002). Specifically, attention and executive functioning have been shown to be particularly sensitive to frontal lobe damage of the dorsolateral, orbital, and medial structures of the prefrontal cortex (McDonald et al., 2002; Stablum, Mogentale & Umiltà, 1996). Not surprisingly, the second most frequent cognitive complaint in a TBI population (after memory impairments) are difficulties in executive functioning such as deficits in self-direction, self-control, cognitive flexibility, planning, problem solving and attention (Lezak et al., 2004). In addition, as discussed earlier, deficits in attention and organization may actually contribute to perceived difficulties in learning and memory that are typically associated with cases of TBI (Lezak et al., 2004). A physiological measure of malingered executive dysfunction would prove to be a valuable instrument in assessing those with reported TBI, and for other patients reporting deficits in attention and concentration, organization, or planning.

P3a

The P300 is a potential candidate for assessing the underlying cognitive processes associated with attention and executive functioning. The P300 is the most widely studied ERP component (Luck, 2005) and has been reliably linked to resource allocation, attention, and memory (Solbakk, Reinvang & Nielsen, 2000). As discussed earlier, P300 is typically elicited through an "oddball" paradigm when stimuli of interest are presented infrequently such that they are perceived as "novelties" among a series of otherwise identical items (Courchesne, Hillyard & Galambos, 1975). The P300 is elicited if one detects a change in the stimulus series (e.g. Johnson et al., 1985; Karis et al., 1984). This experimental design also has the advantage of being applicable to tap several different underlying cognitive processes. For example, when stimuli differ only in terms of their simple physical characteristics, such as when occasional high-pitched tones are presented among a series of identical low-pitched tones, the P300 reflects the attentional shift that occurs when the infrequent (high pitched) stimulus is encountered (e.g. Friedman, Cycowicz & Gaeta, 2001; Knight, 1984; Solbakk, Reinvang, Svebak, Nielsen & Sundet, 2005). This perspective, based on context-updating theories of attention, states that if a change is identified between new stimuli and a prior representation stored in working memory, the attentional processes involved in the subsequent “updating” of this schema produce the resulting P300 (Polich, 2007).

Through these paradigms, P300 has been further delineated into two distinct subcomponents labeled P3a and P3b (Squires, Squires & Hillyard, 1975). P3a is always elicited when a change in stimulus is detected (such as novel and unexpected tones), while P3b requires more conscious task relevant processing such as responding to a specific ‘target’ tone (Polich, 2007). Therefore, both P3a and P3b can be observed in response to unforeseen changes in stimuli; however, the P3a component is not dependent on an overt response (Fjell, Walhovd, Fischl & Reinvang, 2007; Luck, 2005). Within the context-updating theory of attention discussed earlier, P3a is therefore believed to represent the initial processing and subsequent updating in response to novel stimuli (Kok, 2001; Polich, 2007). Specifically, P3a is believed to reflect the executive orienting response to a novel stimulus, an involuntary shift in attention that is believed to be an innate survival mechanism (Friedman et al., 2001; Knight, 1984). By alerting an individual to a change in the environment, they are subsequently able to make a conscious evaluation of whether behavioral action needs to be taken as a result (Luria, 1976).

Within a traditional two-stimulus oddball paradigm, where participants are asked to respond in some way to the infrequently presented target stimuli, discrimination between the P3a and P3b components is often difficult since P3b often overlaps P3a at most scalp positions (Solbakk et al., 2000). Consequently, although the P300 elicited by the response to a target is often measured as a single component, it is actually likely to contain an overlap of both the P3a and P3b waveforms (Luck, 2005). However, when perceptually novel distracters to which no response is required are introduced in addition to the target and background stimuli, a "pure" P3a component is reliably elicited over frontal/central scalp locations (Polich, 2007). The ERP components elicited by this design can be seen in Figure 1. The distracters elicit a P3a component, while the P3b is only observed in response to recognized task-relevant target items to which they have responded. The amplitude of the P3a component is greatest over fronto-central regions with a relatively short latency (250-300 ms from stimulus onset), while P3b is observed at a later time (280-1000 ms from stimulus onset), primarily over parietal areas of the scalp (Harris, 1998; Luck, 2005).

Previous research varies regarding the precise location of neural generators for P3a, which is likely due to the small sample sizes and disparate localization techniques (e.g., intracranial research, lesion studies, functional imaging techniques) that were employed in these studies. However, the frontal/central localization of P3a generators has been supported by numerous studies employing an auditory oddball design (e.g., Berti, Roeber, & Schröger, 2004; Friedman & Simpson, 1994; Knight, 1984; Schröger, Giard, & Wolff, 2000). Furthermore, patients with frontal lobe lesions either produce a diminished P3a, or no P3a at all, in response to novel distracters (Knight, 1984; Knight, Grabowecky, & Scabini, 1995). More recently, Linden (2005) used converging evidence from multiple studies that used various intracranial recording and imaging methodologies, to try and localize the neural generators of P3a. His analysis indicated that the P3a, which has maximum amplitude over frontal/central scalp sites, likely has multiple generators including the lateral prefrontal cortex, inferior parietal lobe/temporoparietal junction, and medial temporal lobe structures, as well as the possible involvement of the inferior frontal gyrus/insula and the anterior cingulate cortex. The combined activation in these areas is believed to represent the executive processes involved in the involuntary orientation of attention to salient changes in stimuli (Courchesne et al., 1975) and the assessment of those stimuli for any necessary behavioral response (Friedman et al., 2001). While there is some overlap in neural generators for P3a and P3b, P3b has been more specifically localized to the posterior cingulate/superior parietal lobe, inferior parietal lobe/temporoparietal junction, inferior frontal gyrus/insula and the anterior cingulate (Linden, 2005).

Activation in the inferior parietal and temporal-parietal regions areas within an auditory oddball design is likely to reflect the sensory processing of the incoming stimuli associated with activation of the auditory association cortex, and is present, regardless of the auditory stimulus type (Friedman et al., 2001; Katayama & Polich, 1998; Knight, Scabini, Woods, & Clayworth, 1989; Opitz, Mechlinger, Friederici, & von Cramon, 1999; Polich, 2007). However, when an individual’s attention is sufficiently engaged in a primary task (requiring the task to be somewhat difficult), and the distracter item is distinct enough to capture attention, then the subsequent orienting response will cause P3a activation with maximal scalp distribution over frontal/central scalp regions, representing the executive attentional shift that has taken place (Friedman et al., 2001; Polich, 2007). This shift of P3a from more parietal to frontal/central scalp locations is therefore dependent on stimulus context (Katayama & Polich, 1998). In a three-stimulus auditory oddball task conducted by Katayama and Polich (1998), P3a localization was influenced by varying the degree of difficulty (and subsequent focal attention required) to complete a task. The relative difficulty was manipulated by utilizing tones of various pitches. Varying the pitch difference between the target and standard tones created both ‘easy’ and ‘difficult’ conditions. When the target and standard tones were very discrepant (50% pitch deviation between standard and target tones), the task was relatively easy and Katayama and Polich hypothesized that relatively little focal attention was being engaged in the primary task. Under these conditions, it appeared that comparatively little orienting to the distracter tones took place, resulting in a larger P3a over more parietal scalp sites. However, when task difficulty was increased by requiring participants to differentiate between target and standard tones that are more similar in pitch (only 3% difference between standards and targets), the amount of cognitive load (and subsequent hypothesized attention) required to complete the primary task increased. When participants were presented with a highly distinct distracter under these conditions, there was sufficient disruption in the primary task to elicit a significant shift in attention. The subsequent orienting response resulted in increased P3a amplitude with a shift to more frontal locations over frontal/central electrode sites. The finding that task demands must be sufficient to engage the individual and necessitate an attentional shift when confronted with distracter items supports the application of frontal/central P3a as a measure of executive functioning.

While P300 has been reliably observed in response to a perceived change in stimuli (Polich, 2007), the relative amplitude and latency of the P300 component has been demonstrated to be influenced by a number of additional factors. P300 latency is believed to correlate with the processing speed and the individual’s subsequent detection and classification of the stimuli (Magliero, Bashore, Coles, & Donchin, 1984; Polich, 2007). In addition, as discrimination between the standard and the target becomes more difficult, the latency of both P3a and P3b components increases (Wronka, Kaiser, & Coenen, 2008). P300 amplitude, however, is inversely related to the relative probability of an item occurring, with the amplitude increasing as the probability of an item occurring decreases (Luck, 2005). As the distinctiveness of the distracter item increases, so does the degree of subsequent attentional disruption that occurs as a result (Friedman et al., 2001; Polich, 2007). Consequently, the amplitude of P3a increases with distracter distinctiveness. While the threshold for this attentional disruption to occur appears to be somewhat low (with some studies demonstrating the effect with distracter/standard differences of only 3%; Berti et al., 2004), the relative amplitude of P3a continues to increase as these distracter items become increasingly distinct (Polich, 2007). Berti and colleagues (2004) required participants to distinguish between tones with short (200 ms) and long (400 ms) durations. For the majority of trials (84%), participants were presented with a standard frequency tone; however, occasionally tones with a ‘deviant’ frequency were presented (ranging from a 1 to 10% difference from the standard tone). A consistent trend was observed over frontal/central electrode sites, with P3a amplitude steadily increasing as deviant tones became more distinct. These findings suggest that the P3a component is not a dichotomous event, but rather exists along a continuum, thus emphasizing the appropriate selection of stimuli in order to maximize the prevalence of the effect. A similar finding was also demonstrated by Yago, Corral, & Escera (2001), in a study where participants attempted to discriminate between a visual target and standard shapes, while being presented with infrequently occurring task-irrelevant auditory tones of various frequencies. P3a amplitude again increased over frontal scalp sites as the distinctiveness of the distracter items increased. Distracter items for this study ranged from a frequency difference of 5% to 80%, without any indication that the effect reached a ‘plateau’ before reaching the 80% deviation. This again supports the notion that when using tonal stimuli, increasing the distinctiveness of the deviant items will produce a more robust frontal/central P3a.

