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Error Awareness: Assessment and Changes with Normal Ageing

by

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Thesis Abstract

Awareness is a complex psychological phenomenon, commonly affected by frontal lobe neuropathologies such as traumatic brain injury (TBI) and Alzheimer's disease (AD). There is not as yet a consensus, however, on how best to assess the extent to which awareness may be impaired.

This thesis comprises two papers. The first of these is a literature review paper that begins with a discussion of the different conceptualisations of awareness. The variety of methods currently being used to assess awareness are then critically discussed. Finally, the new idea of using event-related potential techniques (ERP) as a means of exploring error awareness is introduced.

The second paper aims to put this idea into practice, describing a study of error awareness in normal ageing, examined using an original combination of ERP techniques and psychological measures. Findings showed that older people were able to detect errors as successfully as younger people, although there was evidence to suggest a weakening of the error detection system with age. Equally, no differences in error awareness were found. These findings are discussed within the context of normal ageing, and clinical implications are also considered.

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Literature Review Paper:

A Review of Models and Methods Exploring Current Understanding And Assessment of Awareness

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Abstract

This paper is divided into three sections each exploring the concept of awareness. The first part is concerned with the different conceptualisations of awareness. Its proposed associations with the frontal lobes are considered by exploring the ways in which awareness can become disrupted by injury or illness. In this section, the focus is predominantly on awareness within a behavioural-anatomical model proposed by Stuss and Benson (1986). Other models are also critically discussed. These include attempts to explain how awareness may become disrupted at each level of frontal lobe function (Stuss, Picton & Alexander, 2001), and also specifically for different client groups such as those with Alzheimer's disease (AD) (Morris & Hannesdottir, 2004) or a traumatic brain injury (TBI; Crosson et al., 1989).

The second part of the review focuses on the different methodological approaches that have been used to explore awareness. The benefits and difficulties associated with each method are critically discussed. Based on this discussion, the final section introduces the possibility of using event-related potential (ERP) techniques as a more objective means to explore awareness. Specifically, over the last decade there has been growing interest in the brain's response to errors in fast choice-response tasks (Falkenstein, 2004). Two components locked to the participant's response are of interest: the 'pre-conscious' error-related negativity (ERN) and the 'more conscious' error positivity (Pe) that follows the ERN. The functional significance of these components is discussed, and the potential contribution of relevant ERP literature to our understanding of awareness is outlined.

A Review of Models and Methods Exploring Current

Understanding and Assessment of Awareness

A lack of awareness of deficit is a common symptom for people with Alzheimer's disease (AD) or traumatic brain injury (TBI), of whom many are seemingly unaware of the problems caused by their illness and how these may impact on everyday life (Feher, Mahurin, Inbody, Crook, & Pirozzolo, 1991; Harwood, Sultzer, & Wheatley, 2000). Indeed, a lack of awareness can have a detrimental impact on the lives of both patients and their carers, affecting patients' motivation for treatment, as well as their ability to set realistic goals and compensate appropriately for the skills that are impaired (McGlynn & Schachter, 1989; Ownsworth, McFarland, & Young, 2002). However, there is no consensus on how best to achieve an objective assessment of awareness. This is partly due to the complexity of awareness as a psychological concept (Clare, Wilson, Carter, Roth, & Hodges, 2002).

The frontal lobes, and in particular the prefrontal cortex (PFC), are widely considered to be a major component in an inter-connected neural network supporting the highest level of cognitive function; self-awareness (Stuss & Benson, 1986; Stuss et al., 2001). This paper will initially focus on awareness within the context of a general cognitive model of frontal lobe function (Stuss & Benson, 1986). Current theoretical models and methodologies used to measure impaired awareness within the context of AD and TBI are then critically discussed. Finally, this review will turn to the possible contribution of newer techniques to our understanding of awareness. In particular, components elicited by event-related potential (ERP) paradigms offer a new but exciting understanding of error awareness.

The Frontal Lobes

The frontal lobes do not function in isolation. They have widespread and reciprocal connections with many other brain areas, including the motor, sensory and association cortices, as well as limbic circuits (Fuster, 1989). The frontal lobes are located anterior to the motor cortex, and, based on function, are subdivided into three main areas: the orbital, medial and dorsolateral cortices (Paradiso, Chemerinski, Yazici, Taratro, & Robinson, 1999; Wheeler, Stuss, & Tulving, 1997).

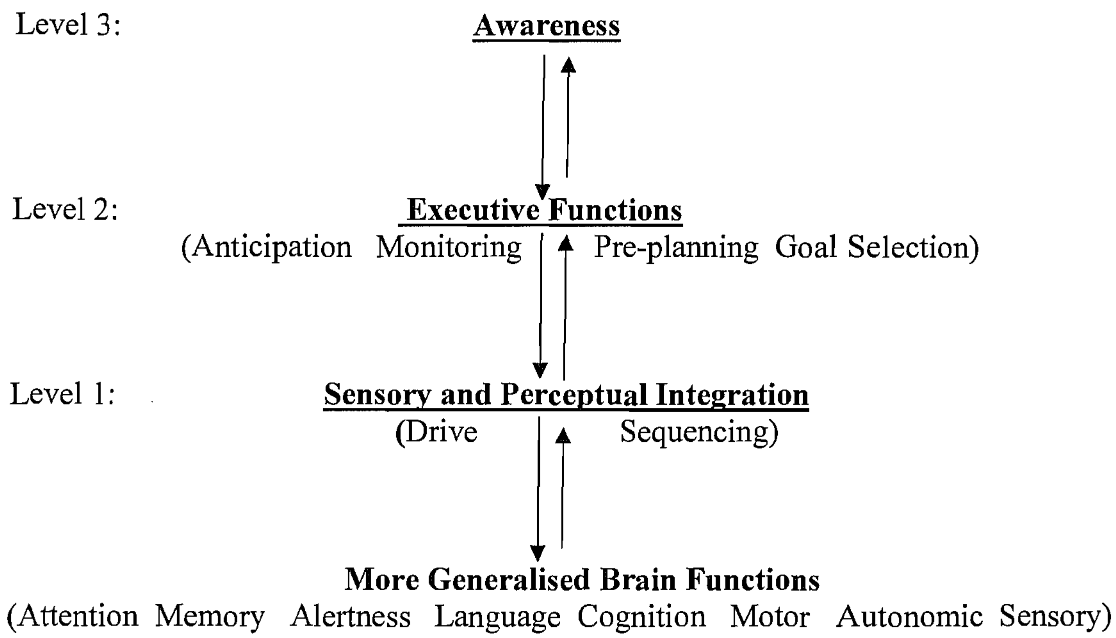
The orbital frontal lobes are believed to underpin behavioural regulation, the anticipation of consequences, decision-making and goal-directed behaviour (Eslinger, Grattan, & Geder, 1995). The medial frontal region includes the anterior cingulate cortex (ACC), part of the brain's limbic system, and is largely concerned with internal states and behaviour such as the experience of emotion (Falkenstein, 2004; Kiehl, Liddle, & Hopfinger, 2000). It also contributes to 'intentional behaviour', attention (Eslinger et al., 1995), and performance monitoring (Ullsperger & von Cramon, 2001). Finally, the dorsolateral prefrontal cortex (DLPFC) supports working memory, decision-making and the organisation of information, thoughts and behaviour (Eslinger et al., 1995; Levy & Goldman-Rakic, 2000). It is likely that these frontal lobe areas work concertedly to support executive function.

The frontal lobes, and in particular the PFC which is the most anterior part of the frontal lobes, are typically described as the central control area of the brain. They are responsible for gathering and organising information, and for the temporal organisation of behaviour (Fuster, 1989; Luria, 1973; Stuss & Benson, 1986). This control is facilitated by widespread, reciprocal interconnections with other, more posterior brain regions, such as the parietal lobes. Control of automated, routine behaviours that are well learnt may function somewhat independently of the frontal lobes, but prefrontal control is required in order to guide responses to novel stimuli or situations, and when a task is perceived to be complex (Rushworth, Hadland, Paus, & Sipila, 2002). This is a fundamental assumption of the supervisory attention system (SAS), which describes frontal lobe control of attention allocation and action priorities (Norman & Shallice (1986). Thus, there is a widely held belief that the frontal lobes have a supervisory role over other brain functions, as well as a key role in mediating higher cognitive processes and in the regulation of activity. They are also believed to be responsible for supporting the highest level of function; self-awareness (Fuster, 1989; Stuss, 1991; Stuss & Benson, 1986).

Stuss and Benson's (1986) Model

Building on earlier theoretical work such as the SAS model (Norman & Shallice, 1986), and more neuropsychological approaches such as those of Luria (1973), Stuss and Benson (1986) developed a model of brain organisation in which three hierarchical, yet interactive, levels of frontal lobe function are proposed. This model and evidence to support it are now described in greater detail.

Figure 1. Stuss and Benson's (1986) Hierarchy of Brain Function



(adapted from Stuss & Benson, 1986)

Level 1: Sensory and Perceptual Integration

The first level of frontal lobe function concerns the integration of sensory and perceptual information, and has two main functions. The first is to organise and maintain information in a meaningful way; a process commonly associated with the DLPFC (Levy & Goldman-Rakic, 2000). This allows for the manipulation of sensory information, the extraction of key information, and the integration of this information with existing knowledge (Stuss & Benson, 1986). The other function within this level concerns motivation, drive and the initiation of behaviour. These processes are more dependent on the medial frontal lobe (Eslinger et al., 1995). Both of these functions interact in a supervisory capacity with the functional systems located more posteriorly in the brain, such as language and memory (Stuss & Benson, 1986).

Level 2: Executive Function

The second level concerns executive function, defined by Stuss and Benson as a higher control process. Functions within executive control include goal selection and anticipation, planning, inhibitory control, cognitive flexibility, behaviour monitoring and use of feedback (Stuss & Benson, 1986; Wecker, Kramer, Wisnieski, Delis, & Kaplan, 2000; Wheeler et al., 1997). This level works at a superior level to sensory integration, consciously directing the posterior, functional systems towards a selected goal during novel and non-routine situations (Stuss, 1989; Stuss & Benson, 1986). In this way, executive function controls the selection of information coming in at a sensory level for attention, activates or inhibits goal-directed behaviour, and works to resolve any discrepancies in information (Stuss et al., 2001).

Neuroanatomical Basis of Executive Function

Executive function is a multifaceted and complex concept. However, many functional magnetic resonance imaging (fMRI) studies support the localisation of executive functions within interconnected neural networks that include the frontal lobes. For example, dual task performance is associated with greater activation in the left inferior frontal cortex (Schubert & Szameitat, 2003); inhibition has been associated with the frontal cortex (Bellgrove, Hester, & Garavan, 2004), and more specifically with the right inferior frontal cortex (Aron, Robbins, & Poldrack, 2004); the DLPFC has been associated with inhibition and attentional control when demands on working memory are increased (Hester, Murphy, & Garavan, 2004) and for the maintenance of task set within working memory while the left frontal cortex sustains attention (Fassbender et al., 2004); whilst conflict monitoring and error processing have been associated with the ACC (Carter et al., 1998; Ullsperger & von Cramon, 2001).

These findings indicate patterns of preferential activation in association with different task demands, while assessing executive function. This supports the assumption that the frontal lobes are likely to be an integral part of these executive control processes.

Level 3: Self-Awareness

The final and highest level in Stuss and Benson's model is that of awareness, or self-awareness. This level can be seen at the top of Figure 1, above all other functions. The concept of self-awareness, also referred to as consciousness, self-consciousness or self-reflectiveness, has been traditionally hard to define (Wheeler et al., 1997). Prigatano and Schachter (1991; p.13) refer to self-awareness as 'the capacity to perceive the self in relatively objective terms, while maintaining a sense of subjectivity', thus combining elements of both internal experience and external reality (Dirette, 2002). It has also been referred to as the ability to be conscious of one's self, while at the same time understanding the relation of self to the social environment (Stuss & Benson, 1986). Based on this definition, one concept that appears closely related to awareness is metacognition (Stuss, 1989). This reflective ability can be defined as introspection, or the evaluation or control of one's own cognitive processes (Shimamura, 2000).

Neuroanatomical Basis of Self-Awareness

There is a widely held belief that self-awareness is localised within the PFC. This belief is supported by the fact that a common consequence of frontal lobe injury is impaired self-awareness (Agnew & Morris, 1998; Fuster, 1989; Stuss, 1989; Stuss, 1991; Stuss & Benson, 1986).

A large body of research has examined AD patients, in whom the frontal lobes are commonly affected. Studies using single photon emission computed tomography

(SPECT) to examine blood flow in patients with AD, found that a lack of awareness (measured using clinician ratings and awareness questionnaires) was associated with decreased cerebral perfusion in the right DLPFC (Reed, Jagust, & Coulter, 1993; Starkstein et al., 1995). A similar study found a positive correlation between awareness deficit (measured using clinician ratings and patient-carer rating discrepancies) and decreased blood flow in the right prefrontal cortex (Derouesne et al., 1999). Although lacking in specificity, these findings are important as they indicate the likely importance of the frontal lobes in supporting awareness.

Other studies are more inferential in their association of awareness with the frontal lobes. An enduring mental model of self over time is key to self-awareness, and necessary in order to make decisions and plan for the future (Wheeler et al., 1997). Wheeler and colleagues propose a link between autonoetic consciousness, (the ability to represent mentally and re-experience subjective experiences in the present, past and future via episodic memory retrieval), and the PFC. They conclude that this mental process occurs via retrieval from episodic memory, and is associated with right PFC functioning (Stuss & Alexander, 2000; Stuss et al., 2001; Tulving, 1983; Wheeler et al., 1997). This is consistent with fMRI research exploring the hemispheric encoding/retrieval asymmetry (HERA) model of episodic memory within the PFC, which has shown that the left PFC is involved in episodic memory encoding, while the right hemisphere is predominantly associated with retrieval (Habib, Nyberg, & Tulving, 2003).

While patients with frontal lobe damage may retain knowledge of past experiences (episodic memory), the personal and emotional significance attached to these memories required for making future decisions (autonoetic consciousness) is often impaired (Wheeler et al., 1997). This is consistent with the view that the right

PFC, in particular, supports autonoetic consciousness, a form of self-awareness. The ability to process both cognitive and emotional information is also recognised as an important role of the ACC, part of the brain's limbic system located within the medial frontal lobes (Bush, Luu, & Posner, 2000; Kiehl et al., 2000). This linking of emotion to memory for judgement and decision-making, via prefrontal episodic retrieval, is also termed the 'somatic marker hypothesis' (Damasio, 1994). Evidence exploring autonoetic consciousness therefore provides support for Wheeler and colleagues (1997) in suggesting that the frontal lobes, in particular the right hemisphere, are integral to brain processes supporting awareness.

Finally, a number of authors have explored metacognition, a phenomenon related to self-awareness, using fMRI and positron emission tomography (PET) studies. Findings have highlighted the frontal lobes, specifically the medial prefrontal cortex (MPFC), ACC and DLPFC, as playing important roles during both metacognitive regulation and attention (Fernandez-Duque, Baird, & Posner, 2000; Schmitz, Kawahara-Baccus, & Johnson, 2004). In support, other neuroimaging studies examining conscious perception and awareness found the same areas implicated during reflective self-awareness and fully conscious motor planning and control (Feinstein, Stein, Castillo, & Paulus, 2004; Frith, 2002; Johnson et al., 2002; Kjaer, Nowak, & Lou, 2002; Stephan et al., 2002).

In summary, the frontal lobes are implicated as supporting processes related to self-awareness such as reflection and metacognitive regulation. However, it is very difficult, if not impossible, to control for other brain processes (e.g. sensory and motor activity) associated with performing these tasks in order to focus on brain processes associated with awareness alone. It is not certain whether we should even strive to tease apart these processes. In other words, awareness may be dependent on 'lower' and 'higher' brain processes working concertedly. This is a fundamental tenet of Stuss and Benson's model.

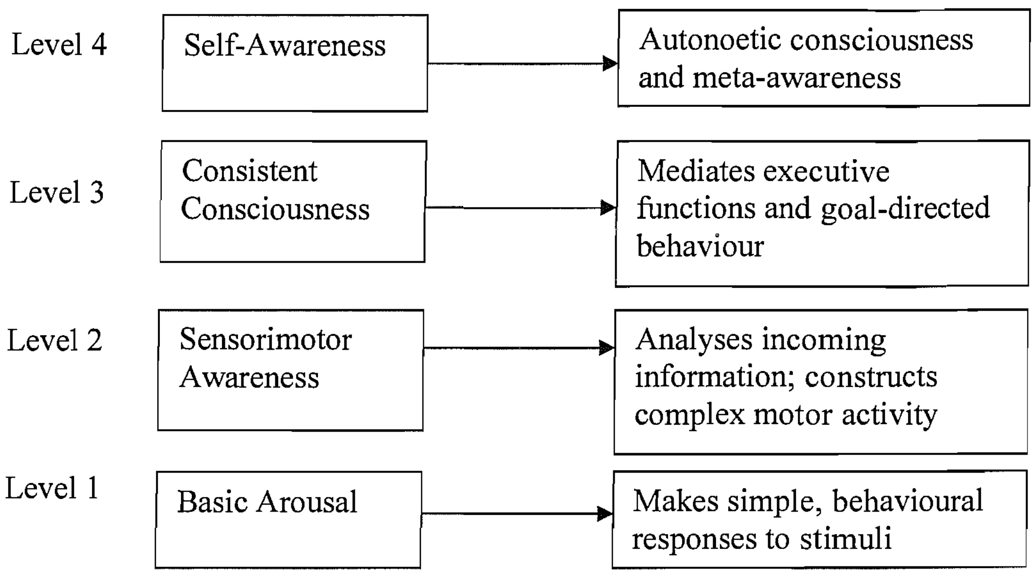
Stuss and Benson: An Interactive Model

Although, from one point of view, the three levels remain distinct from one another in their functions, Stuss and Benson (1986) do not propose that these levels work in isolation. Instead, they are proposed to comprise an interactive model of frontal lobe function. Frontal lobe executive control processes, such as those involved in attention, monitoring, inhibition and error detection (Level 2), appear closely related to the processes involved in metacognition and self-awareness (Level 3) (Fernandez-Duque et al., 2000; Stuss, 1991; Stuss & Benson, 1986). For example, controlling and monitoring one's behaviour and responding to feedback may intuitively require awareness of self and one's own mental operations at that time. Other research highlights the important role that attention has to play in being self-aware (Dehaene & Naccache, 2000; Fernandez-Duque et al., 2000; Wheeler et al., 1997). This supports the fact that the three levels of Stuss and Benson's model, in particular Levels 2 and 3, should not be seen as mutually exclusive, but rather as dynamic and interactive (Stuss & Benson, 1986).

The research discussed to date provides a valuable insight into the areas within the PFC that may be responsible for supporting awareness. These findings, as well as the obvious complexity of awareness and its ability to exist in several different forms, indicate that awareness is likely to function not at one autonomous level, but as part of an interactive system. This review will now focus upon awareness in more detail, using a more recent model to explore how awareness could exist, and become disrupted, at each level of the dynamic frontal lobe framework originally provided by Stuss and Benson (1986).

Awareness and the Frontal Lobes

Figure 2. Stuss et al.'s (2001) Model of Awareness



(Adapted from Stuss et al., 2001)

In 2001, Stuss and colleagues proposed a more complex model to explore how awareness interacts with the functions associated with Stuss and Benson's original three levels (Stuss et al., 2001). Using a similar framework to the one originally provided, another level was added below sensory perception to update the model to a 4-level model of awareness (see Figure 2).

Stuss and colleagues (2001) propose that a 'modelling' process at each level underlies consciousness, so the brain experiences the model rather than the information itself. Some neurons 'model' activity to match incoming information, whilst others compare the modelled activity with input to ensure that they match. The result is a perceptual model and a model for action: an internal representation of self that is constantly compared with the external world (Stuss et al., 2001).

The four levels are hypothesised to respond differentially to task demands. Higher levels can be activated by lower levels unable to process complex data, and higher levels can control lower activities through a top-down process. This means that modelling intensity can be increased, or comparator activity accentuated to increase accuracy of the internal representation. Each level is modular so several processes can occur simultaneously and efficiently (Clare, 2004*a*; Stuss et al., 2001).

The first level is basic conscious arousal, dependent upon the brain stem and projections to the thalamus and cortex. This level supports simple responses to stimuli only, therefore no modelling is required; damage could result in a state of coma (Stuss et al., 2001). The second level is perceptual-motor, thus relating to Stuss and Benson's lowest level of frontal lobe function. Awareness can become disturbed locally at this level by damage to the individual functional and posterior domains originally proposed by Stuss and Benson (see Figure 1). For example, patients with a left posterior temporal lesion and Wernicke's aphasia can lack awareness of their own jumbled speech or lack of comprehension (Stuss et al., 2001). One interpretation is that awareness becomes impaired locally when a pathway between a functional domain and the frontal lobes is disrupted.

The third level is executive mediation, relating to Stuss and Benson's Level 2, and is likely to be located within the lateral PFC (Stuss & Alexander, 2000). Damage to this region would result in executive awareness problems, such as judgement and planning (Stuss, 1989). An example of disturbed awareness at this level would be a patient with Capgras syndrome, who has two similar yet separate experiences (before and after the brain injury), yet lacks the executive skills to combine the two into a single mental model (Stuss et al., 2001).

The highest level is self-awareness, or consciousness of the self. Only humans have this reflective self-consciousness, arising from the integration of memory and emotional state. In this way, we plan our future actions with emotional expectancy, using memories of the self in the present and past (Stuss & Alexander, 2000; Stuss et al., 2001). The right prefrontal hemisphere has been implicated as responsible for episodic retrieval, allowing memories of self and associated emotions to be re-experienced: autonoetic consciousness (Habib et al., 2003; Wheeler et al., 1997). An awareness deficit at this highest level could, therefore, occur following a right prefrontal injury, resulting in global unawareness of its implications (Stuss et al., 2001).

A central idea within this conceptualisation of the highest level is that the frontal lobes have strong connections with the limbic system, which is important for learning, memory and emotion (Sohlberg & Mateer, 2001). Therefore, it is in prefrontal areas, such as the ACC, that perceptual information and affective state become integrated (Bush et al., 2000). Affective information can be accessed to guide decision-making, and the convergence of abstract memories and emotional state demonstrates a level of self-awareness unique to the human mind (Stuss & Alexander, 2000). Taken together, the evidence suggests that both knowledge and affect are key components of self-awareness, as already proposed by researchers exploring somatic markers and autonoetic consciousness (Damasio, 1994; Wheeler et al., 1997).

This model has received some criticism due to the absence of psychological factors affecting awareness such as denial (Clare, 2004*a*). Nevertheless, it provides a clear, theoretical framework to explain how different levels of awareness exist, and the possible consequences of disruption at each level. Both this theoretical model and the earlier, more functional model of Stuss and Benson (1986), illustrate the interactive nature of frontal lobe function and awareness at different levels. However, another criticism could be that there are no conceptualisations of how damage at one level could impact upon awareness at another, although the interactive nature suggests that disruption would be likely to occur in some form. This requires further investigation.

Deficits in Awareness

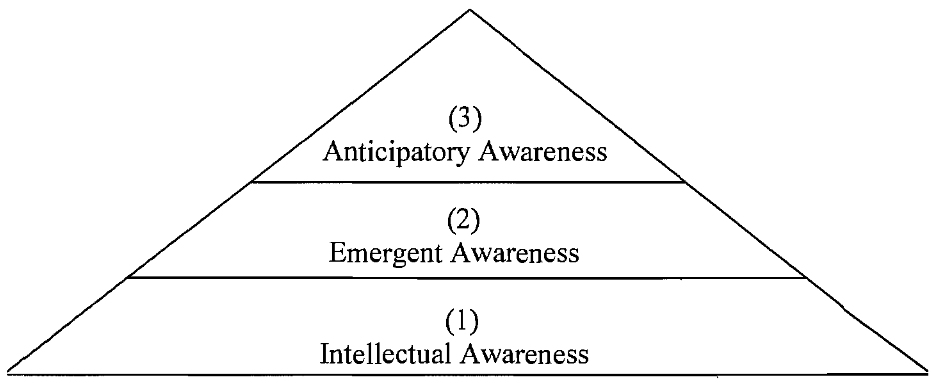
Empirically, awareness has gained interest mainly from a pathological point of view, exploring awareness within the context of deficit. Awareness is commonly disrupted in pathologies affecting the frontal lobes, such as AD and TBI (Clare, 2003; Prigatano & Schachter, 1991; Stuss et al., 2001), therefore, much research has explored awareness within the context of these client groups. The simplicity of some conceptualisations compared with the complexity of others highlights the difficulty in creating a model to explain a complex phenomenon, in a way applicable to understanding every patient's needs.

Awareness and Traumatic Brain Injury (TBI)

Within TBI research, awareness is commonly defined as patients' ability to recognise the functional deficits resulting from acquired injuries (Crosson et al., 1989; Toglia & Kirk, 2000). A lack of awareness of deficit was first termed 'anosognosia' by Babinski in 1914, relating to patients with hemiplegia who had little or no recognition of their deficit. It is now a generic term relating also to a lack of awareness about cognitive deficit (Schachter, 1990). Anosognosia is a separate entity from denial, a psychological defence mechanism with no organic cause (Kihlstrom & Tobias, 1991). The extent to which psychological factors like denial might contribute to awareness problems is not fully understood, and will be discussed in more detail later.

Awareness of deficit comprises more than simply 'knowledge' that a deficit exists (Fleming & Strong, 1995; Prigatano & Schachter, 1991). The patient's subjective interpretation of how this deficit will impact upon their daily functioning, i.e. the feelings associated with the knowledge that a deficit exists, are also important. For example, a patient who demonstrates good knowledge of their difficulties but shows minimal concern about their perceived consequences would be viewed as having poor awareness (Stuss, 1991). In this way, both knowledge and associated emotion can be regarded as key, interdependent elements comprising awareness.

Figure 3. The Pyramid Model of Awareness



(adapted from Crosson et al.,1989)

Several authors have attempted to define this lack of awareness within a working model, following work with TBI patients. For example, Fleming and Strong (1995) described a three-level model respectively encompassing knowledge of deficit, subjective awareness of daily functional limitations as a consequence, and finally, the ability to look to the future and set realistic goals. Crosson and colleagues (1989) also defined three interdependent levels of awareness in a similar but hierarchical conceptualisation called the Pyramid Model (see Figure 3). This model was developed following empirical observation of patients with head injury. The first level, intellectual awareness, is the knowledge that a deficit exists. Intellectual awareness is required before patients can move to the second level, emergent awareness, which describes patients' ability to recognise problems as a result of their deficit when they occur. Finally comes anticipatory awareness, for which both intellectual and emergent awareness are required. This final level concerns the ability to anticipate when a problem may be likely to occur, and to compensate in advance.

These models highlight the fact that awareness is not a unitary phenomenon, and can occur at different levels within different contexts. Indeed, the complexity of awareness as a concept is reflected in the fact that many clinicians report patients to be 'aware at some level' (Hart, Giovannetti, Montgomery, & Schwartz, 1998). The simplicity of the models discussed may reflect the fact that they are specific to the client group, where there is a need for a simple understanding of awareness deficit as this is often a key factor impeding successful rehabilitation. The value of this model in understanding awareness deficit in other client groups, such as AD, may therefore be limited.

Alzheimer's Disease, Awareness and the Frontal Lobes

Another body of research has explored awareness within the context of Alzheimer's disease (AD). Anosognosia is a common symptom, particularly as the disease progresses (Agnew & Morris, 1998; Clare, 2004*a*), and may be associated with disease progression in the frontal lobes, in particular within the right hemisphere (McGlynn & Schachter, 1989; Wheeler et al., 1997). The role of the frontal lobes in carrying out executive functions such as planning and monitoring, and their link with awareness, have already been highlighted (Stuss, 1991; Stuss & Benson, 1986). The relationship of executive dysfunction to anosognosia in AD has, therefore, also been explored.

Although some researchers found no significant association between level of awareness and executive dysfunction, assessed using the Wisconsin Card Sorting Test: WCST (Dalla Barba, Parlato, Iavarone, & Boller, 1995; Starkstein et al., 1995), several other studies contradict those findings. Michon and associates also used the WCST and concluded that assessing executive function was the best indicator of impaired awareness (Michon, Deweer, Pillon, Agid, & Dubois, 1994). Equally, Mangone and colleagues found that assessments of frontal lobe function, particularly the Visual Reproduction Test and the Continuous Performance Test, were the best predictors of impaired insight (Mangone et al., 1991). Other studies also found positive correlations between executive function and level of awareness (Auchus, Goldstein, Green, & Green, 1994; Lopez, Becker, Somsak, Dew, & DeKosky, 1994; Starkstein, Fedoroff, Price, Leiguarda, & Robinson, 1993).

The different methods used to assess executive function could be a reason for discrepancies in findings. Nevertheless, it would appear that, although executive dysfunction may not predict unawareness, the two are commonly associated in AD patients. This supports the interactive nature of Levels 2 and 3, as proposed by Stuss and Benson (1986).

One possibility is that impaired awareness reflects a deficit in self-monitoring caused by frontal lobe dysfunction (Stuss & Benson, 1986). This would result in patients being unable to monitor their performance over time, or make accurate judgements concerning future performance (McGlynn & Kaszniak, 1992). The importance of monitoring and control for metacognitive regulation has been shown. Two research groups (Correa, Graves, & Costa, 1996; Reed et al., 1993) found anosognosia to be associated with high levels of false positive errors on a recognition memory task. Both studies concluded that making false positive errors deprived patients of accurate feedback on their performance. This suggests that an ability to detect that an error has been made is required in order to update any changes in memory functioning, so a deficit in self-monitoring would result in impaired awareness of memory capabilities.

These findings suggest that the frontal lobes and executive functions may be integral to intact awareness. However, although it seems likely that executive function supports awareness at the level of performance monitoring (on-line, or error awareness), there is a lack of empirical evidence to support the view that all aspects of awareness are dependent upon executive function. For example, contrary evidence can be found in case studies describing how patients with a frontal lobe injury can perform normally on some executive function tasks, yet lack the global awareness of self, or metacognitive awareness, necessary to organise their life and make well-judged decisions (Stuss, 1989; Stuss et al., 2001).

The heterogeneity of patient pathology may also be an important factor responsible for variation in findings, highlighting the complex and multi-faceted nature of awareness. This also supports the view that awareness exists in several forms. While on-line awareness of performance may be more dependent on intact executive abilities, higher levels of self-awareness, such as autonoetic consciousness, may be able to function more independently, or may become impaired while performance on tasks that purport to measure executive functions are spared. This possibility requires further investigation.

Another possible reason for the earlier discrepancy in findings may be the inconsistent methods used to measure awareness in these studies (Dalla Barba et al., 1995). These included clinician ratings (Auchus et al., 1994), questionnaires (Derouesne et al., 1999) and patient-carer discrepancy scores (Michon et al., 1994). The measurement of awareness remains a contentious issue (Clare, 2004*b*), and the variety of assessment methods used will be critically discussed in detail later.

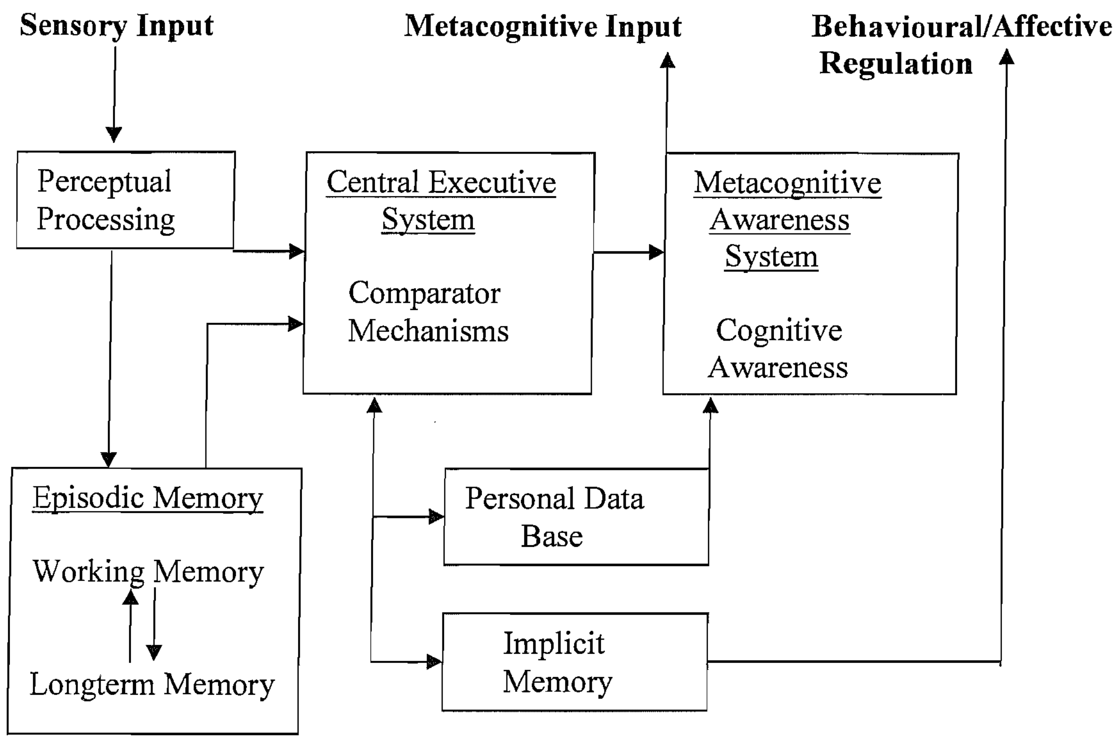
In summary, although findings are inconclusive, they indicate the importance of executive function and the ability to monitor performance, for maintaining an accurate awareness of one's capabilities. This supports the idea that awareness is implicated at different levels, as proposed by Stuss and colleagues (2001), and on-line, or error awareness may be dependent upon intact executive control. Further empirical study is required to determine more clearly the implications for more abstract levels of awareness following executive disruption.

Alzheimer's Disease: A Cognitive Model of Unawareness

As with TBI, awareness deficits following AD can vary in both severity and the cognitive mechanisms affected (Morris & Hannesdottir, 2004). There have been few cognitive models attempting to explain the awareness system and how anosognosia may develop. The most recent of these is the Cognitive Awareness Model (CAM; Morris & Hannesdottir, 2004). This is a revised version of the original Cognitive Awareness Model (Agnew & Morris, 1998), which was based on earlier work by Schachter (1990).

The CAM model attempts to explain in more detail the different ways in which awareness can become disrupted for AD patients while other cognitive mechanisms remain intact. By focussing on empirical evidence from one client group alone, this model may not be applicable to other client groups. However, it provides a detailed conceptualisation of the cognitive mechanisms underlying awareness, and the different ways in which these could become disrupted by the progression of AD.

Figure 4. The Cognitive Awareness Model



(adapted from Morris & Hannesdottir, 2004)

The central concept to this model is monitoring ability; an individual needs to receive accurate feedback about their performance if they are to be able to make an accurate judgement about this (Correa et al., 1996; Reed et al., 1994). Intact sensory/perceptual processing, and the acquisition and storage of events in long-term memory are also required. A Personal Data Base (PDB) stores information regarding cognitive function ability, which is used to aid judgement about future actions and participation in certain tasks. Executive function comparator systems monitor performance by comparing current sensory/perceptual information with information on cognitive capabilities stored within the PDB. If a mismatch is detected, this is fed back into the PDB so knowledge can be updated (Morris & Hannesdottir, 2004).

The authors allow for local, or domain-specific awareness, proposing many comparator systems monitoring different neuropsychological processes, such as language and memory. Global, or metacognitive, awareness is also accounted for by a mechanism known as the Metacognitive Awareness System (MAS). All comparator systems feed into the MAS so that mismatches or cognitive failures are noticed immediately, and inputs from the PDB mean that metacognitive awareness oversees all function with up-to-date knowledge of cognitive abilities. One final mechanism comprises implicit memory, which receives information from the comparators and can guide behavioural responses without conscious awareness. In this way, an individual can unconsciously adjust both their behaviour and affect in response to stimuli (Morris & Hannesdottir, 2004).

The CAM model can be used to illustrate anosognosia for memory problems in AD, showing how awareness can be disrupted at three levels: a) When long-term memory fails, a mismatch between PDB knowledge and past experience cannot occur, or alternatively, a mismatch is detected but PDB knowledge is not updated due to difficulties consolidating information into the knowledge base. This is called mnemonic anosognosia; b) There is a comparator problem at the executive control level. This means that memory difficulties are perceived but there is no signal of failure. Once again, the PDB is not updated, and executive anosognosia results; c) Failure occurs within the MAS, meaning that up-to-date information from the PDB is not acknowledged, and primary anosognosia is the result. However, if the implicit system remains intact, patients may adjust their mood or behaviour (e.g. become angry or agitated) but without knowing why (Morris & Hannesdottir, 2004).

This model successfully explains how and why awareness problems might occur within AD. The importance of intact executive control and monitoring for awareness is emphasised, although this model is more advanced in its ability to explain how awareness can be disrupted when executive control remains intact. As with Stuss et al.'s (2001) model, the possibility for awareness to be disrupted at either a global level or in a specific domain only is explained. However, in addition to knowledge of difficulties, the emotional consequences associated with failure have been proposed to be integral to awareness (Damasio, 1994; Wheeler et al., 1997). Other researchers have therefore identified what the CAM model still lacks: an element to take into account the consequences of emotional disruption (Derouesne et al., 1999). Another missing link is the inability for personal autobiographical information to be consolidated into the PDB via a direct link from episodic memory, in situations encountered for the first time (Ansell & Bucks, submitted). Nevertheless, this model still provides a useful and clinically valuable framework for understanding awareness deficits within the context of AD.

Measuring Awareness

Thus far it has been implied that cognitive and functional models of frontal lobe function and awareness struggle to conceptualise awareness within a single framework where deficits can be fully understood. This may partly be due to methodological issues. The complexity of awareness as a concept, and the different ways in which awareness deficits can manifest themselves across different clinical populations, means that there is not, as yet, a consensus on the best and most accurate means of assessment (Clare, 2004*b*; Morris & Hannesdottir, 2004). The main methods currently used to measure awareness in the context of TBI and AD are now introduced. Firstly, however, the difficulties in differentiating between unawareness of organic origin, and denial, are considered.

Depression and Denial: Confounding Factors

In contrast to 'neuropsychological unawareness', with an organic origin, denial is an emotional reaction in response to change (Sohlberg & Mateer, 2001). In this form, it can play an important role in adaptation to stressful events such as neurological disease or injury, and thus serves to reduce 'reality anxiety' (Kihlstrom & Tobias, 1991). It has been proposed that some individuals, namely those who were high achievers pre-morbidly and viewed illness as a weakness, are more likely to develop defensive denial following a traumatic event such as serious illness (Weinstein & Kahn, 1955). These individuals may overtly deny their deficits, yet comply in other ways such as by willingly taking their medication, indicating implicit awareness (Clare, 2004*b*; Weinstein, 1991). Additionally, individuals in denial are more likely to be resistant when faced with their difficulties, whereas those with anosognosia often appear surprised to be experiencing difficulty (Prigatano, 1988; cited in Lewis, 1991). Thus, there are different levels of denial, which can fluctuate throughout the duration of an illness.

Research has examined the extent to which denial and organic awareness may co-occur. A study by Kortte and colleagues (2003) with brain-injured patients concluded that anosognosia and denial often co-exist. However, they were able to separate individuals by the coping strategies they employed (Kortte, Wegener, & Chwalisz, 2003). Findings showed that patients scoring high on denial also scored high on use of avoidant coping strategies, whereas anosognosia and avoidance were not significantly related. Although these findings support the idea that patients in denial are often resistant when faced with their difficulties, it is unlikely that denial and anosognosia can be reliably separated by examining pre-morbid coping techniques alone.

The motivational defence theory of denial (Weinstein & Kahn, 1955) states that denial occurs as a psychological defence against depression following trauma. Therefore, higher levels of denial should result in lower levels of depression. Several studies have found evidence in support of this hypothesis, showing that higher levels of awareness in AD were associated with more depressive symptomology (Harwood et al., 2000; Smith, Henderson, McCleary, Murdock, & Buckwalter, 2000), and feelings of hopelessness (Harwood & Sultzer, 2001). A relationship has also been found between increased awareness and anxiety (Derouesne et al., 1999; Verhey, Rozendaal, Ponds, & Jolles, 1993). However, equally, some studies have found no associations between depression and awareness (Lopez et al., 1994; Michon et al., 1994; Reed et al., 1993), or denial (Kortte et al., 2003).

These findings indicate that there is not, as yet, a reliable method for differentiating denial from organic unawareness. Mood disturbance may also confound assessment of awareness; for example, depressed patients may report more difficulties due to reduced self-perception rather than increased insight, and reporting more memory problems is a common consequence of depression (Clare, 2004*b*; Smith et al., 2000). The importance of having an assessment measure that can differentiate awareness from these different factors can therefore be seen. Several different methods have been developed, and these will now be discussed in turn.

Clinician Ratings

One means of assessment involves the evaluation of client awareness by a clinician. In this context, patients' awareness of their deficits can be elicited through interview and/or direct observation of their behaviour. A judgement is then made concerning the patient's apparent level of awareness, and their level of awareness may also be rated on a scale (Sohlberg & Mateer, 2001).

One advantage of this type of assessment is that interviews can be carried out in depth exploring relevant issues as they arise. Additionally, clinicians can have some reassurance that patients understand the questions, by rephrasing them if necessary (Clare, 2004*b*), or asking the patient to paraphrase the question. It is also possible to carry out the interview quickly to minimise distress to the client, while making maximal use of the clinician's expertise (Morris & Hannesdottir, 2004).

However, awareness is a complex phenomenon, and there is doubt as to whether it can be elicited and rated reliably following a brief interview (Clare, 2004*b*). The reliability of findings across studies is also questionable, as there is no consistency between the scales being used. For example, Verhey and colleagues rated awareness of deficits on a four-point scale, ranging from 'absent' to 'intact' (Verhey et al., 1993), whereas Auchus and colleagues chose to classify patients as merely 'unaware' or 'aware' (Auchus et al., 1994). However, Feher and colleagues (1991) conclude that awareness is too complex a phenomenon to be rated as 'present' or 'absent'. For example, they noted some patients had a verbal-behavioural dissociation, whereby they denied having problems yet were observed to avoid certain tasks and accept help from carers unquestioningly (Feher et al., 1991), as identified within primary anosognosia (Morris & Hannesdottir, 2004).

The reliability of self-reported information from the patient may also be limited. It is possible that some patients may be aware of their limitations, yet afraid to admit them for fear of being prevented from driving, for example (Sohlberg & Mateer, 2001). Indeed, Allen and Ruff (1990) concluded that the accuracy of self-report information depends on three factors: (a) Awareness - recognition of existing difficulties; (b) Appraisal - the ability to compare the existing self with the pre-morbid self; and (c) Disclosure - the willingness to report self-perceptions accurately. The possibility that patients may be consciously denying their problems also has to be considered (Feher et al., 1991; Weinstein, 1991). These factors highlight the difficulties for clinicians in rating their patient's level of awareness.

Patient-Carer Discrepancy

The central assumption of this assessment method is that the carer will provide an accurate appraisal that can then be used as a benchmark against which to assess the awareness deficits of the patient (Clare, 2004*b*; Morris & Hannesdottir, 2004; Sohlberg & Mateer, 2001). Benefits to this type of assessment include the fact that it does not rely solely on patient self-report. Judgements are also made by a carer who presumably has good knowledge and experience of how the patient functions in daily life. They may, therefore, be in a position to provide more useful information than a clinician could obtain from a brief interview. There is also support for patient-carer discrepancy, with studies showing that patients typically provide higher estimations of their abilities than carers (Clare, 2004*b*; Kotler-Cope & Camp, 1995; Mangone et al., 1991).

However, a major assumption of this method is that carers always provide an accurate and reliable rating, so any discrepancy can be assumed to be due to the patient's impaired awareness (Clare, 2004*b*). It may not be possible, however, to distinguish accurately between the patient-report of deficit, which may be an underestimation, and carer-report, which may be affected by other factors (Trosset & Kaszniak, 1996).

Indeed, several studies have acknowledged the subjectivity and variability of carer ratings. For example, carers suffering from depression or high levels of carer burden may overestimate their relative's difficulties (Dalla Barba et al., 1995; Kotler-Cope & Camp, 1995; Mangone et al., 1991). In contrast, families may choose to underestimate or deny the difficulties of the patient, with a false optimism that they will recover (Fleming, Strong, & Ashton, 1996; Paton, Johnston, Katona, & Livingston, 2004). Other factors such as motivation, personality or relationship with the patient can also affect carers' ratings (Clare, 2004*b*; Dalla Barba et al.,1995).

In addition, to date, there is no standardised questionnaire that is routinely used to measure awareness, reflecting the complexity and controversy surrounding this psychological construct. Questionnaires vary between studies and also in the functions they measure. The focus can be on memory (Feher, Larabee, Sudilovsky, & Crook, 1994; Michon et al., 1994), activities of daily living (Giovannetti, Libon, & Hart, 2002; Mangone et al., 1991), or several cognitive and behavioural functions (Kotler-Cope & Camp, 1995). Although some report good reliability (e.g. Feher et al., 1991), many studies do not report the reliability and validity of the assessment tools chosen to measure awareness (e.g. Giovannetti et al., 2002; Kotler-Cope & Camp, 1995; Mangone et al., 1991). This suggests that findings cannot reliably be generalised.

Patient-Performance Discrepancy

An alternative discrepancy measure involves the assessment of patients' predictions of their performance on a task, compared with their actual task performance. This allows subjective and more objective information to be compared. For example, several studies found evidence showing that AD and TBI patients often overestimate their predicted performance on cognitive tasks. This indicates reduced awareness of their capabilities (Allen & Ruff, 1990; Anderson & Tranel, 1989; McGlynn & Kaszniak, 1991), providing task instructions are understood. Nevertheless, observing a patient's actual task performance may be more informative than the subjective opinions of patients and carers.

One problem with this approach, however, is that the tasks patients are asked to carry out in the clinical situation will be unfamiliar, and possibly quite different to the everyday tasks carried out at home. This means that patients may not be rating the same abilities on the self-report measure as are being assessed using neuropsychological tests. This clearly limits the extent to which any discrepancies can be reliably interpreted (Toglia & Kirk, 2000; Trosset & Kaszniak, 1996). The extent to which patients may compensate for difficulties at home also remains unknown, and it is possible that those who have become used to relying on their carers may have no clear idea of how impaired their abilities really are.

One way of overcoming this problem is by the use of 'postdictions' rather than predictions. This involves patients being exposed to the task and then estimating how well they think they have done. This means that they have an idea about the task and how they performed, and may thus be in a better position to 'self-monitor' their own performance (Correa et al., 1996).

Studies focussing on postdictions have found that AD patients still over-predict their performance on tasks (Correa et al., 1996; Duke, Seltzer, Seltzer, & Vasterling, 2002; Souchay, Isingrini, Pillon, & Gil, 2003). However, those using both predictions and postdictions have found a reduction in overestimation of performance after carrying out the task compared with before (Ansell & Bucks, submitted; Duke et al., 2002; Moulin, Perfect, & Jones, 2000). These findings indicate some intact monitoring skills, and the importance of measuring on-line awareness. It is also possible that, whereas predictions may access participants' beliefs regarding their abilities, postdictions reflect actual self-monitoring of a task (Correa et al., 1996; Souchay et al., 2003). The extent to which findings can be generalised to patients' abilities to cope and compensate within an everyday context, however, remains unknown.