A model of the mechanisms underlying P3a generation has been proposed by Polich (2003). As discussed, when an individual is engaged in a task and distracted by a task-irrelevant deviant stimuli, the attentional focus required to redirect their attention and evaluate the relevance of this new stimuli activates frontal lobe regions of the brain (Katayama & Polich, 1998; Polich, 2003; Posner, 1992). This finding is further corroborated by ERP and neuroimaging research demonstrating frontal lobe involvement in the detection of rare or alerting stimuli (e.g. McCarthy, Luby, Gore, & Goldman-Rakic, 1997). The subsequent frontal lobe activation generates the P3a when the incoming distracter stimulus replaces the prior representation for the standard or the target currently being held in working memory (Desimone, Miller, Chelazzi, & Lueschow, 1995; Polich, 2003). Consequently, when a frontal/central P3a component is present, it likely reflects the presence of executive and attentional processing. However, in order for a task to result in the generation of a P3a component that reflects significant frontal lobe executive involvement, its demands must require the involvement of sufficient attentional focus on the primary task (Polich, 2003, 2007). Within a three-stimulus oddball design, this requires that the target and standard tone stimuli are perceptually similar to each other, making the differentiation between these two stimuli difficult enough to demand the required attentional shift when a distracter is presented. In addition, the distracter stimulus must also be comparatively distinct from the standard.

As the distinctiveness of this tone increases (as well as the degree of subsequent "interruption" that occurs as a result), the relative amplitude of P3a also increases (Polich, 2003).

P3a and Executive Functioning

As a result of its localization to frontal and prefrontal regions of the brain, and its strong associations with innate attentional shifts, the P3a component has been utilized as a measure of executive function in a variety of clinical populations. Barcelo (2003) used the P3a component as a neural correlate of attention switching to assess overall executive function during a modified version of the Wisconsin Card Sorting Task (WCST; Heaton et al., 1993). When healthy participants shifted to using a new sorting principle, a higher amplitude P3a response was elicited. This shift was hypothesized to represent the executive functioning associated with the requirement to "think differently" and to flexibly adopt a new solution. Friedman and colleagues (2008) also utilized P3a to examine executive function in elderly adults by exploring the reallocation of attention in a task-switching paradigm. Participants were presented with single digit numbers and were asked to make one of two judgments, whether the number was less than or greater than five, or whether it was an odd or even digit. Participants completed one of these two tasks until they were prompted to switch to the alternative. In comparison to younger individuals (mean age = 23.1 years), older participants (mean age = 71.0 years) demonstrated a significant decrease in P3a amplitude over midline frontal electrodes for switch trials. The authors concluded that as we age, there is a decline in higher-order executive processing, as evidenced by a decrease in P3a amplitude on the switch trials.

Fjell and colleagues (2007) recorded P3a over frontal electrodes in response to a three-stimulus visual oddball task. Two differently sized blue ellipses served as the standard and target stimuli; distracter items were infrequently presented blue squares. Fjell et al. (2007) demonstrated correlations (r=.35, $P<0.05$) between P3a amplitude in response to the distracter stimuli, and the outcomes on several traditional neuropsychological measures of executive functioning including the Stroop Color-Word Interference Test, the Digit Span Backwards test, the Trail Making Test, phonemic fluency, and Corsi Block Tapping Test. The authors concluded that as executive functioning decreased, so did the associated P3a amplitude. A similar relationship was also demonstrated by Fabiani and colleagues (1998), who showed that P3a amplitude is correlated with performance on the Wisconsin Card Sorting Task (Heaton et al., 1993), a measure of frontal lobe functioning that is often considered to be the "premier" test of executive functioning (Malloy et al., 2006). The authors reported that as we get older and executive functioning decreases (as assessed by the WCST), so to does the amplitude of P3a (Fabiani et al., 1998). While these studies support the notion of P3a as an indicator of overall executive functioning, they also demonstrate a strong correlation between P3a amplitude and traditional behavioral measures of executive functioning.

The correlation between a diminished P3a and declining executive function has also been associated across many different conditions including: amyotrophic lateral sclerosis (ALS) (Hanagasi et al., 2002), oppositional-defiant disorder (ODD) (Baving, Rellum, Laucht & Schmidt, 2006), and bipolar II disorder (Andersson, Barder, Hellvin, Løvdahl & Malt, 2008). Hanagasi and colleagues (2002) used a three-stimulus auditory oddball design, to elicit the P3a in response to "environmental sounds" distracter stimuli.

The amplitude of the P3a was also determined to be correlated with numerous neuropsychological measures of executive functioning, and it was determined that the decreased executive functioning associated with ALS resulted in both decreased amplitude, and increased latency of the P3a component.

In a cued Continuous Performance Test (CPT-AX) similar to a visual oddball paradigm, Baving et al. (2006) presented participants with letter cues (the letter A) as the standard condition. When the cue was followed by the letter X, participants were to make a behavioral response as quickly as possible (target). For some of the trials, however, participants were presented with an alternate cue as a distracter (the letter H). P3a for distracter items was determined to be of lesser amplitude in children with ODD. This finding was correlated with impairments in both the orienting response, as well as executive target processing (Baving et al., 2006).

P3a and Traumatic Brain Injury

Numerous studies have also attempted to explore the relationship between P3a and mTBI (e.g. Elting, et al., 2008; Gaetz, Goodman, & Weinberg, 2000; Kaipio, et al., 1999; Knight, 1984; Potter & Barrett, 1999; Potter, Bassett, Jory, & Barrett, 2001; Reinvang, Nordby, & Nielsen, 2000; Rugg, et al., 1993; Segalowitz, Bernstein, & Lawson, 2001; Sivák, et al., 2008; Solbakk, et al., 2000). These are summarized in Table 4. However, the results of these studies are often difficult to interpret as they are plagued by methodological problems that have resulted in inconsistent findings. Firstly, these studies are hindered by difficulties in recruiting a clinical population, and researchers have often been forced to utilize extremely small sample sizes (n=10 in some cases; Segalowitz et al., 2001). These small sample sizes are particularly problematic when coupled with imprecise inclusion criteria for defining the sample. Considerable latitude has been applied when defining the populations for these studies. Some studies made determinations based on medical records using established criteria such as those developed by the Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine (1993; Solbakk et al., 2000). Others relied solely on patient report and used inclusion criteria for mTBI such as “any blow to the head forcing one to stop whatever one was doing” (Segalowitz et al., 2001), which leaves considerable uncertainty as to precisely who is being included in these studies.

Consequently, among the current literature examining P3a in TBI patients, there is no consensus in the definition of TBI or mild TBI, and these studies include participants with a variety of injuries and defining characteristics such as the presence/duration of loss of consciousness and post-traumatic amnesia. Therefore, very heterogeneous groups have been studied in very small numbers. In addition, most of these studies did not report the existence of cognitive impairment or what types of cognitive sequelae resulted from the injuries. In fact, not a single study reported that cognitive impairments were present in the majority of their sample. Indeed one study disclosed that 87.5% of their sample reported no impairments in attention at all (Potter et al., 2001). This makes it very difficult to determine whether decreased P3a amplitude would even be expected within these samples, regardless of their reported prior injuries. The various studies also examined their participants at various post-injury time periods. Some included patients as long as five years following the self-report of a “mild” head injury or post-concussive syndrome (Gaetz et al., 2000; Potter et al., 2001). For cases of mild TBI or post-concussive syndrome, the majority of cognitive rehabilitation improvement occurs within the first two years following an injury, with many returning to their baseline level of functioning (Lezak et al., 2004). Again, this makes it very difficult to interpret what physiological correlates would be expected within these samples. These studies did not make any attempt to quantify the presence of any accommodation that may have taken place since the time of the injury and, coupled with the questionable presence of cognitive impairments to begin with, it becomes difficult to form reliable hypotheses about these samples. In addition, despite the known (or believed) prevalence of malingering within a TBI population (as discussed earlier), not a single one of these studies made any attempt to assess symptom validity by administering behavioral measures of malingering. In fact, none of the studies even acknowledged the possibility of participants within their sample exaggerating either the presence or the effects of an injury.

With these concerns in mind, while some variability in results is expected due to methodological concerns, the study results suggest definite trends in ERP data that are consistent with previous literature. The majority of mTBI studies show that patients demonstrate decreased P3a amplitude relative to healthy controls (Elting et al., 2008; Knight, 1984; Potter & Barrett, 1999; Reinvang et al., 2000; Segalowitz et al., 2001; Solbakk et al., 2000). However, a few have reported disparate results. Two studies report comparable P3a amplitude between mTBI and control groups, citing the distinguishing characteristic between these two groups as an increased latency of the P3a within the mTBI population (Gaetz et al., 2000; Rugg et al., 1993). This latency increase was attributed to their diminished speed in orienting attention to novel stimuli (Rugg et al., 1993). Two studies have reported no difference at all between mTBI patients and healthy controls in either P3a amplitude or latency (Potter et al., 2001; Sivák et al., 2008). A single study has even reported that patients with mTBI demonstrated increased P3a amplitude (Kaipio et al., 1999). The authors of this study attributed this finding to the possible enhanced processing that was necessary for the more distracting sounds, suggesting a difficulty in suppressing irrelevant stimuli. In addition, of these studies reporting counterintuitive findings, only a single study (Potter et al., 2001) administered any neuropsychological measures to their sample in order to assess whether deficits in attention and executive functioning were actually present. Within this study, only three of 24 participants reported deficits in attention, and test results comparing their experimental and control groups produced mixed findings regarding whether or not any attentional differences between these two groups were present. These unclear test results may have been the reason that no differences between the two groups in P3a amplitude or latency were noted within this study.