Combination Methods

Some studies have attempted to combine assessment methods in order to obtain convergent information about a patient's awareness. For example, patient-carer discrepancy scores may be examined in conjunction with the difference between patient's predicted and actual performance (Clare, 2004*b*; McGlynn & Kaszniak, 1991).

A study by Arkin and Mahendra (2001) used three patient response measures to assess awareness: The Geriatric Depression Scale (GDS), alongside open questions and sentence completion tasks relating to AD effects and impact on life. Interestingly, the use of multiple assessments resulted in patients demonstrating higher levels of insight, perhaps through providing them with different ways of expressing their awareness (Arkin & Mahendra, 2001). There were no associations, however, between level of insight and mental status as measured by the Mini-Mental State Examination (MMSE), and no evidence to suggest that insight decreased with time or disease progression. It is also notable that the three awareness measures did not inter-correlate (Arkin & Mahendra, 2001). This suggests they were tapping into different aspects of awareness, or were not reliably measuring awareness at all.

Derouesne and colleagues (1999) obtained similar findings using a combination of assessment measures: patient-carer discrepancy, clinician assessment and a carer rating of awareness in everyday life. Like Arkin and Mahendra (2001), they found no associations between the measures used. The varying responses of individuals to different measures (e.g. scoring highly on one measure but not at all on the others), also led them to conclude that the presence and severity of unawareness varied according to the assessment method (Derouesne et al., 1999), thus, emphasising the need for a more objective and reliable measure.

Error Awareness

A relatively new method for assessing awareness involves the evaluation of error awareness. This derived from the recognition that self-monitoring, or on-line awareness, is important for the estimation of one's capabilities (Fernandez-Duque et al., 2000). A study by Correa and colleagues (1996) used postdictions, but also examined the number of intrusion errors and self-corrections made on a selection of memory tasks. The basic assumption is that error-correction represents actual recognition or awareness of having made an error. Findings showed diminished awareness for AD patients, as measured by increased errors, reduced error correction rate compared with older adult controls, and greater postdiction inaccuracy. The authors concluded that intact self-monitoring abilities are required in order to update knowledge of current functioning level (Correa et al., 1996). Therefore, findings could be interpreted as indicating impaired on-line, or error awareness, at the executive function level.

Giovannetti, Hart and colleagues have expanded upon this approach by exploring awareness of errors in naturalistic action (Giovannetti et al., 2002; Hart et al., 1998). This allows assessment of patients' execution, monitoring and evaluation of a task, without depending upon carer opinions or the expressive language skills of AD patients (Giovannetti et al., 2002). The use of naturalistic action tasks (e.g. making toast, wrapping presents) also increases validity by measuring awareness on tasks carried out each day, rather than on neuropsychological batteries that are unknown and less relevant to everyday life.

The authors based their research upon the idea that there is a 'closed-loop feedback mechanism' for error detection and awareness, whereby the external environment is continually compared with an internal representation of what is intended (Giovannetti et al., 2002; Norman, 1981). These processes are mediated by executive functions, which focus attention and the comparison of action with intention. This may be similar to the 'modelling' process described by Stuss and colleagues (2001), where internal representations caused by patterns of neuronal activity are constantly being compared with incoming information (Stuss et al., 2001).

Lack of awareness of errors could occur for three reasons: Firstly, if greater cognitive effort is required to carry out tasks due to neurological injury or disease, unawareness could occur as a result of too few cognitive resources to monitor effectively; secondly, there may be a specific impairment in attention or executive function, or; thirdly, an executive function problem could result in difficulty keeping clear representations of action and intention in working memory so errors are not recognised, or problems comparing action with intention may arise (Giovannetti et al., 2002; Hart et al., 1998). The importance of intact executive functioning (Level 2 of Stuss and Benson's model) in order to retain intact on-line awareness of errors (Level 3) is therefore highlighted.

Hart and colleagues (1998) explored patients' awareness of making naturalistic errors following TBI, comparing their behavioural awareness of errors (captured on video), the number of errors corrected, and their self-ratings of performance. Findings showed that TBI patients both detected and corrected fewer errors than controls yet rated themselves as equally competent at the cognitive demands of the tasks (e.g. planning, choosing correctly). They did, however, rate themselves as less competent at coping with the physical demands of the tasks (e.g.

picking up objects). The authors concluded that TBI patients often show greater acknowledgement of physical than cognitive difficulties, as has also been shown in other studies (Anderson & Tranel, 1989). The extent to which denial was involved remains unexplored.

Giovannetti and colleagues (2002) carried out similar research in AD. However, in order to explore whether reduced cognitive resources or executive dysfunction contributed to lack of awareness, they also assessed participants with the MMSE and a neuropsychological test battery including measures of executive function.

Findings showed that AD patients detected and corrected fewer errors than controls. Fewer omission errors (actions wrongly omitted) were detected and corrected compared with commission errors (e.g. perseveration). This supports the closed-loop error monitoring theory, whereby omission errors are less likely to be detected because they result from a failure in correctly activating the necessary internal representation for an intended action (Giovannetti et al., 2002). Interestingly, there were no significant associations between error measures and cognitive function as measured by the MMSE, indicating that reduced cognitive resources did not contribute to patients' lack of awareness. Equally, no significant correlations were found between neuropsychological functions and error measures.

One possibility, therefore, is that on-line error awareness problems are caused by a failure in working memory, so that the patient is unable to maintain clear representations of action and intention and recognise when a mismatch occurs. It is also possible that the neuropsychological tests did not access the specific cognitive mechanisms responsible for error detection and correction, and direct assessment of these is required to gain a more complete understanding of monitoring and awareness (Giovannetti et al., 2002).

These findings are promising for the use of error awareness and monitoring to increase understanding of awareness and the cognitive mechanisms underlying it. As well as providing the means to assess awareness whilst carrying out everyday tasks, patients' ability to compensate is also examined by assessing their self-corrections. By videotaping assessments, behavioural signs of awareness can also be captured, rather than relying upon self-report or the opinions of others. Assessment of error awareness may therefore be a more reliable and objective means of measuring awareness at the executive or on-line level.

Research exploring human errors (Reason, 1990) has identified two specific error types: slips and mistakes. Slips are the result of an execution failure, where there is a mismatch between action and intention. In contrast, mistakes occur due to a failure in planning, when the intention is not appropriate for achieving the desired outcome. In this respect, mistakes are much harder to identify (Reason, 1990). While observing patients' awareness of making errors while carrying out naturalistic tasks may be a more objective means of assessing on-line awareness, this method still relies on the ability of researchers to detect when a patient senses they have made a mistake. Slips, however, are simpler to detect, and can be elicited with ease during fast-choice-response tasks. Exploring patients' ability to detect when action does not match intention therefore provides an objective and efficient means of assessing on-line awareness. A new and exciting technique being used to study this type of error awareness, which is receiving increasing research interest, is the use of event-related potential (ERP) techniques. This will be discussed in more detail later.

Summary

A review of current methods assessing awareness has identified many problems. The difficulties caused by relying on self-report have been discussed, including the many factors that can influence what a patient chooses to confide to a clinician, and the subjective value of relying upon carers' opinions. The importance of assessing on-line monitoring as a means of accessing awareness has also been emphasised, as well as the limitations of neuropsychological tasks. These may not bear much resemblance to the everyday tasks that patients face, and may also fail to elicit behavioural adjustment in response to making an error. The benefits of examining error awareness can therefore be seen, as a means of assessing both awareness of errors, and patients' ability to compensate.

There are still problems, however, with the scientific nature of this method. For example, some patients may be more likely to demonstrate overt behaviours in response to errors due to extravert personality traits, thus making it easier to assess them. Others, perhaps those depressed, may be less motivated to correct their errors and thus wrongly assessed as less aware. Denial also remains a problem, with no objective method yet developed to identify to what extent it can be separated from anosognosia.

It is also possible that the naturalistic tasks being used (e.g. making toast), while familiar, and arguably more valid than neuropsychological testing, are also simpler and more automated. It could be that patients make fewer errors on these tasks, or may correct them more automatically. The level of awareness being assessed is thus unclear, but is likely to differ from a more complex level of on-line awareness required for driving a car, for example, or in a novel situation.

While the study of error processing is a promising basis from which to measure awareness, the behavioural assessment of naturalistic errors is not a reliable enough means alone, given the other confounding problems. What is required is a measure that can differentiate between awareness and factors that may influence the appearance of awareness, such as denial. In other words, it should be related to fast processing, so individuals do not have time to let conscious thoughts, such as those relating to denial, interfere with the measure. One such approach is to elicit brain waves associated with error responses (slips) and with behavioural adjustments following the error. These adjustments can occur in the form of immediate self-correction, or a more general post-error slowing (Coles, Scheffers, & Holroyd, 2001). In the last decade this approach has received increasing interest in the neuroscience literature, but is yet to impact on studies of awareness.

The Electroencephalogram (EEG)

The electroencephalogram, or EEG, is derived from spontaneous electrical activity occurring in the brain (Gale, 1987). These 'brain waves' can be measured through the use of electrodes placed on the scalp, which record activity in microvolt units (μV). EEG trace frequencies (e.g. alpha, beta) have been associated with cognitive activity such as perception and attention, as well as other factors such as sleep, intelligence, personality and psychiatric illness (Andreassi, 1995; Gale, 1987). In this way, it provides an objective measure of neural activity.

Event-Related Potentials (ERP)

In order to establish the pattern of neural activity associated with a specific event, EEG activity is typically divided into time-chunks (epochs) centred round an event such as presentation of a picture, or a button press. These stimulus or response-locked epochs are then averaged according to type (e.g. same tone, correct responses) to elicit an ERP component. Averaging across a number of trials is necessary to bring out the ERP component from the larger-amplitude background activity. Thus, averaging enables a focus on the effects of the specific stimulus or event, over and above ongoing EEG activity (Andreassi, 1995; Falkenstein, 2004).

Positive and negative deflections are derived from the orientation of excitatory and inhibitory post-synaptic potentials in relation to the scalp, and are labelled with a 'P' or 'N' depending upon whether they have positive or negative polarity. They also have a number to indicate their onset time in milliseconds (ms) following a stimulus (Kramer, 1987). Thus, P300 represents a positive component occurring maximally at approximately 300 ms. ERPs can be used to explore how specific brain processes relate to both external events, such as a noise with a picture, and psychological states such as 'recognition'. By placing multiple electrodes upon the scalp, ERPs occurring in response to stimuli can be examined at different scalp locations, and the underlying brain structures responsible for producing the ERP signals can be inferred (Andreassi, 1995). However, it is important to emphasise that, even with large electrode montages covering most of the scalp, this technique has limited spatial resolution.

Stimulus-Locked Potentials: The P300

The P300, or P3, is an ERP component maximal over the parietal lobe that is locked to the presentation of the stimulus rather than the participant's response: this component is perhaps the most widely researched ERP component, and its function is relatively well understood. As its name indicates, the P300 is a positive component that occurs approximately 300 ms following the stimulus presentation, although it can occur at any time between 300-900 ms (Andreassi, 1995; Nelson & Monk, 2001) depending on the participant's age and the integrity of the brain. The P300 is concerned with perception, and has been associated with many cognitive processes including attention, working memory, probability and stimulus processing (Andreass, 1995; Loveless, 1983; Roche et al., 2004).

The P300 probably represents a re-focussing of attention towards a stimulus, in particular a target stimulus that the participant has been told to respond to (Kramer, 1987). Subjectively, this may be experienced as a 'there it is' sensation. The amplitude of the P300 has also been shown to be affected by probability; the higher the probability of the expected target, the lower the P300 amplitude (Bekker, Kenemans, & Verbaten, 2004; Roche et al., 2004). This suggests that the P300 represents a context updating process, responsible for maintaining a mental representation of the target in working memory (Nelson & Monk, 2001). Incoming sensory stimuli are compared with an internal representation of what is expected, and this is updated until the correct representation is achieved. In this way, the P300 reflects conflict between what is expected and the sensory input observed (Bekker et al., 2004; Loveless, 1983).

In summary, the P300 may represent a number of cognitive functions associated with the perception and processing of sensory input. In this respect, it may reflect the more posterior sensory activity linked to Stuss and Benson's (1986) first level of frontal lobe function. This first level receives and organises sensory information, and is then responsible for informing the next level up, executive function, when a stimulus is not as expected so a different output or action may be required. By being responsible for context updating, the P300 also appears to reflect the modelling process described by Stuss and colleagues (2001), when an internal representation of incoming stimuli is updated until a match is obtained (Stuss et al., 2001).

Response-Locked Potentials: I. The Error-Related Negativity (ERN)

Other ERP components include those associated with the response rather than the stimulus. The error-related negativity (ERN) is a fronto-central response-locked negative component that occurs approximately 80 ms after an erroneous response (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Falkenstein, Hoorman, & Hohnsbein, 2001). Originally labelled the 'Ne' (Falkenstein, Hohnsbein, Hoorman, & Blanke, 1991), it has become more widely known as the ERN (Gehring et al., 1993), and reflects the brain's 'error detection system' (Dehaene, Posner, & Tucker, 1994; Gehring et al., 1993). Source localisation techniques, and converging evidence from fMRI, suggest that the neural generators of the ERN include the anterior cingulate cortex (ACC), part of the brain's limbic system (Dehaene et al., 1994; Falkenstein, 2003; Gehring et al., 1993; Holroyd & Coles, 2002; Nieuwenhuis, Ridderinkhof, & Talsma, 2002). The ACC is located in the medial frontal lobes.

The ERN is generated following 'slips', when the correct answer is known but not carried out, rather than 'mistakes', where the correct answer is not known (Mathalon et al., 2003; Reason, 1990). ERN amplitude varies according to the perceived inaccuracy of the error, regardless of actual accuracy, with greater perceived inaccuracy resulting in generation of a larger ERN (Mathalon et al., 2003; Scheffers & Coles, 2000). This may reflect the ease with which the error is identified.

When the importance of accuracy is emphasised, there is also an increased ERN (Dehaene et al., 1994; Gehring et al., 1993), suggesting that the size of the ERN reflects how much the error matters to the individual. Thus, the ERN may also reflect motivation and the affective processing involved in the on-line monitoring of performance. Supporting evidence for this has been found in studies exploring the impact of unexpected loss on the ERN; in other words, when the experiment is manipulated such that monetary loss or unexpected lack of reward occurs. Participants who received feedback that their error had resulted in monetary loss showed the largest ERNs (Gehring & Willoughby, 2002; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003).

As part of the limbic system, the ACC is ideally connected to contribute not only to the recognition of an error, but also to its emotional significance. In this way, it may help guide future decision-making through performance monitoring (Gehring & Willoughby, 2002), and behavioural adjustments following an error facilitated via reciprocal pathways with the PFC (Kerns et al., 2004). The emotional significance may be processed concurrently through ACC connections with the orbital frontal cortex (Barbas, 2000). This is consistent with the Somatic Marker Hypothesis and the key role that emotion has to play in awareness and decision-making (Damasio, 1994).

Our understanding of the function of the ERN has been called into question by more recent evidence describing an ERP component associated with correct trials. A smaller negative ERN-like deflection occurs for correct trials: the CRN, or correct response negativity (Allain, Hasbroucq, Burle, Grapperon, & Vidal, 2004; Coles et al., 2001; Falkenstein, 2004). This indicates that the ERN may have a broader role than error detection alone. For example, although smaller than the ERN in healthy individuals, the CRN has been shown to be just as large on correct trials for patients with a lateral prefrontal injury (Gehring & Knight, 2000). One role of the lateral prefrontal cortex is to maintain an inner representation of the task in hand (Levy & Goldman-Rakic, 2000). It is possible, therefore, that CRN inflation occurs due to response uncertainty (Falkenstein, 2004; Gehring & Knight, 2000; Mathalon et al., 2003).

The fact that ERN onset occurs within approximately 80 ms following an error means that it occurs before any error-related sensory information could have been processed (Dehaene et al., 1994; Gehring et al., 1993), thus making it unlikely that this component reflects conscious error awareness. However, the ERN can also occur following a partial error, such as going to make the wrong response but stopping oneself (Falkenstein, 2004). This suggests preconscious performance monitoring and error detection, rather than awareness that an error has actually occurred. This view was supported by Nieuwenhuis and colleagues (2001), who used an anti-saccade task to examine the relationship between error processing and conscious self-monitoring. Findings showed that an ERN occurred following unperceived as well as perceived errors, indicating that the ERN is more likely to be a preconscious error signal (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001).

There have been two main theories attempting to explain the functional significance of the ERN. These theories are often presented as polar extremes, but have been developed based on different methodologies (response conflict, fMRI and mismatch, ERP) and may not be mutually exclusive.

It has been proposed that the ERN may reflect the increased response conflict that occurs in the ACC when an inappropriate response is activated as well as the correct response, and needs to be overcome. This provides a signal that greater top-down control is required for successful task performance (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Garavan, Ross, Kaufman, & Stein, 2003). This 'conflict hypothesis' was initially proposed by Carter and colleagues (1998). Using fMRI, they found there was more activity in the ACC during incorrect responses, although the area was still activated for correct responses. They concluded that the ERN reflected conditions of high response competition, when there is a greater chance of errors occurring (Carter et al., 1998). Kiehl and colleagues obtained similar findings (Kiehl et al., 2000).

ERP studies, however, have found that the ERN does not correlate with response conflict, and is in fact larger on trials when participants are sure they were wrong, than when there is any doubt (Scheffers & Coles, 2000). It has also been shown that the ERN is smaller on more difficult tasks, which is contrary to what would be predicted by the conflict hypothesis (Falkenstein, 2004).

An alternative explanation of the functional significance of the ERN is the 'mismatch hypothesis'. This states that the ACC monitors performance, and the ERN is generated as the result of a perceived 'mismatch' between the actual response, and an internal representation of what the response should be. In this way, the ACC can be seen to be a 'comparator', comparing action outcome with intent (Falkenstein et al., 1991; Holroyd & Coles, 2002; Scheffers & Coles, 2000). This is consistent with what would be expected from higher executive processes; monitoring performance and indicating when action strays from intent. Findings that the ERN is smaller on harder tasks (Falkenstein, 2004), and absent or disrupted in patients with medial prefrontal damage (Stemmer, Segalowitz, Witzke, & Schonle, 2003) also support this view.

The mismatch theory was extended by Holroyd and Coles (2002). These authors supported the view that the ERN signifies a mismatch between intention and action, but predicted that this is particularly the case when there is more functional significance attached to making errors (Dehaene et al., 1994; Gehring & Willoughby, 2002; Holroyd & Coles, 2002). Their 'reinforcement learning' hypothesis proposed that the ERN occurs not just from a mismatch between action and intention, but between expected outcome and actual outcome. When an error is perceived, this mismatch is detected by the basal ganglia, which send a negative prediction signal to the ACC via the dopamine system, and an ERN results. These error signals 'train' the ACC to improve performance by reinforcement learning (Falkenstein, 2004; Holroyd & Coles, 2002; Holroyd et al., 2003). This theory is supported by findings that the ERN is greater in situations when an unexpected loss occurs as a result of an error (Gehring & Willoughby, 2002; Holroyd et al., 2003). The fact that the ERN has also been shown to be reduced in patients with Parkinson's disease, caused by a disruption in dopamine in the basal ganglia, also adds some weight to the theory (Falkenstein, 2004).

In summary, the ERN appears to reflect an early error detection system, generated by medial frontal lobe structures including the ACC, when there is a mismatch between action and intention and the outcome appears likely to be worse than expected. The importance of the ACC as a structure that monitors performance, but is also responsible for processing associated emotional information, has been discussed. While it appears that the ERN is not a marker of conscious error awareness, it is widely assumed to reflect executive control mechanisms (performance monitoring) of the frontal lobes. In this respect, it may represent functioning at Level 2 of Stuss and Benson's (1986) model, where performance is monitored and adjusted when outcome does not look likely to match intention in fast choice-response tasks requiring high levels of executive control.

Response-Locked Potentials: II. The Error Positivity (Pe)

The Pe is a positive response-locked component of centro-parietal origin that often, but not always, occurs from approximately 300 ms after an error and following the ERN (Falkenstein, Hoorman, Christ & Hohnsbein, 2000). It has not received as much attention as the ERN, and its functional significance remains unclear, but there is some evidence to suggest that it reflects more conscious awareness of having made an error.

Whereas the ERN can occur following a partial error, the Pe is error-specific and is only elicited after a full error is made (Falkenstein, 2004; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000). This supports the assumption that full conscious awareness of the error has occurred. Consistent with this, in the anti-saccade task used by Nieuwenhuis and colleagues (2001), the Pe was much more pronounced for perceived errors than unperceived errors, judged according to participants' self-reported perceptions of having made an error or not after each trial. In addition, perceived errors were followed by considerable post-error slowing, compared with non-perceived errors, where post-error slowing was not observed. Thus, these authors concluded that the Pe represents conscious error recognition (Nieuwenhuis et al., 2001).

Importantly, not all research has been so conclusive. Falkenstein and colleagues (2000) found that, while the Pe was reduced in older participants, they still showed post-error slowing on the first correct trial after an error. Assuming that post-error slowing is a process requiring conscious error recognition, this argues against the Pe as an indicator of conscious error processing (Falkenstein et al., 2000). A study by Band and Kok (2000) obtained similar findings. However, it could also be argued that post-error slowing is an automatic process occurring in response to a general feeling that performance is not as good as intended, rather than a swift reaction in response to awareness of specific errors. There has also been relatively little research examining the Pe in older adults, and other studies have found no significant Pe reduction with age (Falkenstein, 2004; Mathalon et al., 2003). Thus, the conscious error processing theory requires further investigation.

Another possibility is that the Pe reflects the emotional significance of an error (Falkenstein, 2004), suggesting that it may be affected by loss and reward in the same way as the ERN, although this has yet to be explored. This hypothesis is supported by evidence showing that a higher error rate is associated with a reduced Pe. This could be expected if a participant making many errors, or guessing, is less likely to attach emotional significance to error responses (Falkenstein et al., 2000). If the ACC, as part of the limbic system, generates the Pe as well as the ERN, as has been proposed by van Veen and Carter (2002), this would also lend support to this hypothesis. Few studies actually present the results of an ERN-Pe correlation, although Falkenstein et al. (2000) found that the ERN and Pe were differentially variable. In general, it may only be summarised that findings remain inconclusive.

Further research is required to explore the functional significance of the Pe, and its relation to both error processing and the emotional significance of making an error. One possibility is that the Pe reflects the highest level of brain function within Stuss and Benson's (1986) model, self-awareness, or more specifically, on-line awareness at the level of executive function (Level 3 of Stuss and colleagues' (2001) model). More work exploring how the Pe may be affected by normal ageing is also required.

Conclusions

A lack of awareness is a complex phenomenon that can manifest itself at different levels, but in most cases detrimentally affects the lives of sufferers and those who care for them. There is evidence to suggest that awareness is supported predominantly by the frontal lobes, as proposed in Stuss and Benson's (1986) early model of frontal lobe function. This model identified levels that could be empirically investigated individually, but may perhaps facilitate awareness only when functioning concertedly. Stuss and colleagues' (2001) more recent model demonstrated how awareness could be implicated at each level, and by inference, the different ways in which awareness can become disrupted (Stuss et al., 2001). This model demonstrates the key role that executive function has to play in maintaining a stable and coherent model of the world at one level: on-line awareness. Equally, at the highest and most abstract level, reflective self-awareness, memories of past and future events are combined with their associated emotional significance to facilitate autonoetic consciousness, the most personal level of awareness. In this way, the importance of the frontal lobes and their reciprocal links with the limbic system in supporting awareness are emphasised (Wheeler et al., 1997).