As discussed, while still plagued with many of the same methodological flaws outlined above, the majority of research has reported that those with mTBI demonstrate significantly diminished P3a amplitude (e.g. Elting et al., 2008; Knight, 1984; Potter & Barrett, 1999; Reinvang et al., 2000; Segalowitz et al., 2001; Solbakk et al., 2000). As deficits in attention and executive functioning are well documented within a TBI population (Lezak et al., 2004), these findings are consistent with the prior literature associating these abilities with P3a magnitude (e.g. Andersson et al., 2008; Barcelo, 2003; Baving et al., 2006; Friedman et al., 2008; Hanagasia et al., 2002). In contrast to the studies described above, significantly more of these studies made attempts to ensure neuropsychological deficits were present by administering standard behavioral measures of attention to their participants, further validating their findings (Elting et al., 2008; Potter & Barrett, 1999; Reinvang et al., 2000; Segalowitz et al., 2001). Given these results, it appears reasonable to conclude that for those with deficits in executive and attentional processing, whether by TBI or any other cause, decreased P3a amplitude is likely to be seen as a result.

All of the studies producing a decreased P3a over frontal/central scalp sites employed very similar oddball designs. They all presented auditory stimuli, with standard, target, and distracter tones. The target tone deviation from the standard tone (which determines the relative difficulty of the primary task) ranged from 25% (Knight, 1984; Potter & Barrett, 1999) to 50% (Solbakk et al., 2000). Distracter stimuli were either tones with a highly deviant pitch (Segalowitz et al., 2001; Solbakk et al., 2000), or environmental sounds/simulated dog barks (Knight, 1984; Potter & Barrett, 1999). These results demonstrate the sensitivity of the three-stimulus auditory oddball design for assessing executive and attentional shift within an mTBI population.

Rationale and Hypotheses for the Current Study

Previous research has utilized P3a as a measure of executive dysfunction (e.g. Andersson et al., 2008; Barcelo, 2003; Baving et al., 2006; Friedman et al., 2008; Hanagasia et al., 2002), as well as associating it with the relative impairments in executive and attentional processes among those with mTBI (e.g. Knight, 1984; Potter & Barrett, 1999; Reinvang et al., 2000; Segalowitz et al., 2001; Solbakk et al., 2000). As the orienting response (and subsequent P3a) is believed to represent the executive functioning involved in the automatic and involuntary response to novel stimuli

(Courchesne et al., 1975; Daffner et al., 2000), the current study attempts to explore the applicability of this component as an implicit measure of symptom validity for complaints of inattention and executive dysfunction. It is hypothesized that for those with intact cognitive functioning who are attempting to malinger cognitive deficits, their physiological response to distracter items will be comparable to those responding honestly, despite their attempts to appear impaired. This procedure would be useful for any population for which diminished executive function is observed as a consequence of disease or injury, including those with mTBI. The current study will determine whether the simulation of impairments in attention and concentration by healthy individuals influences P3a amplitude.

CHAPTER 2: METHODS

Participants

A priori power analyses using GPOWER 3 software (www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3) were performed to estimate the required sample size. Sample sizes were calculated using power (1-β) at 80% and p=0.05, and were explored using a medium effect size (f = 0.5), which is typically found in between-group ERP studies. Due to the proposed hypotheses, a modest correlation was assumed (r = 0.5). Using these parameters, a total sample size of 26 (13 per group) is required in order to detect a reliable difference in the ERPs between the two groups (F (1, 24) = 4.26, actual power = 80.6%). The participants for the current study consisted of 45 adults and all provided informed consent. Participants were recruited through public advertisement (i.e., Craigslist) as well as from the John Jay College Research Experience Program (REP). All received $40 or course credit for their participation in the study. All participants denied any history of psychiatric or neurological illness or injury, and met all of the inclusion criteria for the study based on their performance on behavioral measures of premorbid intellectual and executive functioning (specific measures detailed below). However, data recording difficulties resulted in the exclusion of 9 participants. Consequently, data from 36 adults (13 males) between 20 and 36 years of age were included for analysis (M = 24.9 years, SD = 4.7). After screening, participants were randomly assigned to either the control condition (M = 24.2 years, SD = 4.4; n = 18; 8 males), or the experimental (malingering) group (M = 25.6 years, SD = 5.1; n = 18; 5 males).

Screening Measures

A number of screening measures were administered to ensure adequate premorbid functioning. The first of these was the Wechsler Test of Adult Reading (WTAR; The Psychological Corporation, 2001), a measure designed to estimate an individual's overall level of intellectual functioning (Strauss, Sherman & Spreen, 2006). The WTAR requires participants to read a series of irregularly spelled words (e.g. cough) and is an established measure for estimating premorbid intelligence (Strauss et al., 2006). Unlike many aspects of intellectual functioning, reading recognition is relatively stable in the presence of cognitive decline associated with normal aging or brain injury (Strauss et al., 2006). As deficits in attention and executive functioning have been correlated with intelligence and mental retardation (e.g. Bergen & Mosley, 1994), all participants were required to have a full-scale score of 80 or higher.

Additionally, in order to screen for pre-existing deficits in executive functioning, all participants were asked perform to the best of their ability on a measure of verbal fluency (FAS) (Strauss et al., 2006) and the Stroop Color-Word Interference Test (Golden, 1978). Verbal Fluency is an established measure of executive functioning and has been demonstrated to be particularly sensitive to the frontal lobe deficits typically observed in cases of TBI (Strauss et al., 2006). Participants were told to generate as many words as possible beginning with a given letter (F, A, or S), within a one minute time period. Participants were scored on the total number of words generated across all three conditions.

The Stroop Color-Word test has been demonstrated to be a reliable measure of response inhibition, attention, and distractibility (Lezak et al., 2004). The Stroop task had three trials. In the first, participants had to read a list of color names (i.e., red, blue, or green) as quickly as possible. In the second trial, participants were presented with a series of "XXX" each printed in a different color (either red, blue, or green) and the participant had to name the color of the ink that the X's are printed in. In the third and most difficult trial, participants were presented with a list of color names (as in trial 1), but each was printed in a different color ink (as in trial 2) and participants were tasked to name the color of the ink that the words were printed in as quickly as possible (ignoring the word). In general, it is difficult to inhibit the tendency to say the word rather than the ink color. The critical measure used for screening was the time that it took to complete trial 3, the color-word interference trial.

For both the FAS and Stroop tests, the scores described above were compared to demographically adjusted norms (FAS: Heaton, Miller, Taylor, and Grant, 2004, Stroop: Stoelting Co.). Scores below the 9th percentile are suggestive of borderline impairment in executive functioning; therefore, a cut-off score above the 9th percentile (based on the respective norms) on *at least one* of these measures was required for participation in the study.

Procedure

All participants successfully met all screening criteria and were subsequently enrolled into the study. Eligible participants were randomly assigned to one of two conditions, either the control group (n = 18, honest responders), or the experimental group (n = 18, malingerers). The two groups showed no significant differences in age; $t(34) = .877$, $p = .387$, education; $t(34) = 1.364$, $p = .182$, gender; $t(34) = 1.027$, $p = .312$, IQ; $t(34) = 1.090$, $p = .283$, or executive function (Fluency; $t(34) = .409$, $p = .685$;

Stroop; *t*(34) = .119, *p* = .906). Participant demographics (see Table 5) demonstrated average range IQ and executive functioning. The control group was instructed to answer honestly and complete all further tasks (WCST and ERP) to the best of their abilities, whereas the experimental group completed the experimental tasks (both WCST and ERP) while simulating cognitive impairments. Malingerers were provided with the instruction "pretend that you experienced an accident at work when you fell from a ladder, striking your head on the floor. While you did not experience any cognitive impairment following the event, you have chosen to pursue civil litigation and sue your employer in order to obtain compensation." In order to do so, "you have subsequently been referred for an evaluation in order to determine the extent of your impairments, and you have to fake poor performance during this evaluation in order to continue with your case." In addition, participants were provided with the following information about the types of cognitive deficits associated with mTBI. "People who have traumatic brain injuries typically have problems with memory, problem solving, processing speed, and maintaining their attention. For example, they typically have trouble remembering new information, are easily distracted, and it often takes them longer to do things than it did before their injuries." Malingerers were instructed to manipulate the measures to the best of their abilities so as to appear impaired. In order to simulate more realistic circumstances associated with malingering they were also provided with an additional incentive. Participants were instructed that their test results would be included with those from a sample of patients with legitimate mTBI. "A reviewer, who is unaware of whether your data comes from a patient with legitimate mTBI, or from someone attempting to fake an injury, will attempt to identify whether you have been faking your symptoms." Participants were instructed that those who are able to successfully "fool" the reviewer into thinking their profile was produced by a patient with mTBI, would be entered into a lottery at the completion of the study for an additional $100. In reality, no comparison was made and all experimental participants were entered into the drawing.

Each participant completed the behavioral task (WCST) before participating in the EEG portion of the study. All tasks and measures were identical across both groups, and took approximately two hours to complete.