The complexity and abstract nature of awareness as a phenomenon has been highlighted. This means that the concept of awareness does not lend itself easily to the development of a reliable and objective means of assessment. Despite this, a number of methodological approaches to the study of awareness have been attempted, and the strengths and limitations associated with each have been discussed. Perhaps the greatest challenge is in overcoming the subjectivity associated with relying on carers and self-report, and the variable reliability of questionnaires. Psychogenic factors such as denial also remain unaccounted for, as there is not yet a reliable method for separating denial from organic unawareness. It is also likely that the highest levels of metacognitive self-awareness, specific to each individual, remain too abstract and intangible to be assessed formally and objectively at present. Assessment of on-line performance monitoring skills, however, has been identified as one means of examining awareness at the executive function level. The measurement of error awareness using naturalistic tasks also allows for a more valid and objective means of assessment, as well as providing patients with the opportunity to correct mistakes and demonstrate awareness through compensation for deficits where possible.

The potential benefits of using ERP techniques to investigate awareness and the neural structures underpinning this phenomenon were introduced. This technique may help provide a more objective and reliable means of measuring awareness related to error processing (slips), using fast-choice-reaction tasks. Review of the ERP literature has found the ACC to be the most likely neural generator of two error-related components: the ERN and the Pe (Gehring et al., 1993; van Veen & Carter, 2002). The ERN has been shown to reflect not just error detection, but also the significance of making an error when outcome looks to be worse than expected (Gehring & Willoughby, 2002; Holroy & Coles, 2002). In this way, it is possible that the ERN reflects performance monitoring at the level of executive function. The Pe, however, has been proposed to reflect a more conscious level of error processing (Nieuwenhuis et al., 2001), perhaps even the emotional significance of failure (Falkenstein, 2004), although more research is required to explore this.

One possibility is that the ERN reflects performance monitoring at the executive function level of Stuss and Benson's (1986) model, while the Pe reflects a more conscious, metacognitive awareness of on-line performance (Stuss and Benson's highest level). Further research is required to indicate the usefulness of this hypothesis, although it has been proposed that cognitive and emotional control are integral to both executive control and metacognition, for example, in planning and carrying out a task against competing options (Fernandez-Duque et al., 2000).

In summary, it is possible that ERP techniques may provide a more reliable and scientific means of assessing awareness, through examining the impact of making errors upon the ERN and the Pe. The information derived from ERP studies could serve to increase our understanding of the processes underlying error awareness, and is therefore worthy of further research interest.

Future Research

A main body of awareness research has focussed on patients with AD and TBI, as disrupted awareness is a common consequence of both these conditions. Research with these two client groups has shown that awareness problems occur as a result of frontal pathology (McGlynn & Schachter, 1989; Stuss, 1991). However, in order to further our understanding of awareness, it would be useful to extend research into other areas.

Schizophrenia is a psychiatric condition characterised by disrupted awareness, causing patients to suffer hallucinations and delusions. The issue of how and why consciousness becomes affected in schizophrenic patients is clearly of research interest. Findings have shown that executive function and self-monitoring are often impaired in schizophrenia, once again implicating the frontal lobe (Antonova, Sharma, Morris, & Kumari, 2004; Kircher & Leube, 2003). It has also been suggested that delusional states could be caused by executive dysfunction, such that patients are unable to integrate experience with mental models to create a stable and coherent mental model of present state (Stuss et al., 2001). Other research has found schizophrenia to be associated with impaired autonoetic consciousness (Sonntag et al., 2003). This indicates disruption at the level of cognitive and emotional processing, moreover, the ACC has been implicated as an important structure affected by schizophrenia (Tamminga, Vogel, Gao, Lahti, & Holcomb, 2000). The possibility of using ERP techniques to assess awareness with this client group would therefore be of interest.

Much research has focussed on AD as a disorder commonly resulting in impaired awareness. However, before exploring how awareness changes with neuropathology in older age, it is first important to explore in what way awareness could be affected by the normal ageing process. It has been proposed that the frontal lobe is selectively impaired by normal ageing (Kramer, Hahn, & Gopher, 1999; West, 1996). Although the 'frontal lobe hypothesis' remains a contentious issue, there is much research to indicate that the frontal lobe is subject to neuronal atrophy, and frontal lobe functions, such as executive control, are less efficient in older age (Groth & Allen, 2000; Raz, 2000; Verhaeghen & Cerella, 2002). Awareness research with older adults has mainly focussed upon awareness of one's own memory function, or metamemory. However, this research is confounded by the assessment difficulties already discussed, such as the unreliability of questionnaires and self-report, and the impact of denial, depression and negative beliefs upon such measures. In order to assess fully how awareness changes with age and is further affected by the pathology of AD, it would be of benefit to explore to what extent ERP techniques can aid our understanding of awareness in normal ageing.

In summary, our current understanding of awareness has been informed by examining how awareness is affected by frontal lobe pathologies such as AD and TBI. Existing measures do not allow for assessment of organic unawareness to be as objective, valid and reliable as is required, given that clinicians use these measures to make important decisions affecting the lives of their patients. It is therefore possible that our knowledge and assessment of awareness can be improved through the use of ERP techniques and research exploring error awareness. Clearly, this possibility requires investigation.

References

Agnew, S.K. & Morris, R.G. (1998). The Heterogeneity of Anosognosia for Memory Impairment in Alzheimer's Disease: A Review of the Literature and a Proposed Model. *Aging and Mental Health, 2(1),* 7-19.

Allain, S., Hasbroucq, T., Burle, B. Grapperon, J. & Vidal, F. (2004). Response Monitoring Without Sensory Feedback. *Clinical Neurophysiology, 115(9),* 2014-2030.

Allen, C.C. & Ruff, R.M. (1990). Self-Rating versus Neuropsychological Performance of Moderate versus Severe Head-Injured Patients. *Brain Injury, 4(1),* 7-17.

Anderson, S.W. & Tranel, D. (1989). Awareness of Disease States Following Cerebral Infarction, Dementia and Head Trauma: Standardized Assessment. *The Clinical Neuropsychologist, 3(4),* 327-339.

Andreassi, J.L. (1995). *Psychophysiology: Human Behaviour and Physiological Response* (3rd ed.). Lawrence Erlbaum Associates, Inc.

Ansell, E.L. & Bucks, R.S. (submitted). Mnemonic Anosognosia in Alzheimer's Disease: A Test of Agnew & Morris (1998).

Antonova, E., Sharma, T., Morris, R. & Kumari, V. (2004). The Relationship Between Brain Structure and Neurocognition in Schizophrenia: A Selective Review. *Schizophrenia Research, 70,* 117-145.

Arkin, S. & Mahendra, N. (2001). Insight in Alzheimer's Patients: Results of a Longitudinal Study Using Three Assessment Methods. *American Journal of Alzheimer's Disease and Other Dementias, 16(4),* 211-224.

Aron, A.R., Robbins, T.W. & Poldrack, R.A. (2004). Inhibition and the Right Inferior Frontal Cortex. *Trends in Cognitive Sciences, 8(4),* 170-177.

Auchus, A.P., Goldstein, F.C., Green, J. & Green, R.C. (1994). Unawareness of Cognitive Impairments in Alzheimer's Disease. *Neuropsychiatry, Neuropsychology and Behavioral Neurology, 7(1),* 25-29.

Band, G.P.H. & Kok, A. (2000). Age Effects on Response Monitoring in a Mental Rotation Task. *Biological Psychology, 51,* 201-221.

Barbas, H. (2000). Connections Underlying the Synthesis of Cognition, Memory and Emotion in Primate Prefrontal Cortices. *Brain Research Bulletin, 52(5),* 319-330.

Bekker, E.M., Kenemans, J.L. & Verbaten, M.N. (2004). Electrophysiological Correlates of Attention, Inhibition, Sensitivity and Bias in a Continuous Performance Task. *Clinical Neurophysiology, 115(9),* 2001-2013.

Bellgrove, M.A., Hester, R. & Garavan, H. (2004). The Functional Neuroanatomical Correlates of Response Variability: Evidence from a Response Inhibition Task. *Neuropsychologia, 42(14),* 1910-1916.

Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S. & Cohen, J.D. (2001). Conflict Monitoring and Cognitive Control. *Psychological Review, 108(3),* 624-652.

Bush, G., Luu, P. & Posner, M.I. (2000). Cognitive and Emotional Influences in Anterior Cingulate Cortex. *Trends in Cognitive Sciences, 4(6),* 215-222.

Carter, C.S., Braver, T.S., Barch, D.M., Botvinick, M.M., Noll, D. & Cohen, J.D. (1998). Anterior Cingulate Cortex, Error Detection and the Online Monitoring of Performance. *Science, 280,* 747-749.

Clare, L. (2003). Managing Threats to Self: Awareness in Early Stage Alzheimer's Disease. *Social Science and Medicine, 57,* 1017-1029.

Clare, L. (2004*a*). The Construction of Awareness in Early-Stage Alzheimer's Disease: A Review of Concepts and Models. *British Journal of Clinical Psychology, 43,* 115-175.

Clare, L. (2004*b*). Awareness in Early-Stage Alzheimer's Disease: A Review of Methods and Evidence. *British Journal of Clinical Psychology, 43,* 177-196.

Clare, L., Wilson, B.A., Carter, G., Roth, I. & Hodges, J.R. (2002). Assessing Awareness in Early-Stage Alzheimer's Disease: Development and Piloting of the Memory Awareness Rating Scale. *Neuropsychological Rehabilitation, 12(4),* 341-362.

Coles, M.G.H., Scheffers, M.K. & Holroyd, C.B. (2001). Why is there an ERN/Ne on Correct Trials? Response Representations, Stimulus-Related Components and the Theory of Error-Processing. *Biological Psychology, 56,* 173-189.

Correa, D.D., Graves, R.E. & Costa, L. (1996). Awareness of Memory Deficit in Alzheimer's Disease Patients and Memory-Impaired Older Adults. *Aging, Neuropsychology and Cognition, 3(3),* 215-228.

Crosson, B., Barco, P.P., Velozo, C.A., Bolesta, M.M., Cooper, P.V., Werts, D. et al., (1989). Awareness and Compensation in Post-acute Head Injury Rehabilitation. *Journal of Head Trauma and Rehabilitation, 4(3),* 46-54.

Dalla Barba, G., Parlato, V., Iavarones, A. & Boller, F. (1995). Anosognosia, Intrusions and 'Frontal' Functions in Alzheimer's Disease and Depression. *Neuropsychologia, 33(2),* 247-259.

Damasio, A.R. (1994). *Descartes' Error: Emotion, Reason and the Human Brain.* G.P. Putnam's Sons, New York.

Dehaene, S. & Naccache, L. (2001). Towards a Cognitive Neuroscience of Consciousness: Basic Evidence and a Workspace Framework. *Cognition, 79,* 1-37.

Dehaene, S., Posner, M.I. & Tucker, D.M. (1994). Localization of a Neural System for Error Detection and Compensation. *Psychological Science, 5(5),* 303-305.

Derouesne, C., Thibault, S., Lagha-Pierucci, S., Baudouin-Madec, V., Ancri, D. & Lacomblez, L. (1999). Decreased Awareness of Cognitive Deficits in Patients with Mild Dementia of the Alzheimer Type. *International Journal of Geriatric Psychiatry, 14,* 1019-1030.

Dirette, D. (2002). The Development of Awareness and the Use of Compensatory Strategies for Cognitive Deficits. *Brain Injury, 16(10),* 861-871.

Duke, L.M., Seltzer, B., Seltzer, J.E. & Vasterling, J.J. (2002). Cognitive Components of Deficit Awareness in Alzheimer's Disease. *Neuropsychology, 16(3),* 359-369.

Eslinger, P.J., Grattan, L.M. & Geder, L. (1995). Impact of Frontal Lobe Lesions on Rehabilitation and Recovery from Acute Brain Injury. *Neurorehabilitation, 5,* 161-182.

Falkenstein, M. (2004). Electrophysiological Correlates of Performance Monitoring. In: Ullsberger, M. & Falkenstein, M. (Eds.) *Errors, Conflicts and The Brain. Current Opinions on Performance Monitoring* (pp. 5-14). Leipzig: MPI of Cognitive Neuroscience.

Falkenstein, M., Hohnsbein, J., Hoormann, J. & Blanke, L. (1991). Effects of Crossmodal Divided Attention on Late ERP Components. II. Error Processing in Choice Reaction Tasks. *Electroencephalography and Clinical Neurophysiology, 78,* 447-455.

Falkenstein, M., Hoormann, J., Christ, S. & Hohnsbein, J. (2000). ERP Components on Reaction Errors and their Functional Significance. *Biological Psychology, 51,* 87-107.

Falkenstein, M., Hoorman, J. & Hohnsbein, J. (2001). Changes of Error-Related ERPs with Age. *Experimental Brain Research, 138,* 258-262.

Fassbender, C., Murphy, K., Foxe, J.J., Wylie, G.R., Javitt, D.C., Robertson, I.H. et al., (2004). A Topography of Executive Functions and their Interactions Revealed by Functional Magnetic Resonance Imaging. *Cognitive Brain Research, 20,* 132-143.

Feher, E.P., Larrabee, G.J., Sudilovsky, A. & Crook, T.H. (1994). Memory Self-Report in Alzheimer's Disease and in Age-Associated Memory Impairment. *Journal of Geriatric Psychiatry and Neurology, 7,* 58-65.

Feher, E.P., Mahurin, R.K., Inbody, S.B., Crook, T.H. & Pirozzolo, F.J. (1991). Anosognosia in Alzheimer's Disease. *Neuropsychiatry, Neuropsychology and Behavioral Neurology, 4(2),* 136-146.

Feinstein, J.S., Stein, M.B., Castillo, G.N. & Paulus, M.P. (2004). From Sensory Processes to Conscious Perception. *Consciousness and Cognition, 13,* 323-335.

Fernandez-Duque, D., Baird, J.A. & Posner, M.I. (2000). Executive Attention and Metacognitive Regulation. *Consciousness and Cognition, 9,* 288-307.

Fleming, J. & Strong, J. (1995). Self-Awareness of Deficits Following Acquired Brain Injury: Considerations for Rehabilitation. *British Journal of Occupational Therapy, 58(2),* 55-60.

Fleming, J.M., Strong, J. & Ashton, R. (1996). Self-Awareness of Deficits in Adults with Traumatic Brain Injury: How Best to Manage? *Brain Injury, 10(1),* 1-15.

Frith, C. (2002). Attention to Action and Awareness of Other Minds. *Consciousness and Cognition, 11,* 481-487.

Fuster, J.M. (1989). *The Prefrontal Cortex: Anatomy, Physiology and Neuropsychology of the Frontal Lobe* (2nd ed.). Raven Press New York.

Gale, A. (1987). The Electroencephalogram. In: Gale, A & Christie, B. (Eds.), *Psychophysiology and the Electronic Workplace* (pp. 223-237). John Wiley & Sons Ltd.

Garavan, H., Ross, T.J., Kaufman, J. & Stein, E.A. (2003). A Midline Dissociation Between Error-Processing and Response-Conflict Monitoring. *NeuroImage 20,* 1132-1139.

Gehring, W.J. & Knight, R.T. (2000). Prefrontal-Cingulate Interactions in Action Monitoring. *Nature Neuroscience, 3(5),* 516-521.

Gehring, W.J., Goss, B., Coles, M.G.H., Meyer, D.E. & Donchin, E. (1993). A Neural System for Error Detection and Compensation. *Psychological Science, 4(6),* 385-390.

Gehring, W.J. & Willoughby, A.R. (2002). The Medial Frontal Cortex and Rapid Processing of Monetary Gains and Losses. *Science, 295,* 2279-2282.

Giovannetti, T., Libon, D.J. & hart, T. (2002). Awareness of Naturalistic Action Errors in Dementia. *Journal of the International Neuropsychological Society, 8,* 633-644.

Groth, K.E. & Allen, P.A. (2000). Visual Attention and Aging. *Frontiers in Bioscience, 5,* d284-297.

Habib, R., Nyberg, L. & Tulving, E. (2003). Hemispheric Asymmetries of Memory: ` The HERA Model Revisited. *Trends in Cognitive Sciences, 7(6),* 241-245.

Hart, T., Giovannetti, T., Montgomery, M.W. & Schwartz, M.F. (1998). Awareness of Errors in Naturalistic Action after Traumatic Brain Injury. *Journal of Head Trauma and Rehabilitation, 13(5),* 16-28.

Harwood, D.G. & Sultzer, D.L. (2001). "Life is Not Worth Living": Hopelessness in Alzheimer's Disease. *Journal of Geriatric Psychiatry and Neurology, 15,* 38-43.

Harwood, D.G., Sultzer, D.L. & Wheatley, M.V. (2000). Impaired Insight in Alzheimer's Disease: Association with Cognitive Deficits, Psychiatric Symptoms and Behavioral Disturbances. *Neuropsychiatry, Neuropsychology and Behavioral Neurology, 13(2),* 83-88.

Hester, R., Murphy, K. & Garavan, H. (2004). Beyond Common Resources: The Cortical Basis for Resolving Task Interference. *NeuroImage, 23,* 202-212.

Holroyd, C.B. & Coles, M.G.H. (2002). The Neural Basis of Human Error Processing: Reinforcement Learning, Dopamine and the Error-Related Negativity. *Psychological Review, 109(4),* 679-709.

Holroyd, C.B., Nieuwenhuis, S., Yeung, N. & Cohen, J.D. (2003). Errors in Reward Prediction are Reflected in the Event-Related Brain Potential. *Cognitive Neuroscience and Neuropsychology, 14(18),* 2481-2484.

Johnson, S.C., Baxter, L.C., Wilder, L.S., Pipe, J.G., Heiserman, J.E. & Prigatano, G.P. (2002). Neural Correlates of Self-Reflection. *Brain, 125,* 1808-1814.

Kerns, J.G., Cohen, J.D., MacDonald, A.W., Cho, R., Stenger, A.V. & Carter, C.S. (2004). Anterior Cingulate Conflict Monitoring and in Control. *Science, 303,* 1023-1026.

Kiehl, K.A., Liddle, P.F. & Hopfinger, J.B. (2000). Error Processing and the Rostral Anterior Cingulate: An Event-Related fMRI Study. *Psychophysiology, 37,* 216-223.

Kihlstrom, J.F. & Tobias, B.A. (1991). Anosognosia, Consciousness and the Self. In: Prigatano, G.P. & Schachter, D.L. (Eds.) *Awareness of Deficit After Brain Injury* (pp. 198-222). New York, NY: Oxford University Press.

Kircher, T.T.J. & Leube, D.T. (2003). Self-Consciousness, Self-Agency and Schizophrenia. *Consciousness and Cognition, 12,* 656-669.

Kjaer, T.W., Nowak, M. & Lou, H.C. (2002). Reflective Self-Awareness and Conscious States: PET Evidence for a Common Midline Parietofrontal Core. *NeuroImage, 17,* 1080-1086.

Kortte, K.B., Wegener, S.T. & Chwalisz, K. (2003). Anosognosia and Denial: Their Relationship to Coping and Depression in Acquired Brain Injury. *Rehabilitation Psychology, 48(3),* 131-136.

Kotler-Cope, S. & Camp, C.J. (1995). Anosognosia in Alzheimer Disease. *Alzheimer Disease and Associated Disorders, 9(1),* 52-56.

Kramer, A.F. (1987). Event-Related Brain Potentials. In: Gale, A & Christie, B. (Eds), *Psychophysiology and the Electronic Workplace* (pp. 197-222). John Wiley & Sons Ltd.

Kramer, A.F., Hahn, S. & Gopher, D. (1999). Task Co-ordination and Aging: Explorations of Executive Control Processes in the Task Switching Paradigm. *Acta Psychologica, 101,* 339-378.

Levy, R. & Goldman-Rakic, P.S. (2000). Segregation of Working memory Functions within the Dorsolateral Prefrontal Cortex. *Experimental Brain Research, 133,* 23-32.

Lewis, L. (1991). Role of Psychological Factors in Disordered Awareness. In: Prigatano, G.P. & Schachter, D.L. (Eds.) *Awareness of Deficit After Brain Injury* (pp. 223-239). New York, NY: Oxford University Press.

Lopez, O.L., Becker, J.T., Somsak, D., Dew, M.A. & DeKosky, S.T. (1994). Awareness of Cognitive Deficits and Anosognosia in Probable Alzheimer's Disease. *European Neurology, 34,* 277-282.

Loveless, N.E. (1983). Event-Related Brain Potentials and Human Performance. In: Gale, A. & Edwards, J.A. (Eds.), *Physiological Correlates of Human Behaviour, Volume 2: Attention and Performance* (pp. 79-97). Academic Press Inc. (London) Ltd.

Luria, A.R. (1973). The Frontal Lobes and the Regulation of Behaviour. In: Pribam, K.H. & Luria, A.R. (Eds.) *Psychophysiology of the Frontal Lobes* (pp. 3-26). Academic Press Inc.

Mangone, C.A., Hier, D.B., Gorelick, P.B., Ganellan, R.J., Langenberg, P., Boarman, R. et al., (1991). Impaired Insight in Alzheimer's Disease. *Journal of Geriatric Psychiatry and Neurology, 4,* 189-193.

Mathalon, D.H., Bennett, A., Askari, N., Gray, M.E., Rosenbloom, M.J. & Ford, J.M. (2003). Response-Monitoring Dysfunction in Aging and Alzheimer's Disease: An Event-Related Potential Study. *Neurobiology of Aging, 24,* 675-685.

McGlynn, S.M. & Kaszniak, A.W. (1991). When Metacognition Fails: Impaired Awareness of Deficit in Alzheimer's Disease. *Journal of Cognitive Neuroscience, 3(2),* 183-189.

McGlynn, S.M. & Schachter, D.L. (1989). Unawareness of Deficits in Neuropsychological Syndromes. *Journal of Clinical and Experimental Neuropsychology, 11(2),* 143-205.

Michon, A., Deweer, B., Pillon, B., Agid, Y. & Dubois, B. (1994). Relation of Anosognosia to Frontal Lobe Dysfunction in Alzheimer's Disease. *Journal of Neurology, Neurosurgery and Psychiatry, 57,* 805-809.

Morris, R.G. & Hannesdottir, K. (2004). Loss of Awareness in Alzheimer's Disease. In: Morris, R.G. & Becker, J.Y. (eds) *Cognitive Neuropsychology of Alzheimer's Disease* (2nd ed., pp. 275-296). Oxford University Press.

Moulin, C.J.A., Perfect, T.J. & Jones, R.W. (2000). Global Predictions of memory in Alzhimer's Disease: Evidence for Preserved Metamemory Monitoring. Aging, Neuropsychology and Cognition, 7(4), 230-244.

Nelson, C.A. & Monk, C.S. (2001). The Use of Event-Related Potentials in the Study of Cognitive Development. In: Nelson, C.A. & Luciana, M. (Eds.), *Handbook of Developmental Cognitive Neuroscience* (pp. 125-136). Massachusetts Institute of Technology.

Nieuwenhuis, S., Ridderinkhof, R.K., Blom, J., Band, G.P.H. & Kok, A. (2001). Error-related Brain Potentials are Differentially Related to Awareness of Response Errors: Evidence from an Anti-Saccade Task. *Psychophysiology, 38,* 752-760.

Nieuwenhuis, S., Ridderinkhof, R.K. & Talsma, D. (2002). A Computational Account of Altered Error Processing in Older Age: Dopamine and the Error-Related Negativity. *Cognitive, Affective and Behavioral Neuroscience, 2(1),* 19-36.

Norman, D.A. (1981). Categorization of Action Slips. *Psychological Review, 88(1),* 1-15.

Norman, D.A. & Shallice, T. (1986). Attention to Action: Willed and Automated Control of Behaviour. In: Schwartz, G.E. & Shapiro, D. (Eds.), *Consciousness and Self-Regulation* (pp. 1-18). New York: Plenum Press.

Ownsworth, T.L., McFarland, K. & Young, R. (2002). The Investigation of Factors Underlying Deficits in Self-Awareness and Self-Regulation. *Brain Injury, 16(4),* 291-309.