Wisconsin Card Sorting Task (WCST)

The WCST (Heaton et al., 1981) is a standard behavioral measure of executive function in a neuropsychological evaluation. The measure was administered manually using 128 cards. Participants were required to place test cards onto target cards according to one of three different sorting criteria (shape, color, number) determined by the examiner (myself), who gave feedback after each response. Therefore, the sorting criterion was learned through trial and error. After 10 correct responses, the sorting criterion changed without the participant knowing. Individuals had to integrate the feedback and determine the sorting criteria to the best of their abilities. The measure was administered to both malingerers and honest responders to assess executive functioning under these response conditions (i.e., malingerers simulated deficits on this measure), and was administered primarily as a manipulation check to ensure that malingerers were demonstrating relatively impaired performance. The data were scored and normed using a computerized scoring program designed for the WCST (Psychological Assessment Resources, Inc.). The indices used for the current study to assess the degree of cognitive "impairment" were the number of categories completed (i.e., the number of times participants correctly identified the sorting rule and made 10 correct consecutive sorts), and the number of perseverative errors (i.e., the number of times that they repeated the same type of error on consecutive trials).

In addition, in order to assess how traditional measures of effort compare with the proposed physiological measure, participants in the current study were examined using the WCST malingering criteria proposed by Bernard et al. (1996). This measure uses a series of discriminant analysis equations utilizing the number of categories completed on the WCST and/or the number of perseverative errors. Details of these equations are provided in Table 6. Comparisons were made to examine the utility of these equations in discriminating between the malingering and the honest responding participants in the current study, and differentiating malingering participants in the current study from the TBI patients reported on by Bernard and colleagues.

ERP Stimuli

The experimental paradigm consisted of an auditory three-stimulus oddball task similar to that utilized by Katayama and Polich (1998), in which infrequently occurring target tones and distracter stimuli were presented among a background of identical standard tones. All stimuli were presented using E-prime 2.0 (Psychology Software Tools, Inc.). Target stimuli were 1900 Hz tones (n=56, p=.14) presented within a series of 2000 Hz standard tones (n=296, p=.73). A simulated dog bark was used as the distracter stimuli (n=56, p=.14) in a similar design to that employed by Knight (1984). All stimuli for the ERP study were presented using headphones (Sennheiser model HD 25-1 II) in order to insure a consistent decibel level (77dB), as well as to minimize possible distractions. Stimuli (408 total) were presented over eight blocks, with breaks between blocks as needed. All stimuli were pseudo-randomly presented for a duration of 100 ms each, with a 1.5 second inter-stimulus interval.

ERP Task

During the ERP task, participants were instructed to respond as quickly as possible to the infrequent (lower pitched) target tones by pressing a designated button on the computer mouse. No response was required for either standard or distracter tones. To ensure that a participant's attention was actively engaged, the stimuli were designed such that the difference between the target and the standard was relatively small (5% deviation). The ability to make a discrimination at this level has been demonstrated to be achievable, even within a TBI population provided the auditory system has not been compromised as a result of injury (Jay, 2000). In line with this, previous research has demonstrated that patients with a history of mild to moderate head injuries do not miss substantially more target items than those in the control groups (Elting, et al., 2008; Knight, 1984; Potter & Barrett, 1999; Potter et al., 2001; Rugg, et al., 1993; Segalowitz et al., 2001; Solbakk et al., 2000). Therefore, those malingering executive impairment, were provided with the additional information that even patients with TBI are able to distinguish between the stimuli and are able to complete the task with a high degree of accuracy.

Recording Procedures

While participants were performing the oddball task, their EEG was recorded using a Neuroscan Synamps RT system and Neuroscan acquisition software (version 4.4), with a 64-channel electrode Quikcap with silver-silver chloride sintered electrodes (Neuroscan, Inc.). Electrodes within the cap are positioned according to the International

10-20 system (Jasper, 1958), and were referenced to a midline central electrode. EEG data was continuously sampled at a digitization rate of 1000 Hz, and electrode impedance was kept below 5 kΩ. All analyses were performed offline using Neuroscan 4.4 Edit software.

Data Analysis

Data were re-referenced to averaged mastoids. Individual trials were digitally filtered with a band pass of 1 to 30 Hz. Sweeps consisted of 1201 data points, which were sampled from 200 ms preceding the stimulus to 1000 ms after the onset. Baseline correction was performed using the averaged EEG in the 200 ms prior to the stimulus onset. Automatic artifact rejection was used to exclude any sweeps where the EEG exceeded plus or minus 50 μV. Individual averaged files were created for each stimulus type. In addition, in order to better isolate the P3 waveform by removing any extraneous ERP components, two difference waves were created for each participant by subtracting the response from the standard tones from both the target and distracter tones, i.e. target minus standard and distracter minus standard (Luck, 2005). Separate grand average waves were compiled for each subtraction wave (target and distracter) for each group (malingerers and controls). Visual inspection of these waves, helped to identify the location and timing of the P3 wave. For the distracter stimuli, the P3 was identified as the most positive peak following the stimulus in the 250-450 ms window. Similarly, for the target stimuli, the P3 was identified as the most positive peak after stimulus presentation in the 250-550 ms range. To investigate how stimulus type and participant response characteristics affected the timing of the P3 over anterior and posterior scalp sites, the latency of the P3 component was measured both at frontal (Fz) and parietal (Pz) midline electrode sites, for both stimulus types, for all participants. Peak-to-peak amplitudes for P3 were measured over frontal/central electrodes (i.e., F1, F2, Fz, FC1, FC2, FCz, C1, C2, Cz, CP1, CP2, CPz, P1, P2, Pz), to both distracter and the target, for all participants.

Two separate repeated measures ANOVAs were performed on the amplitude and latency of the P3, respectively. The comparison of amplitude used within-subjects factors of Stimulus (target, distracter) and Electrode (F1, F2, Fz, FC1, FC2, FCz, C1, C2, Cz, CP1, CP2, CPz, P1, P2, Pz), with Group (malingerers, honest responders) as the between-subjects factor. Similarly, latency data were entered into an ANOVA with within-subjects factors of Stimulus (target, distracter) and Anterior/Posterior location (Fz, Pz), and Group (malingerers, honest responders) as the between-subjects factor. Greenhouse-Geisser corrections were used where required.

CHAPTER 3: RESULTS

P300 Amplitude

The grand averaged waveforms for both malingerers and honest responders for both stimulus conditions and across all 15 electrodes can be seen in Figure 2. P3 amplitude was significantly larger for the distracter stimuli (M = 9.56, SD = 4.25) compared to target stimuli (M = 1.74. SD = 1.87); $F(1,34) = 100.21$, $p<.001$, $\eta_p^2 = .747$. There was also a significant interaction between Stimulus type (target, distracter) and Electrode location; $F(3.1,4.6) = 8.00$, $p<.001$, $\eta_p^2 = .190$. Visual inspection of the grand averaged waveform revealed that the P3 elicited by distracter items appeared to be maximal over more anterior electrode sites, while the P3 to target items was greatest over more posterior regions. A post-hoc ANOVA using within-subjects factors of Stimulus type (target, distracter) and Anterior/Posterior electrode location (Fz and Pz) and a between-subjects factor of Group (malingering, honest responding) was performed to verify this finding. There was a significant interaction between Stimulus type and Anterior/Posterior location; $F(1,34) = 13.78$, $p=.001$, $\eta_p^2 = .288$. Additional ANOVAs examined the anterior/posterior distribution for each stimulus type separately. While there was a non-significant trend for greater P3 amplitudes elicited by the distracter over anterior (M = 9.46, SD = 3.56) versus posterior (M = 8.52, SD = 3.23) sites; $F(1,35) = 3.06$, $p=.089$, $\eta_p^2 = .083$, the P3 to the targets was significantly greater in amplitude over posterior (M = 2.63, SD = 2.09) versus anterior (M = .99, SD = 1.66) electrode sites; $F(1,35) = 10.71$, $p<.005$, $\eta_p^2 = .240$.

When group membership (i.e., malingerers versus honest responders) was included in the analysis, relatively few differences were observed between groups. There was no main effect of Group on P3 amplitude and no interactions with Group with Stimulus or Electrode (all at the p>.1 level). Similarly, the post hoc ANOVA used to investigate the Stimulus by Electrode interaction described above revealed no main effect of Group, nor a Group by Stimulus interaction (p>.1). However, there were some differences observed in the topographical distribution of the effects between groups (see Figure 3). This was evidenced by a non-significant trend towards a Stimulus by Anterior/Posterior location by Group interaction; $F(1,34) = 3.50$, $p=.070$, $\eta_p^2 = .093$. Figure 3 shows that for malingerers there was little difference in the topographical distribution of the P3 for targets and distracters. In contrast, for the honest responders, the P3 was more anteriorly distributed for the distracters but was maximal posteriorly for targets. These results were confirmed using additional posthoc analyses; an ANOVA using Anterior/Posterior distribution (Fz, Pz) as the within-subjects factor and Group as the between-subjects factor for each Stimulus type separately revealed that there was no effect of Group on the anterior/posterior distribution of P3 for distracter items (p>.1), but there was a trend for the effect of Group for target stimuli; $F(1,34) = 3.50$, $p=.070$, $\eta_p^2 = .093$. Further ANOVAs for each Group separately indicated that this anterior/posterior difference in P3 distribution to the targets was driven primarily by honest responding participants; $F(1,34) = 10.73$, $p<.005$, $\eta_p^2 = .387$, as the difference in distribution for malingerers to target items was non-significant (p>.1). Given the atypical distribution of the malingerer's response to target items, additional analyses evaluated the topography of the P3 for only the target items for which malingerers made correct responses (there were inadequate trials to look at the P3 to incorrect trials). The resulting topographical map of the P3 for correct hits can be seen in Figure 4. Figure 4 shows that even on those trials in which a correct response was made, the topographical distribution of the P3 response showed comparatively more activity over more fronto-central electrode sites in comparison to the honest responders.

P300 Latency

The P3 waveform for distracter stimuli averaged across both electrodes (Fz and Pz) had a significantly shorter latency (M = 357.01ms, SD = 29.92) than that for the targets (M = 410.25ms, SD = 55.91); $F(1,34) = 29.60$, $p<.001$, $\eta_p^2 = .465$. The latency of the P3 was also shorter at Fz (M = 379.69ms, SD = 25.69) than at Pz (M = 387.57ms, SD = 23.88); $F(1,34) = 6.82$, $p<.05$, $\eta_p^2 = .167$. These effects were qualified by an Anterior/Posterior by Stimulus interaction; $F(1,34) = 5.83$, $p<.05$, $\eta_p^2 = .146$. Post-hoc ANOVAs with Anterior/Posterior location as the within-subjects factor were carried out for each Stimulus type separately and revealed that there was no difference in latency between anterior (M = 356.42ms, SD = 23.84) and posterior (M = 357.61ms, SD = 20.84) electrode sites for distracter items ($p>.1$), but there was for the target with the latency at anterior electrodes being significantly shorter (M = 402.97ms, SD = 41.50) than at more posterior sites (M = 417.53ms, SD = 39.46); $F(1,35) = 8.34$, $p<.01$, $\eta_p^2 = .192$.

There was no main effect of Group on latency (p>.1); however, there was an interaction between Group and Anterior/Posterior location; $F(1,35) = 4.20$, $p<.05$, $\eta_p^2 = .110$, and a Stimulus by Anterior/Posterior by Group interaction; $F(1,35) = 5.13$, $p<.05$, $\eta_p^2 = .131$. These interactions were explored using posthoc ANOVAs as described above, but for each Group individually. For malingerers, the difference in the P3 latency between Anterior (M = 375.42ms, SD = 36.33) and Posterior (M = 377.11ms, SD = 33.77) electrode sites was non-significant ($p>.1$); however, P3 reached its maximum amplitude for honest responders significantly earlier at more anterior electrode sites (Fz: M = 383.97ms, SD = 36.33, Pz: M = 398.03ms, SD = 33.77); *F*(1,35) = 7.37, $p<.05$, η_p^2 = .302. Additionally, there was a Anterior/Posterior by Stimulus interaction for honest responders; *F*(1,17) = 8.95, $p<.05$, η_p^2 = .35, but not for malingerers (p>.1); in malingerers, distracter stimuli elicited a shorter P3 latency anteriorly compared to posteriorly, but the P3 latencies at Fz and Pz were comparable for the targets.

ERP Behavioral Data

Participants within the control group identified and accurately responded to 91.9% (SD = .154) of the target tones. In contrast, those malingering cognitive impairments responded to only 71.8% (SD = .256) of target items, these results show a significant discrepancy between the two groups [*t*(34) = 2.846, $p<.01$]. Malingerers were also significantly slower to respond to target stimuli (M = 755.74 ms, SD =226.26) than honest responders (M = 546.06 ms, SD =118.10); *t*(34) = -3.486, *p* = .001.

WCST Results

Participants' performance on the WCST also demonstrated significant differences across groups, verifying that the instructions produced significantly poorer performance for those malingering impairments on this behavioral task. Control participants were able to figure out the sorting rules for an average of 4.72 categories (SD = 1.87) and according to the instrument norms (Psychological Assessment Resources, Inc.), their number of perseverative errors (M = 18.83, SD = 11.91) was at the 36th percentile. In contrast, those malingering executive deficits only completed an average of 1.00 category (SD = 1.328), with perseverative errors at the 10th percentile (M = 36.44, SD = 19.51); a level of performance that is significantly lower than that of control participants in both categories completed; *t*(34) = 6.878, *p*<.001, and perseverative errors; *t*(34) = 2.564, *p*<.05.

The malingering criteria proposed by Bernard et al. (1996) produced reasonable discrimination between honest responders and malingerers in the current study (sensitivity = 94%, specificity = 78%). These results are displayed in Table 7. In addition, when evaluating malingerers in the current study using the Bernard et al. equations designed to discriminate between malingerers and those with genuine TBI, the equations accurately identified 78% of the sample as malingering (sensitivity = 78%[1]).

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[1] The specificity of this equation to discriminate between malingerers and those with genuine TBI could not be determined in the present study due to the lack of a TBI population.

CHAPTER 4: DISCUSSION

Consistent with prior research (e.g., Fjell et al., 2007; Harris, 1998; Luck, 2005; Polich, 2007; Squires et al., 1975), the results showed that reliable P3 responses were elicited by both the infrequently occurring target tones and the distracter (dog bark) stimuli. There were several differences between the P3 elicited by the two types of stimuli, which are explainable by the differences in the physical properties of the stimuli and the unique task requirements for each stimulus type. The standard and the target stimuli were somewhat similar; the target stimuli were slightly lower pitched tones (1900 Hz) than the standard stimuli (2000 Hz). However, the dog bark distracter stimuli were highly distinctive. Participants were required to press the mouse button when they heard the infrequently occurring target tone, whereas no response was required to the distracters. In the current study, the P3 elicited by the distracter was considerably larger than that elicited by the target tone. This is not surprising as the dog bark is a very distinctive sound and others have shown a positive correlation between P3 amplitude and the distinctiveness of distracter (Friedman et al., 2001; Polich, 2007). Consistent with prior research (e.g., Harris, 1998; Luck, 2005), the P3 in response to distracter items tended to be maximal over fronto-central scalp sites, while the P3 to the target was greatest over parietal areas. This fronto-central localization of the P3 to distracter stimuli has been suggested to reflect the engagement of executive processes associated with the involuntary capture of attention by highly salient stimuli (Courchesne et al., 1975). The P3 latency for distracter items was earlier (approximately 360ms) in comparison to target items (approximately 470ms), which also confirms the results of others using similar paradigms (e.g., Harris, 1998; Luck, 2005).

Given the latency and topographical distribution of the observed effects, the components elicited by the current paradigm appear to be the P3a and P3b components (in response to distracter and target stimuli, respectively), typically reported in the literature (e.g., Fjell et al., 2007; Harris, 1998; Luck, 2005; Polich, 2007; Squires et al., 1975). These results, therefore, support the idea that the P3 to each stimulus type reflects different cognitive processes, as the task demands for each stimulus were quite different, particularly for those responding to the best of their abilities. The P3a component is believed to represent the initial processing and subsequent updating in response to novel stimuli (Kok, 2001; Polich, 2007), and reflects the *involuntary* executive orienting response to a novel stimulus (Friedman et al., 2001; Knight, 1984). In contrast, the P3b reflects *voluntary* attention and accompanies task relevant behaviors (Polich, 2007). Therefore, it appears the primary task of identifying target tones, that had a 5% deviation in frequency from the standard tones, was difficult enough to capture the participant’s attention (eliciting a P3b), and the distracter stimuli were sufficiently distinct to reorient their attention (eliciting a P3a).

This conclusion is further supported by the significant interaction that was seen between stimulus type and the anterior/posterior locations for the latency of the P3 response. While the latency of the P3 response for distracter items was comparable at anterior versus posterior electrode sites, the P3 for target items was significantly shorter at more anterior sites. A similar finding was also reported by Wronka et al. (2008). This latency difference is likely the result of the relative task demands for the two types of stimuli. The P3b response is elicited by conscious task-relevant processing, such as responding to a specific target tone (Polich, 2007). Therefore, for distracter items, which are task irrelevant and require no overt response, one would not expect a P3b wave to be present. In contrast, P3a is elicited whenever a change in stimulus is detected, regardless of whether or not that change is task relevant (Polich, 2007). Therefore, target items should elicit an initial fronto-centrally maximal P3a component when the stimulus was first perceived, which is quickly followed by the parietally maximal P3b response as the stimulus is perceived as task relevant (Katayama & Polich, 1998). Therefore, the P3 to target items is likely to be a combination of the P3a and P3b components. Given that the P3a is earlier and maximal frontally compared to the more parietally distributed P3b, this likely led to the reported result of an earlier positivity to targets at Fz compared to Pz.

When considering Group membership (i.e., malingering versus honestly responding participants), the results obtained were in line with the hypotheses. Although there were some subtle differences in the ERPs between the malingerers and honest responders, *there were no significant differences in the amplitude or scalp distribution of their involuntary physiological responses (P3a) to the distracter stimuli*. In addition, there were no differences in P3a latency at Fz between malingerers and honest responders, which provides further evidence that the physiological response to the distracter was comparable between the two groups.

There were, however, some notable differences observed between the malingerers and honest responders. Overall, both honest responders and malingerers were able to perform the primary task with a high degree of accuracy (82% overall hit rate). However, despite the fact that malingerers were instructed that those with mTBI are able to perform the primary auditory discrimination task without difficulty, the hit rate for malingerers in the current study was significantly lower (72%) than for honest responders

(92%). In their attempts to appear impaired, malingerers in the current study were inattentive to the primary task and/or focused on alternative stimuli (e.g., daydreaming) and as a result, missed responding to many of the target tones. This finding is further supported by the significantly slower reaction times for malingerers compared to honest responders, in response to target items.