Paradiso, S., Chemerinski, E., Yazici, K.M., Tartaro, A. & Robinson, R.G. (1999). Frontal Lobe Syndrome Reassessed: Comparison of Patients with Lateral or Medial Frontal Brain Damage. *Neurology, Neurosurgery and Psychiatry, 67,* 664-667.

Paton, J., Johnston, K., Katona, C. & Livingston, G. (2004). What Causes Problems in Alzheimer's Disease: Attributions by Caregivers. A Qualitative Study. *International Journal of Geriatric Psychiatry, 19,* 527-532.

Prigatano, G.P. & Schachter, D.L. (1991). Introduction (p.13). In: Prigatano, G.P. & Schachter, D.L. (Eds.) *Awareness of Deficit After Brain Injury* (pp. 3-16). New York, NY: Oxford University Press.

Raz, N. (2000). Aging of the Brain and its Impact on Cognitive Performance: Integration of Structural and Functional Findings. In: Craik, F.I.M. & Salthouse, T.A. (Eds.), *The Handbook of Aging and Cognition* (pp. 1-90). Lawrence Erlbaum Associates.

Reason, J. (1990). *Human Error.* Cambridge University Press.

Reed, B.R., Jagust, W.J. & Coulter, L. (1993). Anosognosia in Alxheimer's Disease: Relationships to Depression, Cognitive Function, and Cerebral Perfusion. *Journal of Clinical and Experiential Neuropsychology, 15(2),* 231-244.

Roche, R.A.P., Dockree, P.M., Garavan, H., Foxe, J.J., Robertson, I.H. & O'Mara, S.M. (2004). *Neuroscience Letters, 362,* 1-5.

Rushworth, M.F., Hadland, K.A., Paus, T. & Sipila, P.K. (2002). Role of the Human Medial Frontal Cortex in Task Switching: A Combined fMRI and TMS Study. *Journal of Neurophysiology, 87(5),* 2577-2592.

Schachter, D.L. (1990). Toward a Cognitive Neuropsychology of Awareness: Implicit Knowledge and Anosognosia. *Journal of Clinical and Experimental Neuropsychology, 12(1),* 155-178.

Scheffers, M.K. & Coles, M.G.H. (2000). Performance Monitoring in a Confusing World: Error-Related Brain Activity, Judgements of Response Accuracy, and Types of Errors. *Journal of Experimental Psychology: Human Perception and Performance, 26(1),* 141-151.

Schmitz, T.W., Kawahara-Baccus, T.N. & Johnson, S.C. (2004). Metacognitive Evaluation, Self-Relevance and the Right Prefrontal Cortex. *NeuroImage, 22,* 941-947.

Schubert, T. & Szameitat, A.J. (2003). Functional Neuroanatomy of Interference in Overlapping Dual Tasks: An fMRI Study. *Cognitive Brain Research, 17,* 733-746.

Shimamura, A.P. (2000). Toward a Cognitive Neuroscience of Metacognition. *Consciousness and Cognition, 9,* 313-323.

Smith, C.A., Henderson, V.W., McCleary, C.A., Murdock, G.A. & Buckwalter, J.G. (2000). Anosognosia and Alzheimer's Disease: The Role of Depressive Symptoms in Mediating Impaired Insight. *Journal of Clinical and Experimental Neuropsychology, 22(4),* 437-444.

Sohlberg, M.M. & Mateer, C.A. (2001). *Cognitive Rehabilitation: An Integrative Neuropsychological Approach.* The Guildford Press, New York, London.

Sonntag, P., Gokalsing, E., Olivier, C., Robert, P., Burglen, F., Kauffman-Muller, F. et al., (2003). Impaired Strategic Regulation of Contents of Conscious Awareness in Schizophrenia. *Consciousness and Cognition, 12(2),* 190-200.

Souchay, C., Isingrini, M., Pillon, B. & Gil, R. (2003). Metamemory Accuracy in Alzheimer's Disease and Frontotemporal Lobe Dementia. *Neurocase, 9(6),* 482-493.

Starkstein, S.E., Fedoroff, P.J., Price, T.R., Leiguarda, R. & Robinson, R.G. (1993). Neuropsychological Deficits in Patients with Anosognosia. *Neuropsychiatry, neuropsychology and Behavioral Neurology, 6(1),* 43-48.

Starkstein, S.E., Vazquez, S., Migliorelli, R., Teson, A., Sabe, L. & Leiguarda, R. (1995). A Single-Photon Emission Computed Tomographic Study of Anosognosia in Alzheimer's Disease. *Archives of Neurology, 52,* 415-420.

Stemmer, B., Segalowitz, S.J., Witke, W. & Schonle, P.W. (2003). Error Detection in Patients with Lesions to the medial Prefrontal Cortex: An ERP Study. *Neuropsychologia, 42,* 118-130.

Stephan, K.M., Thaut, M.H., Wunderlich, G., Schicks, W., Tian, B., Tellmann, L. et al., (2002). Conscious and Subconscious Sensorimotor Synchronization – Prefrontal Cortex and the Influence of Awareness. *NeuroImage, 15,* 345-352.

Stuss, D.T. (1989). Self, Awareness and the Frontal Lobes: A Neuropsychological Perspective. In: Strauss, J. & Goethal, G.R. (Eds.) *The Self: Interdisciplinary Approaches* (pp. 255-278). Springer-Verlag.

Stuss, D.T. (1991). Disturbance of Self-Awareness after Frontal System Damage. In: Prigatano, G.P. & Schachter, D.L. (Eds.) *Awareness of Deficit After Brain Injury* (pp. 63-83). New York, NY: Oxford University Press.

Stuss, D.T. & Alexander, M.P. (2000). Executive Functions and the Frontal Lobes: A Conceptual View. *Psychological Research, 63,* 289-298.

Stuss, D.T. & Benson, F.D. (1986). *The Frontal Lobes.* Raven Press: New York

Stuss, D.T., Picton, T.W. & Alexander, M.P. (2001). Consciousness, Self-Awareness and the Frontal Lobes. In: Salloway, S.P., Malloy, P.F. & Duffy, J.D. (Eds.) *The Frontal Lobes and Neuropsychiatric Illness* (pp. 101-109). Washington, DC: American Psychiatric Publishing Inc.

Tamminga, C.A., Vogel, M., Gao, X., Lahti, A.C. & Holcomb, H.H. (2000). The Limbic Cortex in Schizophrenia: Focus On The Anterior Cingulate. *Brain Research Reviews, 31,* 364-370.

Toglia, J. & Kirk, U. (2000). Understanding Awareness Deficits Following Brain Injury. *NeuroRehabilitation, 15,* 57-70.

Trosset, M.W. & Kaszniak, A.W. (1996). Measures of Deficit Unawareness for Predicted Performance Experiments. *Journal of the International Neuropsychological Society, 2,* 315-322.

Tulving, E. (1983). *Elements of Episodic Memory.* Oxford University Press.

Ullsperger, M. & von Cramon, D.Y. (2001). Subprocesses of Performance Monitoring: A Dissociation of Error Processing and Response Competition Revealed by Event-Related fMRI and ERP's. *NeuroImage, 14,* 1387-1401.

Van Veen, V. & Carter, C.S. (2002). The Timing of Action-Monitoring Processes in the Anterior Cingulate Cortex. *Journal of Cognitive Neuroscience, 14(4),* 593-602.

Verhaeghen, P. & Cerella, J. (2002). Aging, Executive Control and Attention: A Review of Meta-Analyses. *Neuroscience and Behavioral Reviews, 26,* 849-857.

Verhey, F.R.J., Rozendaal, N., Ponds, R.W.H.M. & Jolles, J. (1993). Dementia, Awareness and Depression. *International Journal of Geriatric Psychiatry, 8,* 851-856.

Vidal, F., Hasbroucq, T., Grapperon, J. & Bonnet, M. (2000). Is the 'Error Negativity' Specific to Errors? *Biological Psychology, 51,* 109-128.

Wecker, N.S., Kramer, J.H., Wisniewski, A., Delis, D.C. & Kaplan, E. (2000). Age Effects on Executive Ability. *Neuropsychology, 14(3),* 409-414.

Weinstein, E.A. (1991). Anosognosia and Denial of Illness. In: Prigatano, G.P. & Schachter, D.L. (eds) *Awareness of Deficit After Brain Injury* (pp. 240-257). New York, NY: Oxford University Press.

Weinstein, E.A. & Kahn, R.L. (1955). *Denial of Illness: Symbolic and Physiological Aspects.* Charles C. Thomas, Publisher.

West, R. (1996). An Application of Prefrontal Cortex Function Theory to Cognitive Aging. *Psychological Bulletin, 120(2),* 272-292.

Wheeler, M.A., Stuss, D.T. & Tulving, E. (1997). Toward a Theory of Episodic Memory: The Frontal Lobes and Autonoetic Consciousness. *Psychological Bulletin, 121(3),* 331-354.

Empirical Paper:

An Event-Related Potential and Psychological Study of Error Awareness and Normal Ageing

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Abstract

A lack of awareness is a common consequence of pathologies affecting the frontal lobes, such as Alzheimer's disease (AD) and traumatic brain injury (TBI). However, there is limited understanding of possible changes in awareness across the lifespan, and little consensus as to how awareness can be objectively and reliably measured. The study of two event-related potential components may be particularly informative. The error-related negativity (ERN) and the error positivity (Pe) have been associated with error-detection and post-error awareness processes, respectively. The aims of this study were twofold: Firstly, to compare these components in a sample of healthy older (mean age 75.7 years, $n = 15$) and younger (mean age 21.4 years, $n = 15$) adults; and secondly, to explore the relationship between these components and behaviour (post-error slowing; self-correction), attention (Test of Everyday Attention) and awareness (discrepancy; video evidence of behaviour during the ERP task) measures.

Despite a comparable error-rate, both ERN ($p = .012$) and Pe ($p = .004$) amplitudes were significantly attenuated in older adults, but not to the extent that the error detection system (CRN/ERN difference) was impaired. Older adults demonstrated similar error awareness to younger adults, as assessed by discrepancy. Significant associations were found with measures of behaviour, attention and awareness, particularly in the older adult group. These findings are discussed within the context of normal ageing. The contribution to existing knowledge regarding the functional significance of the ERN/Pe complex is also highlighted. Finally, implications for future research are considered.

An Event-Related Potential and Psychological Study of Error Awareness and Normal Ageing

Awareness is a complex psychological phenomenon that is hard to define. Often thought synonymous with consciousness, self-reflection and metacognition (Wheeler, Stuss, & Tulving, 1997), it has also been described as the ability to perceive one's own internal reality, whilst maintaining an objective understanding of how the self fits into the external world (Dirette, 2002; Prigatano & Schachter, 1991; Stuss & Benson, 1986). Despite the large volume of awareness research, there remains uncertainty about the most reliable and objective means of assessment (Clare, 2004*b*; Morris & Hannesdottir, 2004). Importantly, our understanding of how awareness may change across the lifespan is also poor.

Awareness has been associated with the frontal lobes (Fuster, 1989; Stuss, 1991; Wheeler et al., 1997). Indeed, Stuss and colleagues have conceptualised awareness as being the highest level of frontal lobe functioning (Stuss & Benson, 1986). They proposed a hierarchical, yet interactive, model comprising three levels of frontal lobe function: sensory and perceptual integration at the lowest level, then executive function, and finally self-awareness at the highest level. Stuss and colleagues (2001) later extended this to a four-level model, including basic conscious arousal. This model aimed to explain further the multi-faceted nature of awareness, and how it could manifest itself at each level of functioning. In this conceptualisation, awareness exists at a level of executive function termed 'consistent consciousness', which aims to mediate executive functions and goal-directed behaviour. In this view, the concertedly working executive functions of attention, memory, performance monitoring and inhibition may underpin awareness of ongoing behaviour (Fernandez-Duque, Baird, & Posner, 2000).

This is supported by evidence showing that impaired awareness is a common consequence of frontal lobe damage (Stuss, 1991; Wheeler et al., 1997). More specifically, unawareness of deficit with organic cause, or anosognosia, is common following traumatic brain injury (TBI), or neurodegenerative diseases such as Alzheimer's disease (AD), which involve the frontal lobes (Agnew & Morris, 1998; Clare, 2004*a*; Fleming & Strong, 1995; Schachter, 1990). However, as conditions such as AD are associated with ageing, it is important to gain a clear understanding of how awareness may change with normal ageing, before the impact of neuropathology can be fully understood.

Normal ageing is associated with changes in brain morphology, including the frontal lobes (Ferrer-Caja, Crawford, & Bryan, 2002; Fuster, 1989; Raz, 2000; West, 1996), and with decline in executive function (Band & Kok, 2000; Groth & Allen, 2000; Kramer, Hahn, & Gopher, 1999; May & Hasher, 1998; Nielson, Langenecker, & Garavan, 2002; Smith et al., 2001; Verhaeghen & Cerella, 2002). For example, older adults have been found to perform at a lower level than younger participants on tasks assessing attention (Groth & Allen, 2000; Kramer et al., 1999; Smith et al., 2001; Verhaeghen & Cerella, 2002), inhibitory control (May & Hasher, 1998; Nielson et al., 2002), and performance monitoring (Band & Kok, 2000). Thus, there is evidence indicating that frontal lobe functions are vulnerable to decline with healthy ageing. By contrast, little is known about the impact of normal brain changes on Stuss's highest level of frontal-lobe function, namely awareness. This may be partly due to methodological difficulties.

The issue of how best to measure awareness remains controversial (Clare, 2004*b*; Morris & Hannesdottir, 2004). Awareness in patient populations is typically assessed by questionnaires, interviews, and carer-reports, but this approach can be highly subjective, and dependent upon patients' willingness to disclose or carers' perceived burden of care (Allen & Ruff, 1990; Clare, 2004*a*; Kotler-Cope & Camp, 1995; Sohlberg & Mateer, 2001), as well as other psychological factors such as denial (Clare, 2004*b*; Weinstein, 1991). Assessing on-line awareness, or awareness of actual task performance, may be more objective and reliable (Correa, Graves, & Costa, 1996). This can be achieved by comparing 'postdictions' (participants' estimations of performance accuracy following the task) with actual task performance (Duke, Seltzer, Seltzer, & Vasterling, 2002; Souchay, Isingrini, Pillon, & Gil, 2003). Further information may be provided by videotaping naturalistic behaviour and looking for signs of performance monitoring during the tasks (Giovannetti, Libon, & Hart, 2002; Hart, Giovannetti, Montgomery, & Schwartz, 1998). In both these studies, patients (TBI and AD) showed less behavioural awareness of errors and reportedly made fewer attempts to correct errors compared to age-matched controls, suggesting reduced awareness.

Other researchers have administered fast-choice-response tasks such as the Stroop, Eriksen Flanker or Go/NoGo tasks (Eriksen & Eriksen, 1974) to explore performance monitoring in laboratory settings (e.g. Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997; Scheffers & Coles, 2000). This allows behavioural responses to errors, such as error correction, to be recorded more systematically than in naturalistic settings. A key theory underpinning this line of research is the idea that the error-processing system in the brain consists of two components: an error-detection or 'monitoring system', and a 'remedial action system' for error compensation. The monitoring system works to identify any mismatches between the intended and actual response, whilst the remedial system intervenes either to correct or compensate for errors as they occur (Coles, Scheffers, & Holroyd, 2001).

Many of these laboratory studies of on-line performance monitoring concurrently measured brain activity associated with errors in the form of event-related potentials (ERP). Over the last decade, two components, the error-related negativity (ERN) and error positivity (Pe), have been increasingly investigated (see Falkenstein 2004, for review), and are of interest to the study of awareness. Both the ERN and Pe occur immediately after an error in fast-choice-response tasks (Falkenstein, Hohnsbein, Hoorman, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN/Pe complex is maximal over the frontal lobes (Fz, FCz), and converging evidence from functional imaging and dipole source localization studies have implicated the anterior cingulate cortex (ACC) as the probable neural generator (Dehaene, Posner, & Tucker, 1994; Falkenstein, 2004; Holroyd & Coles, 2002; Nieuwenhuis, Ridderinkhof, & Talsma, 2002; van Veen & Carter, 2002).

The ERN is believed to reflect early, preconscious error detection, or a mismatch between action and intention (Dehaene et al., 1994; Falkenstein, 2004; Holroyd & Coles, 2002). It is larger in cases where accuracy is emphasised (Gehring et al., 1993) and perceived inaccuracy is greater (Scheffers & Coles, 2000), and occurs following partial as well as full errors (Falkenstein, 2004).

It has been proposed that the delayed Pe reflects additional error processing, such as conscious error awareness (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001), or the emotional assessment of errors (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). However, its functional significance remains controversial. Due to its specificity, occurring approximately 300ms after a full error, and following the ERN (Falkenstein, 2004; Vidal, Hasbroucq, Grapperon, & Bonnet, 2000), there is an obvious appeal to describing it as an ERP signature of error awareness. The Pe has also been associated with more conscious post-error slowing in younger participants

(Nieuwenhuis et al., 2001), although Falkenstein and colleagues (2000) reported that, despite demonstrating an attenuated Pe, older participants showed normal post-error slowing to a degree that was actually greater than that of younger participants. Reports that higher error rates predict a smaller Pe (Falkenstein et al., 2000) also suggest that, like the ERN, this component is vulnerable to increasing task complexity and emotional evaluation, indicating perhaps less association with awareness of errors. Thus, the relevance of this component to the awareness literature is uncertain, but the available evidence suggests the importance of further investigation.

To date, there is limited understanding of the ERN/Pe complex within the context of normal ageing. Several studies have found reductions in ERN amplitude in healthy older people compared with younger controls, independent of either task or error type (Band & Kok, 2000; Falkenstein, Hoormann, & Hohnsbein, 2001; Mathalon et al., 2003), possibly due to a disruption in the dopamine system associated with healthy ageing (Holroyd & Coles, 2002; Niewenhuis et al., 2002). Less is known about the Pe: there is some indication that Pe amplitude is reduced in older participants (Band & Kok, 2001; Falkenstein et al., 2000), but other studies have found no such reduction with age (Falkenstein, 2004; Mathalon et al., 2003).

In summary, little is known about the impact of normal ageing on error awareness, and while there is some preliminary evidence for the utility of ERP methodology, results are conflicting. This has implications for research with patient populations at risk of impaired awareness. Thus, the aim of the present study was to explore performance monitoring (error detection and awareness) in a group of younger and older adults using a combination of psychological and ERP methodologies. As well as recording the ERN/Pe complex and task behaviours (self-correction; post-error slowing), performance on a Stroop-like fast-choice-reaction task was simultaneously videotaped to capture behavioural awareness of errors. Postdictions were taken to record participants' perceived accuracy on the task, and a discrepancy measure assessed actual error awareness. Neuropsychological measures of attention were carried out to assess underlying executive function.

Consistent with previous studies (Allain, Hasbroucq, Burle, Grapperon, & Vidal, 2004; Falkenstein et al., 2000; Mathalon et al., 2003), it was predicted that the ERN/Pe complex would be detectable in both younger and older participants, and that the ERN would be significantly larger than a smaller negative deflection associated with correct trials (CRN). Secondly, it was predicted that older participants would demonstrate an attenuated ERN compared with younger participants, as has been found previously (Band & Kok, 2000; Mathalon et al., 2003). Although current research exploring the impact of ageing on the Pe remains scant and inconclusive, it was hypothesised that a similar effect to that of the ERN would be found for the Pe (Band & Kok, 2001; Falkenstein et al., 2000); the ERN and Pe components occur together, so it is conceivable that any normal ageing process that reduces the power of the ERN may also reduce the power of the Pe.

Thus, the first aim of this study was to replicate previous findings. In order to extend this body of research, it was additionally hypothesised that there would be group differences in measures of behaviour, awareness (discrepancy and video data) and neuropsychological measures of attention/executive function. Associations between ERP data (ERN/Pe complex) and measures of attention and error awareness would provide support for the integrative models of Stuss and colleagues (Stuss & Benson, 1986; Stuss et al., 2001).

Method

Participants

Approval for the study was obtained from the School of Psychology Ethics Committee, University of Southampton (Appendix A). Some older participants were recruited through local social groups, where information sheets with contact details were distributed (Appendix B). Others were recruited through an older adult participant pool held by the School. Younger participants were recruited from the student participant pool in the School of Psychology. All participants were given an information sheet before taking part in the study (Appendix C), which also informed participants of their right to withdraw at any time. Signed consent for participation in the study was obtained (Appendix D).

Twenty-two younger and 20 older participants were screened for their predicted IQ and anxiety level. All participants completed a basic demographic questionnaire to screen for significant health or psychological problems (Appendix E). Vision was normal or corrected-to-normal. As the study was focussed on healthy ageing, older adults were also screened for cognitive impairment. Data from two older participants were excluded due to their inability to cope with the ERP paradigm (extreme error rate, judged subjectively to indicate a lack of understanding of task instructions), and from three due to the quality of their ERP data (unreadable, due to considerable blink and movement artefact). The data from seven younger participants were withdrawn due to lower predicted IQ scores. This resulted in final numbers of 15 participants in each group with comparable predicted IQ scores.

Methods

Baseline Measures

Cognitive Impairment. Older adults were screened with the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975, Appendix F). This is a standardised screening tool for cognitive impairment with older adults. It has been widely used in both clinical practice and research. A cut-off of ≥ 26/30 was applied (Monsch et al., 1995).

Predicted IQ. The Wechsler Test of Adult Reading (WTAR, Wechsler, 2001) was used to predict IQ, as this correlates highly with the Wechsler Adult Intelligence Scale, 3rd edition (WAIS-III; Wechsler, 1989). The WTAR is a standardised measure for use with individuals aged 16-89. It has good validity and reliability and wide clinical application (Appendix G).

Anxiety. Participants were also assessed for anxiety, as a relationship has been found between higher levels of anxiety and increased ERN amplitude (Hajcak, McDonald, & Simons, 2003). The Beck Anxiety Inventory (BAI; Beck & Steer, 1990) is a standardised measure designed to discriminate anxiety from depression (Appendix H). It has good internal consistency (.60), good test-retest reliability over a one week period (.75), and is widely used to assess anxiety in clinical and research settings.

ERP Paradigm

The 4-CRT is a Stroop-like task originally developed by Kaiser et al. (1997), and later modified by Hogan, Vargha-Khadem, Kirkham, and Baldeweg (2005). Participants are presented with a series of green and red (25% probability) arrows on a computer screen at intervals of 1500 ms. Arrows point either left or right, and participants are instructed to press the corresponding mouse button (green arrows) or the opposite mouse button (red arrows), and to be as fast and accurate as possible. Each block consists of 100 arrows (approximately 2.5 minutes), and four blocks were administered. Older participants who found the task particularly difficult and who could not tolerate four blocks, were encouraged to try an easier version of the task consisting of green arrows only (2-CRT). This allowed the participant to end the testing session positively. Data obtained from two such participants are not included in this paper.

EEG Acquisition

A Neuroscan NuAmps system was used to record EEG data. Twelve silver/silver-chloride electrodes were individually positioned according to the international 10-20 system (Jasper, 1958); the number of scalp electrodes was kept to a minimum (Fz, FCz, Cz, Pz, Oz, C3, C4, Appendix I) in order to ensure the cooperation and comfort of older participants. Horizontal and lateral eye-movements were recorded from electrodes positioned around the right eye. Continuous EEG data were recorded at a sampling rate of 500 (band-pass of 0.05 to 70 Hz) using a linked-mastoid reference. Impedances were kept below 10KOhm.

Error Awareness Measures

Participants consented to being videotaped whilst performing the 4-CRT. This allowed the recording of their overt awareness (e.g. verbal outbursts, grimaces) when they made an error. These were coded according to the rating system devised by Hart and colleagues (1998, Appendix J), and the total number of error awareness behaviours observed throughout all 4-CRT trials was calculated (Hart et al., 1998). Twenty percent of the data set was rated by a second researcher blind to level of performance, showing high inter-rater reliability ($r = .92, p = .001$). A postdiction measure was also administered, requiring participants to indicate the percentage of responses they thought had been correct after each 4-CRT block. A mean percentage perceived accuracy score for all 4-CRT trials was calculated. A measure of error awareness (discrepancy) was then developed, by calculating the discrepancy between participants' perceived accuracy score and their actual level of performance. Greater discrepancy indicates less awareness of errors.

Neuropsychological Measures

The Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) is a standardised measure of attention and executive function. It has good reliability and has been validated with a range of patients. Three subtests from the TEA were used: Selective attention was assessed using the 'Map Search' task, involving visual target selection. An A3-size city map is presented. Participants have two minutes to circle as many target stimuli as possible (e.g. knife and fork symbols). Sustained attention was measured using an auditory task, 'Elevator Counting'. This required participants to count tones presented over a sustained period of time. Finally, switching attention was assessed with the 'Visual Elevator' task, requiring participants to demonstrate mental flexibility as they count elevator floors up and down. Subtests yielded a scaled score (range 1-19), apart from Sustained Attention, where only the raw score is used (range 1-7).

Procedure

The study was carried out in a research room at Southampton University, using a scripted procedure to ensure consistency with participants (Appendix K). After reading the information sheet and signing a consent form, older participants completed the MMSE. This meant that procedures could be adapted for any participants scoring less than 26/30. These participants would complete one 2-CRT and one 4-CRT task with only a few leads attached. They would also carry out the

Selective Attention subtest. This meant that participants whose data could not be used would be put through minimal experimentation, whilst remaining unaware that they were no longer participating.

Following the BAI (and MMSE if required), the electrodes were placed on the participant's scalp and they completed the ERP computer tasks while being video-ed. Postdiction measures were taken after each 4-CRT block. TEA tasks were subsequently carried out, and the WTAR was completed at the end. The procedure lasted approximately one and a half hours for younger participants, and two hours for older participants. Much of this time comprised attaching the electrodes and ensuring that impedances were below 10Kohm. Care was taken to ensure that participants were comfortable and relaxed throughout. Following testing, participants received a debriefing sheet (Appendix L) and their travel expenses.

Data Processing

ERP Paradigm. The purpose of this study was not to examine possible differences between compatible and incompatible (green and red) stimuli, therefore these data were collapsed together to increase the number of error trials and thus the signal to noise ratio. The mean response times for error and correct trials, percentage of error trials, and percentage of error trials self-corrected was calculated for each participant. Post-error slowing was obtained by subtracting the mean response time for correct trials from the mean response time for correct trials following error trials.

ERP Components. Continuous data for all four blocks of the 4-CRT task were appended for each participant. Ocular artefact reduction was performed according to the algorithm of Semlitsch, Anderer, Schuster, and Presslich (1986). Continuous EEG data were epoched at –500 to 500 centred on button press, and baseline corrected at –100 to 0 ms. Epochs were automatically rejected if they exceeded –50 to 50Hz, following which all accepted trials were manually inspected and rejected if ocular artefact remained. Correct and error responses were averaged separately to elicit a CRN and ERN/Pe waveform. Peak amplitudes and latencies were measured at FCz after filtering (low bandpass 20Hz), defined as the maximum negative peak (0 and 200 ms: CRN, ERN) followed by the most positive peak (200 to 500 ms: Pe).

Analysis. One-sample Kolmogorov-Smirnoff tests were carried out to check the distribution of all variables. Non-parametric statistics were used for those that were not normally distributed. ERP, behavioural, attention, and awareness data were first compared between groups using independent samples *t*-tests, or the non-parametric equivalent (Mann Whitney *U* tests) when normality/sphericity assumptions were not met (discrepancy, postdiction and video data). Bonferroni corrections were not carried out due to a priori hypotheses regarding the expected pattern of findings, and the risk of making a type two error.

The integrity of the error-processing system (CRN/ERN difference) was analysed using a 2 by 2 mixed design ANOVA with one within-subjects factor of Component (CRN, ERN) and one between-subjects factor of Group (young, old). Finally, two-tailed Pearsons correlations (or the non-parametric equivalent, Spearman's Rho) were used to investigate the relationship between ERP, behavioural, attention and awareness variables.

Results

Baseline Behaviour

As indicated in Table 1, groups did not differ significantly in predicted IQ or anxiety scores.

Table 1

Participant Baseline Measures

M (SD)	Younger Participants (*n* = 15)	Older Participants (*n* = 15)	*t*-tests *t* (28)
Age	21.4 (3.3)	75.7 (5.1)	-
MMSE	-	28.3 (0.9)	-
Predicted IQ	111.2 (3.3)	112.3 (3.3)	0.9
BAI Anxiety	5.1 (3.6)	2.9 (3.7)	-1.7

Note. † = p < .05; ‡ = p < .01; MMSE = Mini-Mental State Examination; Predicted IQ = Wechsler Test of Adult Reading; BAI = Beck Anxiety Inventory.

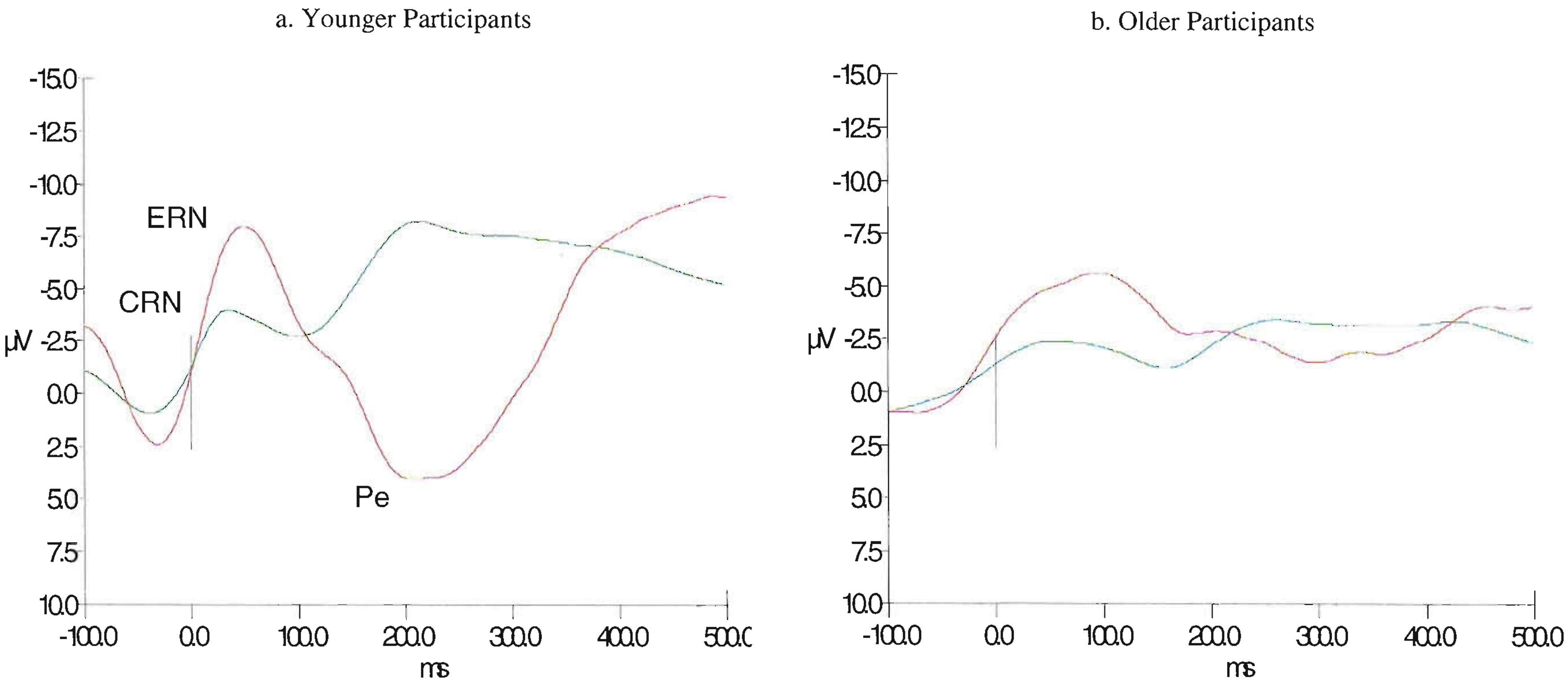
Group Comparisons

Groups were first compared on ERP components, behaviour, attention, and error awareness (see Table 2).

ERP Components.

The expected pattern of CRN/ERN components was observable in the waveforms of both older and younger participants (see Figures 1a and 1b). As predicted, these components appeared to be more prominent in the younger group. However, a one-sample *t*-test found the Pe waveform was not significantly different from zero in the older group, $t\ (14) = 1.40$; $p = .184$, although it was clearly discernable in the younger group as predicted, $t\ (14) = 3.97$; $p < .001$. This may have been due to methodological limitations in the study, such as sample size, or procedural limitations, such as impedance levels. Consequently, planned comparisons with this measure were still carried out, but will be discussed subject to this limitation.

Figure 1. Component Waveforms for Both Groups (FCz)



Note. Red = error trials; green = correct trials; CRN = correct response negativity; ERN = error-related negativity; Pe = error positivity.

Table 2

Group Comparisons on ERP Components, Behaviour, Attention and Awareness

M (SD)	Young (*n* = 15)	Old (*n* = 15)	*t* (28)
ERP Components			
CRN Amplitude (μV)	-5.5 (2.8)	-3.7 (2.6)	1.80
Latency (ms)	35.0 (15)	47.0 (21)	1.81
ERN Amplitude (μV)	-13.2 (4.9)	-7.8 (6.0)	2.68 †
Latency (ms)	53.0 (23)	72.0 (35)	1.73
Pe Amplitude (μV)	6.7 (6.5)	0.9 (2.3)	-3.26 ‡
Latency (ms)	249.0 (39)	291.0 (95.0)	1.56
ERP Behaviour			
Correct RT (ms)	385.0 (46.4)	590.0 (77.0)	8.80 ‡
Error RT (ms)	386.0 (36.0)	562.0 (71.4)	8.70 ‡
Errors (%)	5.7 (2.9)	5.7 (3.3)	-.01
Error-Correction (%) [a]	7.9, 0.0, 0-100	33.3, 33.3, 0-84.9	33.50 ‡
Post-Error Slowing (ms)	65.0 (38.5)	85.0 (81.5)	0.88
Neuropsychology			
Selective Attention	12.3 (1.94)	11.8 (1.9)	-0.67
Sustained Attention [a]	7, 7, 5-7	7, 7, 7	1.38
Switching Accuracy	11.0 (2.30)	12.6 (2.7)	1.75
Switching Speed	11.1 (3.14)	11.6 (1.9)	0.49
Error Awareness			
Discrepancy (%) [a b]	-9.6, -9.2, -32.5 – 2.3	-13.7, -32.9 [c], -32.9 – 0.0	93.00

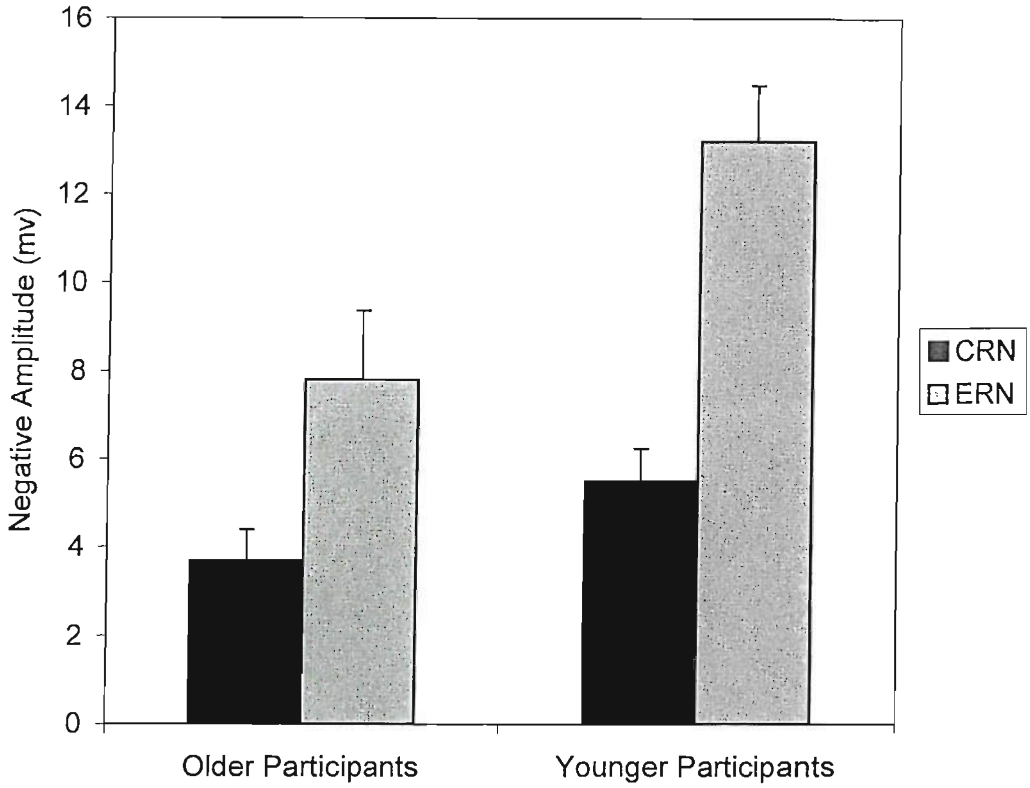
Postdiction (%) [a] (Perceived Accuracy)	84.9, 60.0, 60.0-98.8	79.3, 75.0, 58.8-99.0	86.00
Video Data [a]	4.0, 3.0, 0-25.0	8.0, 5.0, 3.0-16.0	62.50

Note. † = $p < .05$; ‡ = $p < .01$; [a] = Non-parametric measures of median, mode and range reported with Mann Whitney U statistics; CRN = correct response negativity; ERN = error-related negativity; Pe = error positivity. [b] Discrepancy calculation = postdiction – (100 – error rate), therefore negative values indicate underestimation. [c] = Multiple modes exist, therefore the smallest value is given.

A significant Group difference was found for ERN and Pe amplitude (see Table 2). There was also a trend towards a CRN Group difference.

Importantly, despite lowered ERN amplitude, a mixed design ANOVA revealed that the expected profile of CRN<ERN activity was evident in both groups; Component main effect, $F(1,28) = 43.73, p < .001$. In line with the group comparisons reported above, a significant effect of Group was also found, $F(1,28) = 7.45, p = .011$; the Group by Component interaction fell just short of statistical significance, $F(1,28) = 4.03, p = .054$ (see Figure 2).

Figure 2. Group Comparison of CRN/ERN Components



Note. Bars represent standard error.

ERP Behavioural Measures. The groups differed significantly in measures of response time for both error and correct trials (see Table 2). Older participants also corrected significantly more errors than younger participants. Interestingly, groups did not differ significantly in error rate or post-error slowing. The comparable error rate allows for greater confidence that any differences found between the groups in ERP components were not due to a lack of understanding of task instructions.

Attention and Awareness Measures. Contrary to the hypotheses, no significant differences were found between groups on either attention or awareness measures (see Table 2).

Associations between Measures

Subsequent analyses explored associations between ERN/Pe components and measures of behaviour, attention and error awareness (see Table 3). Sustained attention did not correlate with other variables in the older participant group, possibly due to the fact that there was a ceiling effect. This indicated its lack of sensitivity as a measure; therefore, it was not included in subsequent analyses.

There was a high negative association between postdiction and error rate for both groups (younger participants: $r = -.71, p = .005$; older participants: $r = -.64, p = .010$), indicating that participants' perceived accuracy was significantly associated with their actual performance. However, there were no significant associations between video data and error rate for either participant group (younger participants: $r = .23, p = .456$; older participants: $r = .19, p = .513$). This lack of association suggests that capturing error awareness on video may be a less reliable measure of performance awareness in these groups. As a result, only the discrepancy measure (the difference between postdiction and actual performance accuracy) was used for subsequent analyses.

A correlation analysis of discrepancy (a negative statistic, as most participants underestimated their performance) with attention measures also found discrepancy to be significantly associated with selective attention for younger participants ($r = .69, p = .007$), and with switching accuracy for the older group ($r = .75, p = .001$). For both groups, higher attention scores were associated with greater error awareness (smaller discrepancy) on the computer task.

Table 3

Correlation Co-efficients in Participants Comparing ERN/Pe Components with Behavioural, Attention and Awareness Measures

	Younger Participants		Older Participants	
r	ERN Amplitude (μV)	Pe Amplitude (μV)	ERN Amplitude (μV)	Pe Amplitude (μV)
ERP Behaviour				
Correct RT (ms)	.12	.23	.08	.10
Error RT (ms)	.07	-.01	.00	.26
Error Rate (%)	.14	-.30	.58 †	.05
Error-Correction (%) [b]	-.12	-.02	-.13	-.25
Post-Error Slowing (ms)	-.16	-.30	-.35	.07
Neuropsychology				
Selective Attention	.36	.48	.23	.10
Switching Accuracy	-.25	.09	-.33	-.01
Switching Speed	.27	.01	-.23	-.19
Error Awareness				
Discrepancy [b] (%)	.38	.66 †	-.60 †	-.40
Postdiction [b] (%) (Perceived Accuracy)	.35	.76 ‡	-.71 ‡	-.32

Note. † = $p < .05$; ‡ = $p < .01$; [b] = Spearman's Rho statistic; ERN amplitude and discrepancy are negatively scored.

ERN/Pe Component Associations

Correlation analyses allowed possible relationships between ERP components and other variables to be explored. Although the strength of association between variables is more important than the significance level, on this occasion, all significant findings are discussed with a view to highlighting relationships between variables that may be worthy of consideration in future research.

ERP Behavioural Measures. There were no significant associations between ERP and behavioural data for the younger group (see Table 3). For older participants, one significant association was found: error rate was positively associated with ERN amplitude (a negative statistic), revealing that, in this group, lower error rate was associated with a larger ERN (see Table 3).

Attention Measures. No significant associations between ERN/Pe components and attention measures were found for either group (see Table 3).

Awareness Measures. A significant positive association was found between discrepancy (a negative statistic) and the Pe in younger adults only (see Table 3). This indicated that better error awareness (a smaller discrepancy) was associated with larger Pe amplitude. By contrast, for the older group the opposite pattern was found, and discrepancy was associated with ERN (also a negative statistic) and not with Pe amplitude (see Table 3). A negative association indicated that better error awareness (a smaller discrepancy) was associated with a larger ERN for older participants. These relationships were repeated in ERN/Pe associations with perceived accuracy (postdiction), with greater perceived accuracy associated with a larger Pe in younger participants, and, by contrast, a larger ERN in the older group (see Table 3).

The possibility of a correlation between the ERN and the Pe was explored. No significant associations between ERN and Pe amplitudes were found for either younger ($r = -.42, p = .120$) or older ($r = -.48, p = .072$) participants, although there was a trend for a relationship in the older participant group. Associations between the Pe and anxiety were also examined. However, this was not a significant relationship for either participant group (younger: $r = .01, p = .974$; older: $r = -.04, p = .902$), perhaps because of the very low anxiety scores recorded.

Summary of Key Findings

As predicted, ERN component latencies were identifiable in both groups, but significantly attenuated in older participants. The ERN was also significantly greater than the CRN for both older and younger participants, as was expected, indicating that, importantly, the error detection system was working efficiently for both groups. The Pe was clearly identifiable in the younger group, but, in contrast to predictions, was not significantly different from zero in the older group.

Contrary to hypotheses, no significant differences were found between groups on measures of attention or awareness; response times were significantly slower for older participants on the computer task. Older participants also corrected significantly more errors than younger participants and demonstrated greater post-error slowing, although this last difference did not reach statistical significance.

A strong negative association between error rate and postdiction was found. No significant association was found with video data. Discrepancy was also significantly associated with attention in both participant groups.

Correlation of ERP components with other variables showed a strong association between Pe amplitude and both error awareness (discrepancy) and perceived accuracy (postdiction) for younger participants. These findings were not reflected in the older group, possibly due to the weak or non-significant Pe effect. For older participants, however, a larger ERN was associated with reduced error rate, better error awareness and greater perceived accuracy.

Discussion

This study investigated error awareness in younger and older adults, using ERP techniques and measures of behavioural response, attention and awareness. The first aim was to explore the impact of normal ageing on error awareness. In support of previous studies (Falkenstein et al., 2001; Mathalon et al., 2003; Nieuwenhuis et al., 2002) all component amplitudes were reduced in healthy older adults compared with a younger group. Importantly, these differences were not explained by an increased error rate or reduced error awareness in older compared to younger participants. This study also sought to make a novel contribution to the literature by exploring the potential relationship between ERP components associated with error processing (ERN/Pe) and measures of behaviour, attention and error awareness, with the aim of identifying more objective and reliable measures of error awareness.

Group differences

CRN and ERN components were clearly identifiable in both age groups. However, the Pe was not significantly discernable in the older participant group. Components were of significantly lower amplitude in older compared to younger participants, a finding which is in line with previous research (Falkenstein et al., 2001; Mathalon et al., 2003; Nieuwenhuis et al., 2002). Despite the lower power of the ERN in older adults, their error detection systems still distinguished error from correct trials, and this was evident in significantly larger ERN compared to CRN amplitudes. Furthermore, and consistent with previous findings (Falkenstein et al., 2001; Mathalon et al., 2003), these ERP differences occurred in the absence of any group differences in percentage of error trials. This suggests that neural systems underpinning error processing in older adults are functional despite reduced power. Thus, there is only partial evidence to support the prediction that the error detection system is weakened with normal ageing. No significant correlation between the ERN and Pe was found for either participant group, supporting the view that they reflect different error-related processes. However, there was a trend for a relationship in the older participant group, which may relate to generalised neurological ageing changes affecting the strength of the EEG signal.

A comparison of the behavioural data found that, consistent with previous findings (Falkenstein et al., 2000), older participants demonstrated greater post-error slowing than younger participants. However, this difference did not reach statistical significance. Older participants also had significantly longer response latencies (Mathalon et al., 2003), and self-corrected significantly more of their errors than the younger group (Band & Kok, 2000). These findings suggest that accuracy was important to older participants (Band & Kok, 2000), who were able to monitor their performance effectively and compensate for errors even more than younger participants, despite an attenuated ERN.

The fact that this monitoring system was intact in both older and younger participants, despite older participants having significantly smaller ERN amplitudes, also indicates that the importance of error detection and compensation may lie in the ERN/CRN differentiation, rather than in amplitude per se. This is consistent with previous research with participants with lateral prefrontal injuries, who performed poorly due to an inability to maintain an inner representation of the task. This was reflected in the fact that no such ERN/CRN differentiation was found, and these participants also demonstrated reduced error-correction (Gehring & Knight, 2000). In this way, the ERN has been defined as a comparator mechanism, detecting when action does not match intention (Falkenstein et al., 1991; Holroyd & Coles, 2002; Scheffers & Coles, 2000). A key finding of the present study is that the 'ERN comparator' was therefore shown to work in older participants, although with reduced power compared to a younger group. If the ERN and compensatory systems are elicited simultaneously by an error signal via the dopamine system, as has been proposed (Coles et al., 2001; Holroyd & Coles, 2002), it may be that this signal is adequate for activating error compensation so long as there is sufficient CRN/ERN differentiation.

Also consistent with a functioning error-detection system was the lack of any significant difference between groups on measures of error awareness (discrepancy) and perceived accuracy (postdiction). Postdiction was negatively and significantly associated with the percentage of actual errors made for both groups. However, no associations were found between percentage of error trials and number of overt error behaviours recorded on video for either group. Despite previous support for overt behaviours as an indication of awareness (Giovannetti et al., 2002; Hart et al., 1998), in lab-based studies, these findings indicate that measuring overt error behaviours may be a less reliable means of assessing on-line awareness. One possibility is that individuals, such as those who have suffered a brain injury, may be less inhibited in their behaviour, or less able to control their behavioural reactions when making errors. It may be, therefore, that this measure is less sensitive when used with healthy individuals.