This difference in attention during the task appeared to result in differences in the physiological response to the targets between the two groups with respect to both timing and topographical distribution. For those malingering cognitive impairments, the latency of the P3 elicited by targets was comparable at anterior and posterior scalp sites. However, the P3 to targets in honest responders was significantly earlier at anterior compared to posterior scalp locations. As discussed above, the results obtained in the honest responding group are typical for this task (Katayama & Polich, 1998; Wronka et al., 2008). However, it appears that in the malingering group, the P3 elicited by the targets is dominated by the earlier fronto-centrally maximal P3a response. Since the P3b is only produced when a response is made (Polich, 2007), no P3b would have been elicited on trials where malingerers failed to respond (nearly 30% of the target trials), resulting in a smaller P3b overall. However, if the malingerers were aware that the target tone was present on these missed response trials, an involuntary P3a would still have been elicited. This idea that the P3 to targets is dominated by the P3a response is also supported by the fact that the P3 response for targets was slightly shorter (407.61ms) for malingerers in comparison to honest responders (427.44ms).

The difference in response style between the two groups also appeared to have an effect on the scalp distribution of the P3 to target items. While there were no differences in scalp distribution for distracter items between groups, there was a trend for the effect of Group on the scalp topography of P3 to targets. While honest responders showed significantly greater P3 amplitude over more posterior electrodes, the difference in amplitude of the P3 across anterior and posterior electrodes was non-significant for malingerers. There are two possible explanations as to why the malingering group may have shown a more frontally distributed P3 to the target stimuli in comparison to the honestly responding group. While the low response rates discussed earlier may have contributed to this more anterior pattern of activation for malingerers, post-hoc analysis revealed that even for trials in which correct responses were made, this pattern of activation was still seen. Therefore, it appears as if malingerers were engaging additional cognitive processes even when they were responding accurately. This finding is in line with prior research, demonstrating that increased frontal lobe activity is reliably elicited when a person successfully engages in independent, purposeful, self-serving behavior (Lezak et al., 2004). The frontal lobes have been demonstrated to be responsible for developing approach strategies to a task, or planning and carrying out a cognitive task (Lezak et al., 2004). For those answering honestly, the primary task of identifying target tones was not difficult and thus required relatively little contribution from the frontal lobe executive systems. However, malingerers were attempting to anticipate the stimuli and employ various strategies in order to manipulate the task, which may have increased the frontal lobe activation in the primary task.

Overall, the study shows that participants attempting to malinger cognitive impairment were unable to simulate the P3a deficits seen in those with genuine brain injuries. The majority of studies indicate that those with mild TBI show a significant decrease in P3a amplitude to distracter stimuli relative to controls (Elting et al., 2008; Knight, 1984; Potter & Barrett, 1999; Reinvang et al., 2000; Segalowitz et al., 2001; Solbakk et al., 2000). However, within the current study, no group differences were observed in P3a amplitude, topography, or latency. In fact, not only were malingerers unable to produce a significant change in their basic orienting response, but the very process of attempting to employ additional strategies to appear impaired produced other physiological markers of deceptive responses that were particularly salient in their responses to the target items. Malingerers may have actually utilized greater executive abilities to plan, organize, and implement their strategies, thus increasing frontal lobe activity and producing a different timing and topographical distribution in response to target stimuli in a simple discrimination task. Additionally, their lack of attention may also have contributed to the altered timing and topography of the P3 to targets. These differences in their physiological response to target stimuli not only make them distinct from honest responders, but it further differentiates them from mTBI patients as well. Prior research has typically shown that mTBI patients and controls differ only in terms of the amplitude and latency of the P3a component but not the P3b component, (e.g., Elting et al., 2008; Knight, 1984; Potter & Barrett, 1999; Rugg et al., 1993; Sivak et al., 2008). In summary, *although malingerers put forth significantly less effort on the primary ERP task of responding to the target tones, the physiological response to the distracter, which can be considered to be an involuntary response, did not alter*. The current analysis therefore indicates that in a three-stimulus oddball paradigm, the P3a may be a reliable indicator of an individual's genuine level of underlying executive functioning, as it appears to be resistant to attempts of manipulation.

The ERP results are even more salient in comparison to those obtained on the behavioral index of malingered executive dysfunction (WCST). During the standard administration of this measure, as used in a traditional clinical evaluation, the results indicated that those malingering impairments produced significantly worse performance for both categories completed and the number of perseverative errors; two scores that have been demonstrated to be the most sensitive to frontal lobe injury (Lezak et al., 2004). If these participants were in a clinical setting they would be at risk for being mistaken as having genuine impairment.

The WCST malingering criteria used by Bernard et al. (1996) were somewhat effective at differentiating between malingerers and honest responders in the current study, with an overall accuracy of 86%. Nearly all of the malingerers were accurately identified as malingerers, and only a single participant was misidentified (sensitivity = 94%). However, the specificity of the measure was somewhat weaker (78%). In comparison to the initial validation study by Bernard et al. (1996), the sensitivity of this measure in the current sample was similar, but the specificity was much lower (92%; Bernard et al., 1996). This was due to a high number of false positives (22% compared to 8% reported by Bernard et al.). This difference in specificity may be due to differences in executive abilities between the control participants in the current study and those used by Bernard and colleagues. In general, the honest responders in the current study showed poorer and more variable performance on the WCST than that reported by Bernard et al. Within the current sample, the average number of categories completed was lower (M = 4.72) and showed greater variability (SD = 1.87) than the controls in the sample used by Bernard et al. (M = 5.6, SD = 0.6). A similar pattern was seen in the number of perseverative errors across samples (current sample: M = 18.83, SD = 11.91; Bernard et al.: M=6.9, SD = 5.6). However, TBI patients are a very heterogeneous group whose level of impairments can vary significantly (Lezak et al., 2004), therefore it may be more ecologically valid to compare them to a more heterogeneous group of controls more similar to those used in the current study.

When scores from malingerers were compared to published data from patients with TBI (Bernard et al., 1996), the equations accurately identified 78% of the participants as “malingering;” however, if used in clinical practice, 22% would have been misclassified as having genuine impairment. The sensitivity of this measure was also somewhat lower than that reported by Bernard et al. (86%) in their validation study.

While the general effectiveness of this WCST malingering measure may be similar to other behavioral measures of malingering (e.g., the VIP-NV has a reported 74% sensitivity and 86% specificity; Frederick, 1997), there is still considerable room for improvement. It is crucial that malingering measures in general maintain the capacity not only to identify malingerers, but also to ensure the protection of those answering to the best of their abilities, as well. Misclassification of honest responders is problematic, particularly for measures intended for forensic application. An errant classification of an individual with genuine cognitive impairment in a civil case may result in the loss of treatment, services, or legal entitlement to compensation. The false identification of malingering in a criminal context carries even greater implications. A legitimately impaired individual may be prosecuted despite a lack of competency. The inability to understand legal proceedings or to consult effectively with one’s attorney could result in an unfair and biased trial (Rosenfeld et al., 2000). These concerns provide further rationale to investigate physiological indicators of effort, such as the one described in the current study.

A person's overt behavioral response will always be subject to manipulation and misinterpretation. Therefore, there is likely to be an increased emphasis on developing physiological indices of cognitive functioning in the future, particularly to assist clinicians in the determination of symptom validity. The strength of physiological indices, much like behavioral measures, lies in their convergent validity. By developing multiple correlates of cognitive functioning, ideally across multiple domains, the clinician can be more confident that the results of a cognitive evaluation are an accurate representation of the individual's abilities. The current paradigm is proposed as a supplement to the measures being developed to assess malingered memory deficits. By utilizing a comprehensive battery of both physiological and behavioral measures, clinicians will be able to place greater reliance on the validity of their results and conclusions. While physiological measures such as the one proposed are unlikely to achieve widespread use by clinical neuropsychologists due to the time, expense, and expertise required, a reliable physiological measure can serve as an additional tool to be used in exceptional cases in which the implications are particularly high (e.g., criminal cases, high stakes civil litigation, etc.).

The current study was a pilot study intended to investigate the feasibility of a physiological measure of executive functioning, as well as to demonstrate the resistance of the P3a component to participant manipulation. As such, the limitations observed in the current study will have to be remedied in future validation studies. Firstly, the present sample had a high number of participants (*n* = 9) that were excluded from the study due to recording difficulties. This high number was likely due to the environment in which the study took place. Participants were run in a non-shielded room on a busy college campus. Therefore, data collection was at times hindered by line noise, resulting in the observation of 60 Hz activity in the majority of the excluded participants. This variable should be eliminated in future validation studies. The current study was also designed to look for differences at a group level. However, before such measures can be used in a clinical setting, future research is needed to ascertain whether techniques such as bootstrapping can be used to accurately discriminate malingering participants from genuine mTBI patients at the individual level.