Contrary to predictions, but as could be predicted with an intact functioning error-detection system, there were also no significant differences between groups on any attention measures. This is in contrast to previous studies that have reported a decline in measures of executive function with age, such as dual-task performance and attention switching (Groth & Allen, 2000; Kramer et al., 1999; Verhaeghen & Cerella, 2002). One possibility is that on-line awareness is dependent, to a certain extent, upon intact executive function (Stuss et al., 2001). This is consistent with previous research, in which attention has been associated with awareness (Fernandez-Duque et al., 2000). If groups did not differ on measures of on-line awareness, it is reasonable to predict that they would not differ significantly on measures of attention/executive function. This would support the ideas of Stuss and colleagues who have linked on-line awareness to executive function (Stuss & Benson, 1986), more specifically at the level of consistent consciousness (Stuss et al., 2001).

Group associations

This study also sought to explore associations between the ERN/Pe complex and measures of behaviour, attention and awareness, with a view to combining these measures to develop a more objective and reliable means of assessing error awareness. ERN amplitude was positively associated with error rate for older participants only, indicating a relationship between lower error rate and increased ERN amplitude for this group. One possibility is that participants making few errors notice it all the more when an error is made. This is consistent with previous research, indicating that greater perceived inaccuracy is associated with an increase in ERN amplitude (Mathalon et al., 2003; Scheffers & Coles, 2000). There was no such association, however, in the younger group. It is possible that the increase in ERN with error rate was simply more noticeable in the older group, where ERN amplitude was significantly lower than for younger participants.

There were no associations between the ERN/Pe complex and attention. However, attention measures were significantly associated with discrepancy for both groups. Higher error awareness (smaller discrepancy) was associated with better scores on selective attention for younger participants, and switching accuracy for older participants. These findings provide further support for the proposed association of attention and awareness at the level of executive function (Stuss & Benson, 1986; Stuss et al., 2001).

The relationship between ERP components and error awareness was also explored. Findings showed a significant positive association between discrepancy and Pe amplitude for the younger group, indicating that younger participants with more accurate error awareness were those with a larger Pe. The opposite relationship was found with older participants, where better error awareness was associated with larger ERN amplitude but not with the Pe. Significant associations were also found between the ERN/Pe complex and perceived accuracy (postdiction). Greater Pe amplitude was associated with higher postdiction scores for younger participants. This indicated that those who believed they had performed better on the computer task, also had higher Pe amplitudes. For older participants, however, a higher postdiction score was associated not with Pe amplitude, but with larger ERN amplitude instead.

One way to explain these findings is to consider Falkenstein et al.'s (2000) emotional significance theory of the Pe. According to this theory, it would make sense for those performing better to attribute more emotional significance to those errors they do make. This may not be reflected in the older participant group because of their weak Pe, possibly due to the reduction in dopamine associated with normal ageing (Falkenstein, 2004; Mathalon et al., 2003). Equally, older participants with higher error awareness and postdiction scores may have larger ERN amplitudes because they were generally higher performing and able to detect more easily when there was a mismatch between action and intention, resulting in a larger ERN. This view is supported by the fact that, for older participants, greater ERN amplitude was also associated with lower error rate.

Another possibility is that older participants had reduced Pe amplitudes compared to younger participants, due to lower expectations of their ability to perform well on the computer task, and therefore attached less emotional significance to making an error. In contrast, younger participants may well have expected to perform better, therefore it was of more significance to them when they made an error. No significant associations were found between anxiety and the Pe for either group. However, the ERN has been shown to be greater in cases where loss occurs as the result of making an error (Gehring & Willoughby, 2002), therefore it is possible that the Pe is similarly affected. This possibility deserves further exploration in future research with a larger sample size, as only tentative inferences can be made from the present study due to the failure to find a significant Pe effect in the older group.

Previous research has also linked the Pe to post-error slowing, a more conscious remedial action, and proposed the Pe to be a marker of conscious error awareness (Nieuwenhuis et al., 2001). The findings of this study did not support this hypothesis. No association was found between Pe amplitude and post-error slowing for either group. Indeed, while older participants had Pe amplitudes that were not significantly identifiable, they also demonstrated greater post-error slowing. These findings indicate that the Pe is unlikely to be a marker of conscious error awareness. This is supported by the fact that, for older participants, Pe amplitude was not associated with either percentage of error trials or error awareness. In addition, older participants showed good awareness of performance accuracy, despite smaller Pe amplitudes than the younger group.

Therefore, the findings of the present study did not support Nieuwenhuis et al.'s (2001) view that the Pe represents conscious error awareness. Rather, the finding that increased Pe was associated with greater awareness of performance and perceived accuracy for the younger group, supports Falkenstein et al.'s (2000) theory that the Pe represents the emotional significance of making an error. The fact that this was not reflected in the older group could be due to either a disruption in dopamine resulting in a weaker Pe, or due to the lower expectations of older participants of their ability to do well when completing the computer task, or both. Further research on ageing and the Pe is required.

Conclusions

In summary, these findings indicate that the brain's error detection system, as defined by CRN/ERN differentiation, is weakened with ageing but remains efficient. The remedial action system does not appear to be affected. This is consistent with previous research, where a significant ERN reduction in older people was found in the absence of any performance deficits (Falkenstein et al., 2001; Mathalon et al., 2003). It has been proposed that one reason for this decrease in component amplitudes is the reduction in dopamine associated with normal ageing (Mathalon et al., 2003; Nieuwenhuis et al., 2002). If the ACC elicits the Pe as well as the ERN, as has been indicated (van Veen & Carter, 2002), then it is logical that ageing processes in the brain will affect both these components similarly.

There were no significant differences between groups on the discrepancy measure, indicating that error awareness is not compromised by the normal ageing process. Contrary to hypotheses, there were also no differences between groups on measures of attention. Significant associations between discrepancy and attention measures for both groups, however, provide support for the theoretical link between on-line awareness and attention/executive function at the level of consistent consciousness while carrying out goal-directed behaviour (Stuss & Benson, 1986; Stuss et al., 2001).

The fact that associations were found between error rate and postdiction for both groups, supports the potential usefulness of the discrepancy measure to explore performance monitoring and error awareness with younger and older people. While components may become attenuated with normal ageing, the CRN/ERN differential combined with the discrepancy measure may provide a new means of determining an individual's ability to detect errors and demonstrate awareness of their performance accuracy.

This study is a promising first step in the use of ERP techniques in combination with psychological measures, to improve our understanding and objective assessment of error awareness within the context of normal ageing. There are clear implications for future work with clinical populations, using fast-choice-response tasks and measures of discrepancy, CRN/ERN differentiation and compensation, as an objective means of assessing error awareness. Although the findings of this study did not support the idea that the Pe represents conscious error awareness (Nieuwenhuis et al., 2001), further research exploring to what extent the Pe represents the emotional significance of making an error (Falkenstein et al., 2000) is recommended. The use of ERP techniques in the differentiation of organic unawareness from psychological factors such as denial, is also worthy of further investigation.

Study Limitations

One limitation of this study was the sample size, due to the amount of data that could not be used. Although the sample was more than sufficient for ERP research, future studies with a longer timescale should attempt to recruit more participants. Another possibility is that the older and younger participants recruited for this study had different expectations and motivations when attempting the task. This means that the different Pe findings for each group could be due to sampling, if the emotional significance theory of the Pe is taken. This problem is one experienced by all cognitive ageing researchers, however.

The low ceiling effect of the sustained attention task used meant that it was a less valid measure. Although not impacting upon the general findings, future research should endeavour to use a more sensitive measure, and also consider the impact of broader measures of executive function.

The WTAR was chosen to match younger and older participant groups on predicted IQ level, due to its high correlation with the WAIS-III. It was important to choose as brief a measure as possible to include in, what was, a lengthy study for older people. However, as a test of reading ability, one possibility is that older participants were predisposed to perform better than younger participants, having acquired an increased vocabulary through life experience. The fact that no differences in error rate between groups were found suggests that this selection criterion was not a fundamental problem affecting performance in the present study. However, future research should endeavour to include a full battery of tests to determine pre-morbid intelligence where possible.

In addition, no adjustment for multiple comparisons was made, which can lead to an increased likelihood of findings being significant. However, since comparisons were limited to those key variables relevant to the stated hypotheses, the possibility of a Type 1 error was reduced.

Although not a direct limitation of the study, time constraints dictated the level of analysis carried out on the component data. It is planned that more detailed analysis will be carried out to investigate group differences between stimulus-locked components (P300), to assess for differences in stimulus perception. Separate analysis of components on congruent (green arrows) and incongruent (red arrows) trials would also be of interest.

Previous research with older participants has found ERN amplitude to be reduced in more complex tasks (Band & Kok, 2000; Falkenstein, 2004). Therefore, analysis of performance on the simplified version of the 4-CRT task, the 2-CRT, will explore the impact of normal ageing on the CRN/ERN/Pe components in a reduced complexity task. This will ensure that attenuated component amplitudes were not simply the consequence of a task that was perceived as much harder by older people.

References

Agnew, S.K. & Morris, R.G. (1998). The Heterogeneity of Anosognosia for Memory Impairment in Alzheimer's Disease: A Review of the Literature and a Proposed Model. *Aging and Mental Health, 2(1),* 7-19.

Allain, S., Hasbroucq, T., Burle, B. Grapperon, J. & Vidal, F. (2004). Response Monitoring Without Sensory Feedback. *Clinical Neurophysiology, 115(9),* 2014-2030.

Allen, C.C. & Ruff, R.M. (1990). Self-Rating versus Neuropsychological Performance of Moderate versus Severe Head-Injured Patients. *Brain Injury, 4(1),* 7-17.

Band, G.P.H. & Kok, A. (2000). Age Effects on Response Monitoring in a Mental Rotation Task. *Biological Psychology, 51,* 201-221.

Beck, T.A. & Steer, R.A. (2000). *The Beck Anxiety Index*, San Antonio TX: The Psychological Corporation.

Clare, L. (2004*a*). The Construction of Awareness in Early-Stage Alzheimer's Disease: A Review of Concepts and Models. *British Journal of Clinical Psychology, vol. 43, pp 115-175*

Clare, L. (2004*b*). Awareness in Early-Stage Alzheimer's Disease: A Review of Methods and Evidence. *British Journal of Clinical Psychology, 43*, 177-196.

Coles, M.G.H., Scheffers, M.K. & Holroyd, C.B. (2001). Why is there an ERN/Ne on Correct Trials? Response Representations, Stimulus-Related Components and the Theory of Error-Processing. *Biological Psychology,56,* 173-189.

Correa, D.D., Graves, R.E. & Costa, L. (1996). Awareness of Memory Deficit in Alzheimer's Disease Patients and Memory-Impaired Older Adults. *Aging, Neuropsychology and Cognition, 3(3),* 215-228.

Dehaene, S., Posner, M.I. & Tucker, D.M. (1994). Localization of a Neural System for Error Detection and Compensation. *Psychological Science, 5(5),* 303-305.

Dirette, D. (2002). The Development of Awareness and the Use of Compensatory Strategies for Cognitive Deficits. *Brain Injury, 16(10),* 861-871.

Duke, L.M., Seltzer, B., Seltzer, J.E. & Vasterling, J.J. (2002). Cognitive Components of Deficit Awareness in Alzheimer's Disease. *Neuropsychology, 16(3),* 359-369.

Falkenstein, M. (2004). Electrophysiological Correlates of Performance Monitoring. In: Ullsberger, M. & Falkenstein, M. (Eds.) *Errors, Conflicts and The Brain. Current Opinions on Performance Monitoring* (pp. 5-14). Leipzig: MPI of Cognitive Neuroscience.

Falkenstein, M., Hohnsbein, J., Hoormann, J. & Blanke, L. (1991). Effects of Crossmodal Divided Attention on Late ERP Components. II. Error Processing in Choice Reaction Tasks. *Electroencephalography and Clinical Neurophysiology, 78,* 447-455.

Falkenstein, M., Hoormann, J., Christ, S. & Hohnsbein, J. (2000). ERP Components on Reaction Errors and their Functional Significance. *Biological Psychology, 51,* 87-107.

Falkenstein, M., Hoorman, J. & Hohnsbein, J. (2001). Changes of Error-Related ERPs with Age. *Experimental Brain Research, 138,* 258-262.

Fernandez-Duque, D., Baird, J.A. & Posner, M.I. (2000). Executive Attention and Metacognitive Regulation. *Consciousness and Cognition, 9,* 288-307.

Ferrer-Caja, E., Crawford, J.R. & Bryan, J. (2002). A Structural Modeling Examination of the Executive Decline Hypothesis of Cognitive Aging

Through Reanalysis of Crawford et al.'s (2000) Data. *Aging, Neuropsychology and Cognition, 90(3),* 231-249.

Fleming, J. & Strong, J. (1995). Self-Awareness of Deficits Following Acquired Brain Injury: Considerations for Rehabilitation. *British Journal of Occupational Therapy, 58(2),* 55-60.

Folstein, M., Folstein, S.E., McHugh, P.R. (1975). "Mini-Mental State" a Practical Method for Grading the Cognitive State of Patients for the Clinician. *Journal of Psychiatric Research, 12(3),* 189-198.

Fuster, J.M. (1989). *The Prefrontal Cortex: Anatomy, Physiology and Neuropsychology of the Frontal Lobe* (2nd ed.). Raven Press New York.

Gehring, W.J. & Knight, R.T. (2000). Prefrontal-Cingulate Interactions in Action Monitoring. *Nature Neuroscience, 3(5),* 516-521.

Gehring, W.J., Goss, B., Coles, M.G.H., Meyer, D.E. & Donchin, E. (1993). A Neural System for Error Detection and Compensation. *Psychological Science, 4(6),* 385-390.

Giovannetti, T., Libon, D.J. & hart, T. (2002). Awareness of Naturalistic Action Errors in Dementia. *Journal of the International Neuropsychological Society, 8,* 633-644.

Groth, K.E. & Allen, P.A. (2000). Visual Attention and Aging. *Frontiers in Bioscience, 5,* d284-297.

Hajcak, G., McDonald, N. & Simons, R.F. (2003). Anxiety and Error-Related Brain Activity. *Biological Psychology, 64,* 77-90.

Hart, T., Giovannetti, T., Montgomery, M.W. & Schwartz, M.F. (1998). Awareness of Errors in Naturalistic Action after Traumatic Brain Injury. *Journal of Head Trauma and Rehabilitation, 13(5),* 16-28.

Hogan, A., Vargha-Khadem, F., Kirkham, F. & Baldeweg, T. (in press). *Developmental Science.*

Holroyd, C.B. & Coles, M.G.H. (2002). The Neural Basis of Human Error Processing: Reinforcement Learning, Dopamine and the Error-Related Negativity. *Psychological Review, 109(4),* 679-709.

Jasper, H. (1958). Report of the Committee on Methods of Clinical Examination in Electroencephalography. *Electroencephalography and Clinical Neurophysiology, 10,* 370-375.

Kaiser, J., Barker, R., Haenscel, C., Baldeweg, T. & Gruzelier, J.H. (1997). Hypnosis and Event-Related Potential Correlates of Error Processing in a Stroop-Type Paradigm: A Test of the Frontal Hypothesis. International Journal of *Psychophysiology, 27,* 215-222.

Kotler-Cope, S. & Camp, C.J. (1995). Anosognosia in Alzheimer Disease. *Alzheimer Disease and Associated Disorders, 9(1),* 52-56.

Kramer, A.F., Hahn, S. & Gopher, D. (1999). Task Co-ordination and Aging: Explorations of Executive Control Processes in the Task Switching Paradigm. *Acta Psychologica, 101,* 339-378.

Mathalon, D.H., Bennett, A., Askari, N., Gray, M.E., Rosenbloom, M.J. & Ford, J.M. (2003). Response-Monitoring Dysfunction in Aging and Alzheimer's Disease: An Event-Related Potential Study. *Neurobiology of Aging, 24,* 675-685.

May, C.P. & Hasher, L. (1998). Synchrony Effects in Inhibitory Control Over Thought and Action. *Journal of Experimental Psychology: Human Perception and Performance, 24(2),* 363-379.

Monsch, A.U., Foldi, N.S., Ermini-Funfschilling, D.E., Berres, M., Taylor, K.I., Seifritz, E. et al. (1995). Improving the Diagnostic Criteria of the Mini-Mental State Examination. *Acta Neurologica Scandinavia, 92(2),* 145-150.

Morris, R.G. & Hannesdottir, K. (2004). Loss of Awareness in Alzheimer's Disease. In: Morris, R.G. & Becker, J.Y. (Eds.) *Cognitive Neuropsychology of Alzheimer's Disease* (2nd ed., pp. 275-296). Oxford University Press.

Nielson, K.A., Langenecker, S.A. & Garavan, H. (2002). Differences in the Functional Neuroanatomy of Inhibitory Control Across the Adult Life Span. *Psychology and Aging, 17(1),* 56-71.

Nieuwenhuis, S., Ridderinkhof, R.K., Blom, J., Band, G.P.H. & Kok, A. (2001). Error-related Brain Potentials are Differentially Related to Awareness of Response Errors: Evidence from an Anti-Saccade Task. *Psychophysiology, 38,* 752-760.

Nieuwenhuis, S., Ridderinkhof, R.K. & Talsma, D. (2002). A Computational Account of Altered Error Processing in Older Age: Dopamine and the Error-Related Negativity. *Cognitive, Affective and Behavioral Neuroscience, 2(1),* 19-36.

Prigatano, G.P. & Schachter, D.L. (1991). Introduction. In: Prigatano, G.P. & Schachter, D.L. (eds.) *Awareness of Deficit After Brain Injury* (pp. 3-16). New York, NY: Oxford University Press.

Raz, N. (2000). Aging of the Brain and its Impact on Cognitive Performance: Integration of Structural and Functional Findings. In: Craik, F.I.M. & Salthouse, T.A. (Eds.), *The Handbook of Aging and Cognition* (pp. 1-90). Lawrence Erlbaum Associates.

Robertson, I.H., Ward, T., Ridgeway, V. & Nimmo-Smith, I. (1994) *Test of Everyday Attention.* Flempton: Thames Valley Test Company.

Schachter, D.L. (1990). Toward a Cognitive Neuropsychology of Awareness: Implicit Knowledge and Anosognosia. *Journal of Clinical and Experimental Neuropsychology, 12(1),* 155-178.

Scheffers, M.K. & Coles, M.G.H. (2000). Performance Monitoring in a Confusing World: Error-Related Brain Activity, Judgements of Response Accuracy, and Types of Errors. *Journal of Experimental Psychology: Human Perception and Performance, 26(1),* 141-151.

Semlitsch, H.V., Anderer, P., Schuster, P., Presslich, O. (1986). A Solution for Reliable and Valid Reduction of Ocular Artefacts, Applied to the P300 ERP. *Psychphysiology, 23,* 695-703.

Smith, E.E., Geva, A., Jonides, J., Miller, A., Reuter-Lorenz, P. & Koeppe, R.A. (2001). The Neural Basis of Task-Switching in Working Memory: Effects of Performance and Aging. *Proceedings of the National Academy of Science, 98(4),* 2095-2100.

Sohlberg, M.M. & Mateer, C.A. (2001). *Cognitive Rehabilitation: An Integrative Neuropsychological Approach.* The Guildford Press, New York, London.

Souchay, C., Isingrini, M., Pillon, B. & Gil, R. (2003). Metamemory Accuracy in Alzheimer's Disease and Frontotemporal Lobe Dementia. *Neurocase, 9(6),* 482-493.

Stuss, D.T. (1991). Disturbance of Self-Awareness after Frontal System Damage. In: Prigatano, G.P. & Schachter, D.L. (Eds.) *Awareness of Deficit After Brain Injury* (pp. 63-83). New York, NY: Oxford University Press.

Stuss, D.T. & Benson, F.D. (1986). *The Frontal Lobes.* Raven Press: New York.

Stuss, D.T., Picton, T.W. & Alexander, M.P. (2001). Consciousness, Self-Awareness and the Frontal Lobes. In: Salloway, S.P., Malloy, P.F. & Duffy, J.D. (Eds.)

The Frontal Lobes and Neuropsychiatric Illness (pp. 101-109). Washington, DC: American Psychiatric Publishing Inc.

Van Veen, V. & Carter, C.S. (2002). The Timing of Action-Monitoring Processes in the Anterior Cingulate Cortex. *Journal of Cognitive Neuroscience, 14(4),* 593-602.

Verhaeghen, P. & Cerella, J. (2002). Aging, Executive Control and Attention: A Review of Meta-Analyses. *Neuroscience and Behavioral Reviews, 26,* 849-857.

Vidal, F., Hasbroucq, T., Grapperon, J. & Bonnet, M. (2000). Is the 'Error Negativity' Specific to Errors? *Biological Psychology, 51,* 109-128.

Wechsler, D. (2001). *The Wechsler Test of Adult Reading.* New York: The Psychological Corporation.

Weinstein, E.A. (1991). Anosognosia and Denial of Illness. In: Prigatano, G.P. & Schachter, D.L. (eds) *Awareness of Deficit After Brain Injury* (pp. 240-257). New York, NY: Oxford University Press.

West, R. (1996). An Application of Prefrontal Cortex Function Theory to Cognitive Aging. *Psychological Bulletin, 120(2),* 272-292.

Wheeler, M.A., Stuss, D.T. & Tulving, E. (1997). Toward a Theory of Episodic Memory: The Frontal Lobes and Autonoetic Consciousness. *Psychological Bulletin, 121(3),* 331-354.

Appendices

APPENDIX A

University of Southampton

School of Psychology

University of Southampton
Highfield Southampton
SO17 1BJ United Kingdom

Tel +44 (0)23 8059 3995
Fax +44 (0)23 8059 4597

10 June 2004

Kate Radley
Department of Clinical Psychology
University of Southampton
Highfield
Southampton SO17 1BJ

Dear Kate,

Re: Awareness of Function and Aging

I am writing to confirm that the above titled ethics application was approved by the School of Psychology Ethical Committee on 8 June 2004.

Should you require any further information, please do not hesitate in contacting me on 023 8059 3995.

Please quote approval reference number CLIN/03/41.

Yours sincerely,

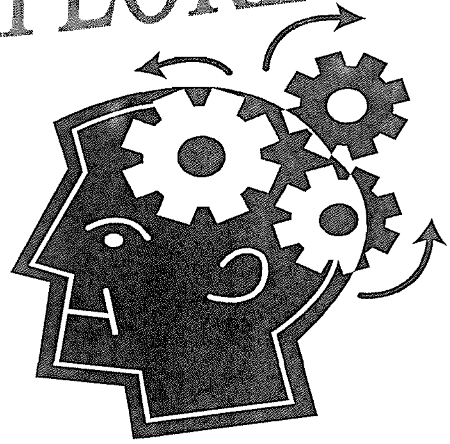
K M Lucas

Kathryn Lucas
Secretary to the Ethics Committee

APPENDIX B

University of Southampton

Help EXPLORE the MIND



URGENTLY SEEKING VOLUNTEERS AGED 65 TO 105!

All About Us......

We are a research team at the University of Southampton School of Psychology, investigating how the mind works in different age groups. We are particularly keen to further our understanding of how growing older affects mental functioning. This is particularly important in today's society, where people are living longer and most of us are living well into older age.

Why is Research Important?

It is hoped that by increasing our understanding of normal, healthy ageing, the research we undertake at the university will offer insights into how we can assist older people to maintain their independence even longer.

Could You Help?