APPENDIX

Table 1

Beta weights included in the WCST logistic regression equations developed by Bernard et al. (1996) and Suhr and Boyer (1999)

	Predicted Group	
Bernard et al. (1996)	*Simulated Malingerers*	*Controls*
Categories	0.327	2.321
Constant	-0.664	-7.858
	Simulated Malingerers	*TBI Patients*
Perseverative Errors	0.306	0.431
Categories	2.731	6.997
Constant	-8.027	-22.226
	Simulated Malingerers	*Mixed CNS Patients*
Perseverative Errors	0.228	0.304
Categories	1.733	2.899
Constant	-6.20	-10.158
Suhr & Boyer (1999)	*Undergraduate sample (control vs. simulated)*	*Patient sample (TBI vs. suspected)*
Failures to Maintain Set	0.96	1.01
Categories	-0.42	-0.75
Constant	1.36	3.16

Note. Individuals are classified by multiplying the WCST raw scores by the appropriate coefficients shown above. The sum of the products is then added to the indicated constant. For the Bernard et al. criteria, the individual’s scores are calculated using two equations (on the same line) for each “type” of patient (i.e., either controls, those reporting TBI, or those reporting mixed CNS). One equation provides the coefficients for the selected clinical group (e.g., actual TBI patients), while the other provided the coefficients for the appropriate comparison group of simulating malingerers. When the scores from the two equations are compared, the greatest value indicates the most likely ‘group’ membership. For the Suhr and Boyer criteria, the individual’s raw scores are entered into whichever of the equations is considered to be most appropriate. Different cutoff scores are then used to determine whether the participants are malingering based on differing levels of desired sensitivity/specificity (cutoff scores can be seen in Table 2).

Table 2

Suhr and Boyer (1999) cutoff values for malingering using the WCST

Logistic regression score	**Probability of malingering**
4.69	0.99
3.68	0.95
3.16	0.90
2.41	0.85
1.69	0.80
1.43	0.75
1.17	0.70
0.91	0.65
0.42	0.60
0.16	0.55
0.00	0.50

Note. The specified regression score is used to predict the degree of certainty in a malingering determination (e.g., when a cutoff score of 3.68 is used, there is a 95% chance that the individual is malingering).

Table 3

Cutoff values and sensitivity/specificity for different combinations of WCST indicators using the two sets of cutoff criteria (Greve et al., 2002)

	Unique responses	**Suhr & Boyer**	**Bernard et al.**
Cutoff #1	>0	>1.9	>-3.0
Cutoff #2	>1	>3.68	>0.0

	Cutoff #1		**Cutoff #2**	
	Specificity	*Sensitivity*	*Specificity*	*Sensitivity*
Suhr	.89	.47	.94	.34
Bernard	.89	.38	.94	.10
Unique	.94	.35	1.00	.22
Suhr OR Bernard	.88	.53	.88	.41
Suhr OR Unique	.82	.66	.94	.47
Unique OR Bernard	.82	.53	.94	.34
Unique OR Bernard OR Suhr	.82	.66	.88	.50
Suhr AND Bernard	.88	.31	1.00	.09
Suhr AND Unique	1.00	.16	1.00	.09
Unique AND Bernard	1.00	.19	1.00	.03
Unique AND Bernard AND Suhr	1.00	.13	1.00	.00

Table 4

The diversity of study characteristics of those examining P3a amplitude among patients with mTBI

	Increased P3a amplitude	**Decreased P3a amplitude**	**Increased P3a latency**	**No P3a difference between groups**
Sample Size	11[2]	14[1] 20[4] 12[6] 52[7] 10[8] 40[10]	16[3] 52[7] 20[9] 40[10]	31[5] 24[11]
Injury	"Chronic severe closed head injuries" [2]	-"CT scan evidence of unilateral prefrontal lesions" [1] -"Mild frontal closed head injury" [4] -"History of head injury" [7] - "reported a mild head injury on a questionnaire given to an introductory psychology class"[8] - "Moderate to severe TBI"[10]	- Received "closed head injury" [3] -"History of head injury" [7] -"post-concussive syndrome" cases [9] - "Moderate to severe TBI"[10]	-"mild TBI" [5] -"mild head injured" [11]
Characteristics	-Loss of consciousness (LOC) from 10 min to 21 days with post-traumatic amnesia (PTA) 4 days to 3 mos[2] -Glasgow Coma Scale (GCS) range 5 to 14[2] -Bifrontal contusions, diffuse axonal injury (DAI), hematomas, and hygromas[2]	-No intracranial pressure, midline shift[1] -Left and right sided lesions[1,4] -Intracranial tumors and infarcts[1] -Reported LOC (<30 min) or PTA (<24 hrs) "was accepted as evidence of head injury"[4] - 1 with aneurysm, 19 with "varying degrees of traumatically induced frontal brain damage confirmed by neuroradiological examination (CT/MRI) performed within 6 months after trauma" [4] -LOC range few seconds to 60 min with PTA range 0 to 30 min[6] - "a single episode of a verifiable head trauma with an episode of amnesia or unconsciousness"[7] - 66% of sample classified as "mild" (the rest are unclear)[7] - mTBI defined as "any blow to the head forcing one to stop whatever one was doing"[8] -LOC in 80% of cases[8] - 29 cases had DAI, 7 cases had focal injury, 2 cases had acute epidural hematoma with DAI, and 1 case had acute subdural hematoma with DAI.[10]	-fulfilled at least one of the following: GCS ≤ 8, intracerebral hematoma, PTA > 48 hrs. [3] - "a single episode of a verifiable head trauma with an episode of amnesia or unconsciousness"[7] - 66% of sample classified as "mild" (the rest is unclear)[7] - < grade 3 concussion and any one of the following: LOC < 30 min., GCS of 13-15, PTA < 24hrs., any alteration in mental state at the time of the accident (e.g. feeling dazed, disoriented, or confused), or focal neurological deficit(s) that may or may not be transient.[9] - 29 cases had DAI, 7 cases had focal injury, 2 cases had acute epidural hematoma with DAI, and 1 case had acute subdural hematoma with DAI.[10]	- "mTBI was defined as any blow to the head resulting in short-term impairment of neurological functions (e.g. unconsciousness (< 30 min), confusion, disorientation and post-traumatic amnesia (< 24 hrs) which can be accompanied by other symptoms and signs (headache, nausea, vomiting, drowsiness, dizziness, emotional changes and cognitive deficits)"[5] -Normal MRI in 74%[5] -PTA range 1–1320 min. and LOC was present in 9 (range 0.03–20 min).[5] -GCS was 15 in 23 patients and 14 in 8.[5] -LOC range from few seconds to 60 min and PTA ranges from none to 30 min.[11]
Time Period	1-3 years post injury[2]	> 4 months post injury [1] > 6 months post injury[4] < 3.5 yrs post injury [6] 1-10 years post injury [7] 1-13 years post injury [8]	6 months to 3 yrs post injury [3] 1-10 years post injury [7] 19-59 months post injury [9]	< 3 yrs post injury[5] < 5 yrs post injury[11]
Clinical Sequelae	All patients had "typical neuropsychological deficits following severe CHI including attention memory and behavioral changes" [2]	-11 of 14 with no cognitive deficits -6 of 20 with mild to moderate cognitive complaints with no deficits in remaining 14 [4] - All participants had no "persistent symptoms" [6]	Neuropsychological deficits: "yes" [9]	3 of 24 report attention problems and 3 of 24 report memory deficits[11]

[1] Knight (1984) [2] Kaipio et al. (1999) [3] Rugg et al. (1993) [4] Solbakk et al. (2000) [5] Sivak et al. (2008) [6] Potter & Barrett (1999) [7] Reinvang et al. (2000)
[8] Segalowitz et al. (2001) [9] Gaetz et al. (2000) [10] Naito et al. (2005) [11] Potter et al. (2001) [12] Elting et al. (2008)

Table 5

Participant demographics

	Age (M)	Gender	Education (M)	Ethnicity	Estimated IQ (M)	Verbal Fluency (M)	Stroop (M)
Controls	24.2	8 males	14.1 years	5 White 6 African American 7 Other	100.2	37th percentile	50th percentile
Malingerers	25.6	5 males	15.1 years	5 White 5 African American 8 Other	103.5	45th percentile	50th percentile

Note. All differences between groups were non-significant.

Table 6

Bernard et al. (1996) criterion utilized in the current study to compare malingerers and honest responders using the WCST

	Predicted Group	
Bernard et al. (1996)	*Simulated Malingerers*	*Controls*
Categories	0.327	2.321
Constant	-0.664	-7.858
	Simulated Malingerers	*TBI Patients*
Perseverative Errors	0.306	0.431
Categories	2.731	6.997
Constant	-8.027	-22.226

Note. The two discriminant analysis equations (in the upper part of the table) were used to classify each individual as a simulated malingerer or a control. For each individual, a score for each predicted group was calculated by multiplying the number of categories completed on the WCST, and then adding the specified constant. The two scores were compared and the one with the greatest value indicated the most likely ‘group’ membership. Similar procedures were employed for comparing the malingerers in the current sample to the TBI patients/malingerers in the Bernard et al. sample. The WCST data (categories and number of perseverative errors) for each malingering participant were entered into the two equations comparing ‘TBI patients’ to ‘simulated malingerers’ (in lower part of the table). For each predicted group, WCST scores were multiplied by the appropriate coefficients and then the sum of the products was added to the indicated constant. The resultant scores were compared and the greatest value indicated group membership.

Table 7
WCST malingering results comparing honest responders and malingerers

	Bernard et al. equations	
	Malingerers	*Honest Responders*
Correctly Identified	17	14
Incorrectly Identified	1	4

Figure 1

Example of both P3a and P3b components in response to distracter and target items, respectively recorded of the Fz electrode. P3a (dotted line) is only observed in response to novel distracter items, while P3b (solid line) is only seen following identified target items. Adapted from Polich (2007).

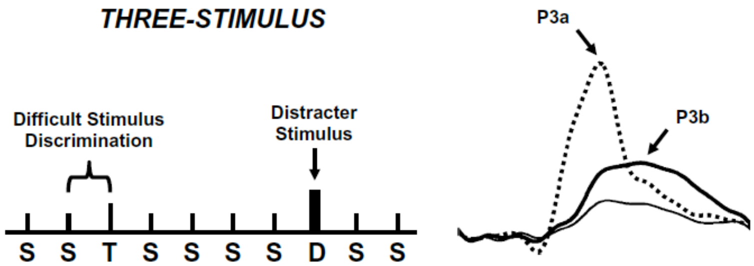


Figure 2

Grand average ERPs elicited by the two stimuli types (target and distracter) for both malingerers and honest responders across the 15 fronto-central electrodes.

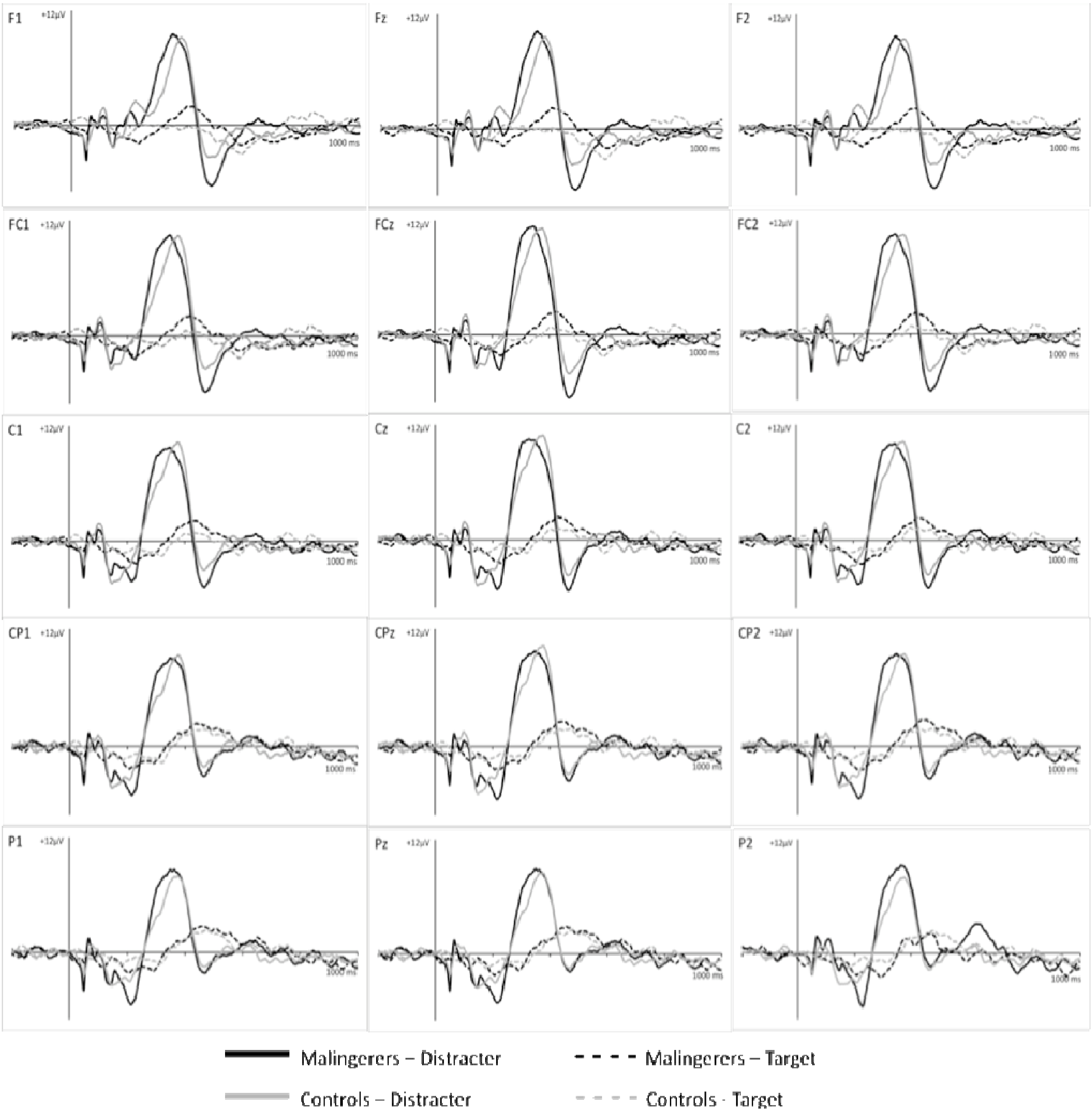


Figure 3

Scalp distributions for both Honest Responders (top) and Malingerers (bottom) for distracter (left) and target stimuli (right).

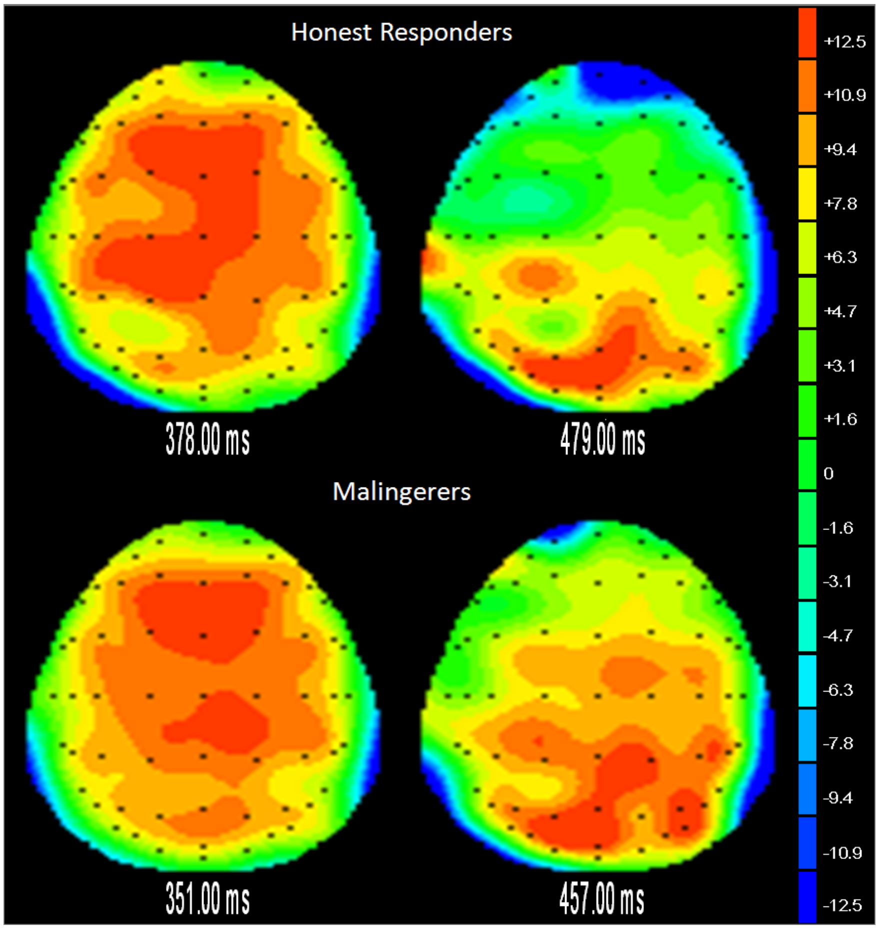
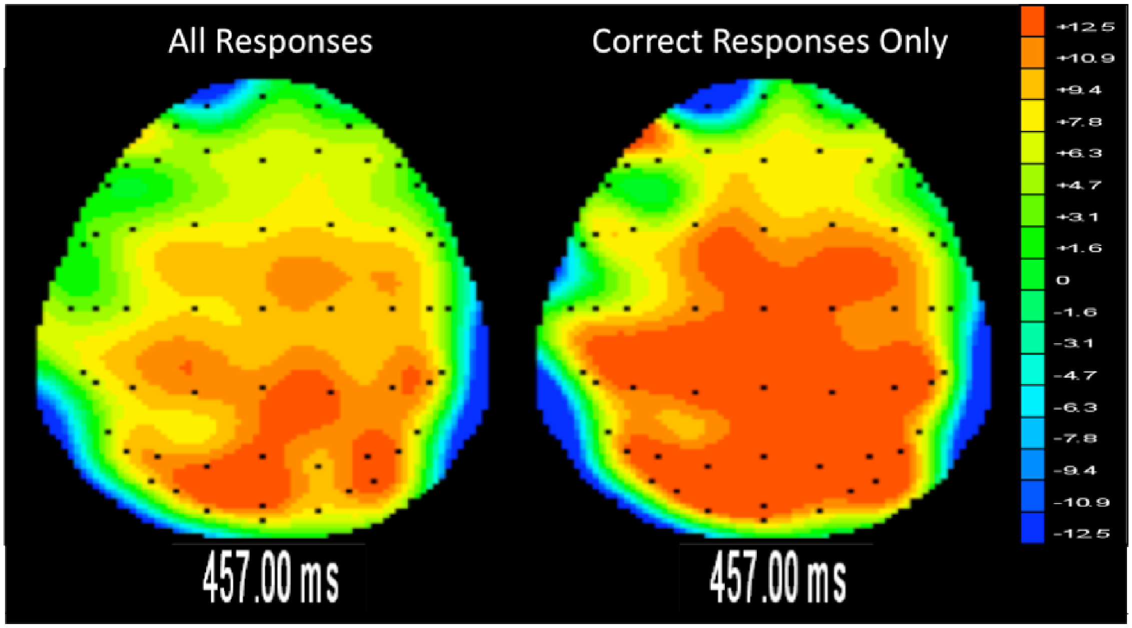


Figure 4

Scalp distributions for Malingerers in response to target items. Distributions are shown for all responses (left), as well as for correct responses only (right).



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