We are currently seeking "everyday folk" over the age of 65, to help us with a study exploring attention in different age groups. This would involve answering some questions, and completing a few simple tasks. There are no wrong or right answers, and we are not looking for perfect performance. There is also no such thing as being too old to take part!

What Now?

If you think you might be interested, we would appreciate the opportunity to tell you more. If you fill in your details on the slip below and return it in the prepaid envelope, we will then contact you by telephone at a time that suits you. This will allow us to provide you with further details about this research, to help you decide whether or not you would like to take part. Alternatively, you may prefer to contact us yourself on the below number (Monday to Friday, 9am to 5pm). **Please note: We will ring you only once to offer more information, and there will be no pressure to take part in any research. It will be left up to you to contact us again should you decide you would like to.**

Many thanks for taking the time to read this information. We look forward to hearing from you.

Kate Radley
University of Southampton
School of Psychology
Southampton SO17 1BJ

Tel: 07734 296266
Email: kar102@soton.ac.uk

....

University of Southampton Research Team

I would like to receive more information about the study on attention across the lifespan at Southampton University.

(Please Print)

Name……………………………………………………..

Tel. No…………………………………………………….

Best time to call………………………………………..

....

APPENDIX C

Information for Participants

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully, and do ask if there is anything that is unclear to you, or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of this study?

This study aims to explore the effects of aging on attention, so we can gain a greater understanding of how attention changes across the lifespan.

Why have I been chosen?

In order to gain an understanding of how attention changes with age, this study requires a selection of younger participants and a selection of older participants, so that comparisons between the two groups can be made.

Do I have to take part?

It is entirely up to you whether you want to take part. If you do decide to be a participant, you are also able to change your mind and withdraw your participation at any stage.

What will happen if I do take part?

This study will take place at the University of Southampton Psychology Department. You will complete a short exercise and questionnaire, followed by a practical task that will test your attention and last approximately 20/25 minutes. You will then complete a computer task lasting about 15 minutes. You will be videotaped completing this task, and a measure of your brain activity will be taken by attaching some small electrodes to your head with a light, water-based gel. This procedure is not invasive, and it is completely painless and harmless. When we have finished each task, you will be asked to estimate how well you felt you did. The whole study will take about an hour to complete.

You will receive your travel expenses if you have travelled to the university. These will be repaid by mileage at the public transport rate.

Will my taking part in this study be confidential?

All information that is collected about you during this study will be kept strictly confidential. Data will be kept anonymously, and the results of the study will not include any personal or identifying information. All data will be kept securely at the University of Southampton, and subsequently destroyed.

What will happen to the results of the study?

The results of this study will be put forward for publication in a psychology journal. A summary of the results for participants will be available on request.

Who is organising and funding the research?

I am a second year clinical trainee at the University of Southampton, Doctoral Programme in Clinical Psychology. This research is being conducted as part of my training.

Who has reviewed the study?

The School of Psychology Research Ethics Committee, University of Southampton has reviewed the study.

If you have any questions about your rights as a participant in this research or you feel that you have been placed at risk, you may contact the Chair of the Ethics Committee, School of Psychology, University of Southampton, Southampton SO17 1BJ. Tel: 023 8059 3995.

Contact for further information

If you have any questions, or you wish to request a summary of the research findings, please contact:
Kate Radley, Clinical Psychology, School of Psychology, University of Southampton, SO17 1BJ.
Tel: 023 8059 5321, Email: kar102@soton.ac.uk

APPENDIX D

CONSENT FORM

Study Examining the Effects of Aging on Attention

Name of Researcher:

Kate Radley
Department of Clinical Psychology
School of Psychology
University of Southampton
Southampton
SO17 1BJ
Tel: 023 8059 5321

1. I confirm that I have read and understand the information sheet dated .... for the above study. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time. ☐

3. I agree to take part in the above study. ☐

4. I agree to being video-taped while participating in this study. ☐

5. I would like to receive a written summary of the findings from this study. ☐

Participant's Name (printed) ....

Participant's Signature .... Date......................

Researcher's Name (printed) ....

Researcher's Signature .... Date.....................

APPENDIX E

Participant Health Screen

Name:	
Date of Birth:	
Right or Left Handed?	Right / Left / Ambidextrous
Gender	Male / Female
Occupation (or Previous Occupation)	
Address:	
Telephone:	
Do you drive?	Yes / No
Age started School	
Age left school	
Further Education?	Yes / No If yes, what?
Do you wear reading glasses?	Yes / No If yes, please remember to bring them
Are you currently on any routine medication?	Yes / No If yes, please specify:

Do you have any medical conditions such as epilepsy?	Yes / No If yes, please specify:
Have you ever been treated for depression or any other mental health problem?	Yes / No If yes, please specify:
Have you ever suffered a head injury?	Yes / No If yes, please specify:
Do you have any mobility problems, e.g. need a walking aid or wheelchair?	
Do you have any experience using computers?	Yes / No If yes, please specify:

APPENDIX F

FOLSTEIN MINI-MENTAL STATE

I. ORIENTATION (ask the following questions)		✓	Response
What is today's date?	Date (e.g. 21st)		
What is the year?	Year		
What is the month?	Month		
What day is today?	Day (e.g. Monday)		
Can you also tell me what season it is?	Season		
Can you also tell me the name of this hospital?	Hospital		
What floor are we on?	Floor		
What town or city are we in?	Town or city		
What county are we in?	County		
What country are we in?	Country		

II. IMMEDIATE RECALL		✓	Response
Ask subject to repeat these words, allow 1 second per word, and up to 6 trials.	"Ball" "Flag" "Tree" Number of trials ___		

III. ATTENTION / CALCULATION	Response ✓		Response ✓	
Start with 100 and take away 7. 5 times.	93		D	
	86		L	
AND Spell the word "world" backwards.	79		R	
	72		O	
Score serial 7's in total, 0 - 5	65		W	

IV. RECALL		✓	Response
Can you recall the words I said before? Score 0 - 3.	"Ball" "Flag" "Tree"		

V. LANGUAGE		✓	Response
What is this? Watch.	Watch		
Pencil.	Pencil		
Repeat after me, "No ifs, ands or buts".	Repetition		
"Take the paper in your right hand,	Right hand		
Fold it in half	Folds in half		
and put it on your knee".	Paper on knee		
"Close your eyes".	Closes eyes		
Writing sentence	Writes sentence		
Copying pentagons	Draws pentagons		

TOTAL SCORE (maximum score is 30)	Serial 7s	WORLD bk

APPENDIX G

Wechsler Test of Adult Reading (WTAR, Wechsler, 2001)

Participants are asked to read out loud a series of 50 words that become progressively harder. They are asked to attempt all words, whether they are familiar or not. The raw score is then transformed to a predictive IQ score, consistent with the score that could be expected on the Wechsler Adult Intelligence Scale, 3rd edition (WAIS-III, Wechsler, 1997).

Examples include: Porpoise
Paradigm
Hegemony

APPENDIX H

Beck Anxiety Inventory (BAI, Beck & Steer, 1990)

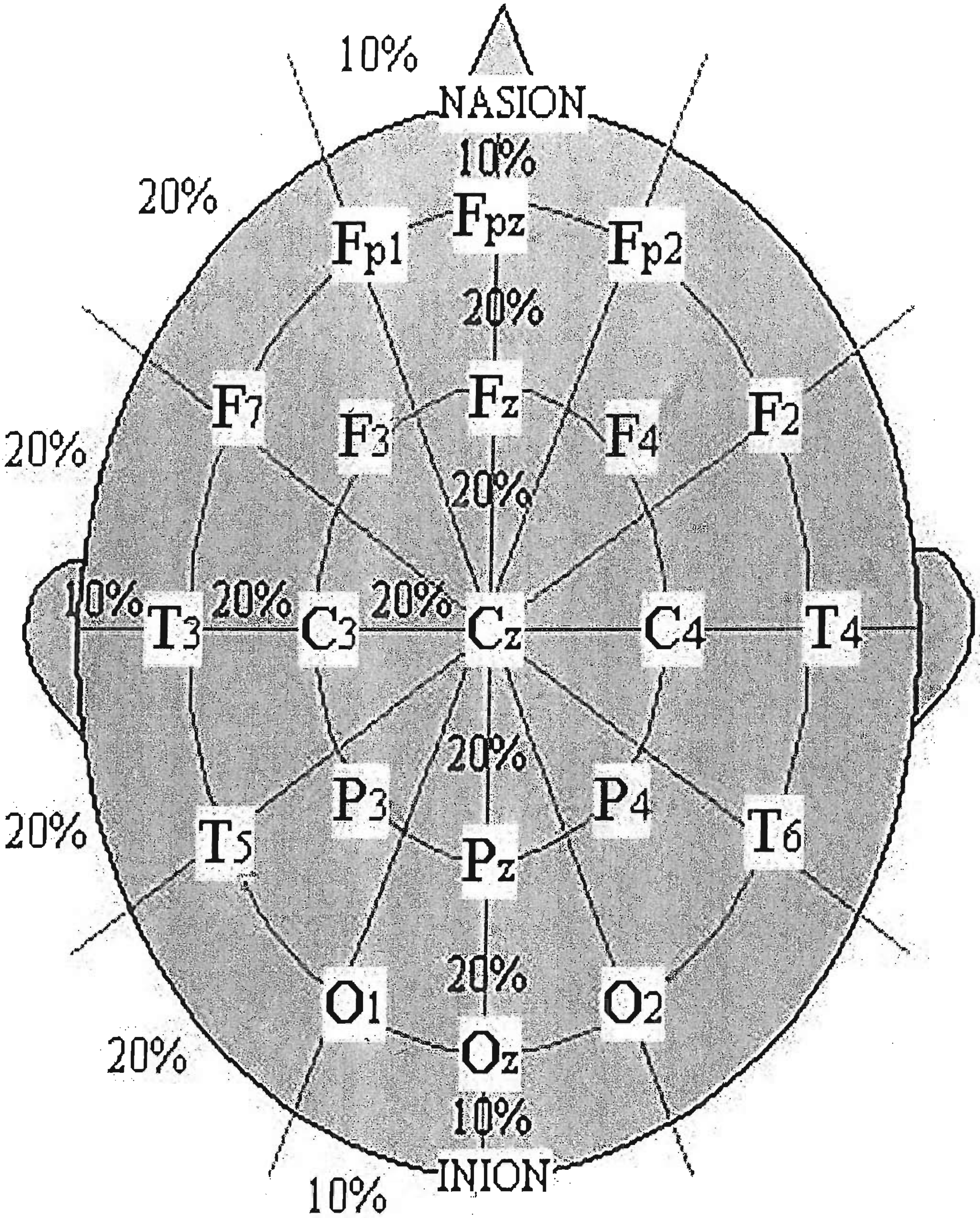
Participants are given a list of 21 symptoms commonly associated with anxiety, and are asked to rate how often they have experienced each one recently (over the past week, including today) due to anxiety alone. Ratings go from 'Not at all' to 'Severely'. Each question is scored from 0-3, and a final score out of 63 is given.

Symptoms include:

- Dizzy or light-headed
- Shaky / unsteady
- Hot / cold sweats

APPENDIX I

The 10-20 System (Jasper, 1958)



APPENDIX J

Video Coding

1 = Verbalisation (question or comment acknowledging that an error had occurred).
2 = Audible but non-word exclamation (e.g. gasp, oops etc.).
3 = One of three facial expressions (grimace, smile or laugh).
4 = A strictly defined type of head-shaking behaviour.
5 = A visual start.

(adapted from Hart, Giovannetti, Montgomery, & Schwartz, 1998).

- Write down exactly what you see, separating the 4-CRT blocks. Only code afterwards.

- Code whichever behaviour appears most prominent at the time.

- For each individual participant, a judgement needs to be made as to whether the behavioural signs that are recorded on the video represent error awareness or not. If in doubt, do not code.

- If it is not clear whether or not there was a behavioural reaction, rewind and watch again. Code as normal if there was a clear reaction. If there is still doubt concerning whether a reaction was made or not, do not code.

- For each participant, total up the number of each behaviour that occurred for all four 4-CRT blocks. Then total the full number of behaviours for each participant.

APPENDIX K

Instructions and Procedure

Introduction

Hello, my name is Kate and I'm a clinical psychology trainee at Southampton University. Thank you very much for taking part in this research. I am interested in how attention changes across the lifespan.

What is going to happen today, is that I will ask you to complete a simple task on the computer, followed by some short, attention-based tasks, and finally I will ask you some questions about memory and anxiety. Many of these you may find extremely easy, and some a bit more taxing, but I have to ask everyone the same questions. Just do the best that you can. You are not obliged to continue if you do not wish to do so, and just let me know if at any time you've had enough and you want to stop.

Any information that you give me is confidential. This means that I will be the only person who knows what you have told me today, and that your individual results will not be identifiable. I will not be able to tell you the results of the tasks straight away because I will have to go and score them after we have finished. However, if you are interested to know more, I will be able to send you a summary of the research next year when it is completed.

Task Outline

In a bit I am going to ask you some questions, and get you to complete a few, short attention-based tasks. I will also be asking you to carry out a simple task on the computer over here. Don't worry if you don't usually use computers, because all you will be doing is pressing a button when you see a target appear on the screen (*to older participants who may be concerned about using computers*). There is a video camcorder by the computer too. If you don't mind, while you are completing the task, I will be video-ing you, as this is a great way of capturing everything so I don't have to remember it all at the time. The video is not on now, and I will let you know when I am going to turn it on and off again later.

As I explained before, while you are carrying out the computer task, I will be recording measures of your electrical brainwaves on this computer here. The way that we do this, as I explained to you when we spoke before, is by using tiny leads like mini stethoscopes that are lightly attached to your scalp with a bit of gel (*show a lead and the gel*). It's a bit like when a woman is expecting a baby and has an ultrasound scan, and they use gel like this to get a good connection. However, we can't actually see inside your head, so it might be more helpful to think of it like when a doctor uses a stethoscope so he can hear your heartbeat. See how the leads look like mini stethoscopes. In the same way, it is totally painless and non-invasive. Nothing is put into you, and nothing is taken out of you. This is what it looks like, and how it all works: (*Demonstrate how a lead will attach to the head, and show the picture of the head so they can see where the leads will go*). Is that all OK? The other thing is that, because the gel is salt-water based, it will leave some sticky residue in the hair. This is why we are offering people a free hair wash after taking part in the study (*to older participants only*). Do you have any questions, or is there anything you'd like me to explain a bit more?

***If the person decides to withdraw*: If you are not comfortable with the computer task, it is possible to complete the task without any leads attached. This would be one option if you still wanted to participate in the study. If you are not happy being video-ed completing the task, then I do not have to video you if you would prefer it.
***If they would like to withdraw completely*: Thank you anyway for taking the time to come and find out more about this study. Deciding not to participate today does not mean you cannot participate in this study in the future. If you have a think and change your mind later, just let me know. My contact address is here on the information sheet.

Information and Consent

Before we start, could you please read this information sheet carefully. It is yours to keep, and says pretty much what I have just said to you. (*After they have read the information*) Do you have any questions at all? Then, if you are happy to take part in the research, could you please tick the relevant boxes and sign this form to show that you give your consent? This says that you wish to take part in the research, are aware of your rights to confidentiality and to withdraw at any stage, consent to being video-ed, and that I have explained what is being asked of you. If you tick this box here then I will send you a summary of the results of this study when it is finished. (*Sign consent form*).

Thank you. Before we start, can I ask if you wear reading glasses, and if so, could you please put them on now. Because you will have leads attached while completing the computer task, which we will do in a minute, if you need to go to the toilet at all then now is a good time to go!

I would like to start off by asking you a few questions:

MMSE (for older participants only)

Now I am going to ask you some questions about memory and thinking skills. I will ask you a range of questions, many of which you may find quite simple, but please do not be insulted. I have to ask everyone the same questions. Please have a go at everything, and if you're not sure, just have a guess. Is that OK?

- What is today's date? (*Some people will give date, month and year immediately. For those who have trouble, move on straight away to "What day is today?", then back to month, year and finally date*).

- What is the year?

- What is the month?

- What day of the week is it?

- What season is it?

- What is the name of this place?
- What floor are we on?
- What city are we in?
- What county are we in?
- What country are we in?
- Now I am going to say some words. Listen carefully, and when I have said all the words, please repeat them back to me: Apple, table, penny. (*If the person is unable to recall the words correctly, ask them to listen carefully and have another go at it. If appropriate, apologise for poor pronunciation of the words. Repeat until the person repeats the words correctly, or stop after 3 trials*).
- Now I've got some mental arithmetic for you: Starting with one hundred, take away seven....and take away seven from that....then take away seven again from that. I will tell you when to stop. (*Stop after 5 subtractions. If asked, you may prompt them with the previous answer they gave. Note the prompt and do not score the response as correct even if the calculation is correct*).
- Now please spell the word "WORLD" backwards, as in the world that we live in.
- I asked you to repeat some words earlier, what were they? (*Delayed recall. You may admit that you did not tell them at the time that you were going to ask them to recall them*).
- Now I am going to say a short sentence to you. It is an unusual one. Listen carefully and then repeat it after me: "No ifs, ands or buts".
- Read this please and do as it says.
- What is this called? (*Show a wristwatch*).
- And this? (*Show a pencil*).
- (*Put paper on table*). Listen carefully and then do what I say. I can say it only once: "Take the paper in your right hand, fold it in half and put it on your knee". (*Put paper back on table and hand person a pen*).
- Write a short sentence for me please. Write anything you like, so long as it makes sense. (*If unsure what it says, ask them to read it aloud*).
- (*Turn paper over. Show pentagons*). Please copy this. It doesn't have to be a work of art, just get all the corners in.

Thank you.

BAI

If you look at this questionnaire, below is a list of common symptoms of anxiety. Please carefully read each item in the list. Indicate how much you have been bothered by each item during the past week, including today, by placing an X in the corresponding space in the column next to each symptom. Please ask if there is anything you are not sure about. Try not to think about each question too much, just tick what you feel is right for you. (*Person completes questionnaire*). Thank you.

ERP Task

(*Seat person at stimulus computer*). This is the video here, but it is not on at the moment. I only want to record you completing the task, and I will tell you when I am about to switch it on. I'm just going to set up the computers now. (*Set up stimulus computer and ERP computer, then show picture of head again to demonstrate where the leads will be going. Explain there are three leads that are on the face, and I will be putting those ones on first.*). I'm going to start off now by taking a measurement of your head. (*Pause*). Can I put a little of this toner on your hand please, just to check that you're not allergic to it? Let me know if you feel any tingling or irritation, in which case we won't use any today. (*Attach leads on face and behind the ears first, without glasses on if worn, so participants can then put their glasses back on again. Chat to participant while attaching leads and explain what I'm doing throughout. Keep checking they are OK and everything feels comfortable. Make note of highest impedance.*).

(*When all leads are attached, get the participant to turn and look at the ERP computer so they can see the recordings from the leads, and ask them to do a few good blinks so they can see how that appears on the screen*). We're now ready to get started, so I'm going to turn the video on now if that's OK (*turn video on*). Right now, I would like you to look at the green arrows on this screen. Some arrows point to the left, and some to the right (*point left and right at the same time in case participant is left/right dyslexic*). I want you to let me know which way each arrow points. You do this by clicking the left and right buttons on the mouse. It is important that you hold the mouse in the right way. Rest it in the palms of your hands in your lap like this. Rest your left thumb over the left mouse button and your right thumb over the right mouse button. When you see a left-pointing arrow, you can press the left mouse button with your left thumb. When you see a right-pointing arrow, you can press the right mouse button with your right thumb. The arrows appear quite quickly, so please try to respond as fast as you can, but as accurately as you can. Everybody makes mistakes on this task, and it can be quite frustrating so feel free to shout at the computer if you want to! Sometimes you will automatically try to correct your errors and this is also ok. Feel free to blink throughout, and you don't have to sit as still as possible because of the leads, although I know it can feel like that because I've had all this done to me too. This task will last about 2 minutes, and afterwards I will ask you how well you thought you did. Is that OK? (*Start recording on ERP computer and begin task on stimulus computer*).

(*When completed 2-CR task, stop recording on ERP computer*): How was that? What percentage do you think you got correct? (*Write down answer*). OK, now I am going to make the task a little harder. Please respond to the green arrows as before, but this time there will be some red arrows as well. When you see a red arrow, you should respond in the opposite way. If you see a red left-pointing arrow, press the right mouse button with your right thumb. If you see a right-pointing red arrow, press the left mouse button with your left thumb (*demonstrate right and left*). So just to make sure, which button would you press for a green arrow pointing this way (left)? And which button would you press for a red arrow pointing that way (right)? As before, try to respond quickly and accurately, and feel free to shout at the computer! Is that OK? (*Set up 4-CR1 file, start recording and begin task on stimulus computer*).

(*Repeat the procedure for 4-CR2, 4-CR3, and 4-CR4. After each task, ask what percentage they thought they got correct*).

At the end of the computer task, stop the video. Thank the person for their patience, and remove leads and as much of gel as possible. Offer a glass of water.

TEA

If you want to come and sit back down here again, I have a few more tasks, but we should be finished in about another twenty minutes if that's OK. Now I will be looking at your concentration on a range of everyday tasks. I want you to imagine that you are on a long trip to Philadelphia (United States). I will ask you to do various tasks such as looking at maps, while you are on this imaginary trip. Let me explain the first task:

- Now I want you to imagine that you are in a lift in your hotel. The visual floor indicator light that should show you what floor you are on is not working. You need to know which floor you are at, so you can get off to go to your room. The lift is only going up. You are helped by the fact that as the lift passes each floor, a tone sounds. So by counting the tones, you can work out which floor the lift is at. Tell me how many floors you count, or in other words, which floor you have reached when the lift stops. The lift starts on the ground floor each time, and it is only going up. This task is on the tape player, so just say how many tons you have counted when the voice on the tape says "how many?". You will notice that the distance between the tones may vary.

  (*Play the first example , counting with the person, and if they are right say* "That's right, you would be on the third floor". *If they are wrong, rewind the tape and play again until they understand the first example. The say* "Let's have another practice" *and go onto the second example. Once they have got that right, go onto the subtest).*

  Now, I would like you to do the same thing, with another series of lift tones.

- Try to imagine that during your trip, you decide to stay in a large hotel, many stories high. While you are staying there, you find that the indicator in the lift that tells you what floor you are on is not working properly. (*Show first visual lift example page*). Look at this series of pictures. As you can see, each one shows a lift. The little arrows here show you what direction to follow, as the pictures do not simply go from left to right each time, but snake round like so. Every so often there is a large arrow, like this one. An arrow pointing down means that the lift is going down, so you need to reverse count. An arrow pointing up means that the lift is going up. What I want you to do is count out the floors. Say "up" and "down" when you come to the large arrows, as this avoids counting them. Remember, the big arrows are not floors, they only tell you which way the lift is going. So, in this first example, you would say – one – two – down – one – up – two. Now you try. (*Repeat until person understands*). OK, now you try the next example. (*Repeat until person understands*).

Now, try and do the same with the next set of pictures. Work as quickly and as accurately as you can. Count out loud as you move along the lifts.

- The symbol here (*show symbol from cuebook*) shows where restaurants can be found in the Philadelphia area. There are many symbols like this on the map. (*Indicate on map, then turn map over*). Let's say you are with a friend or partner. They are driving while you are navigating. You want to know where restaurants are located in case you decide to stop for a meal. What I would like you to do is to look at the map for two minutes and circle as many of those restaurant symbols as you can. You are searching for them all over the map because you're travelling around and do not know exactly where you might end up. I will stop you when one minute has gone by to ask you to swap pens. OK? (*Turn map over to reveal symbols, hand them a red pen and begin timing. After one minute, ask them to change pens and give them a blue one instead. Stop them at the end of two minutes*).

Thank you.

WTAR

This is the final task. I'm going to show you some words that I want you to pronounce. (*Place folder in front of person*). Beginning with the first word on the list, pronounce each word aloud. Just have a go, even if you're unsure, as some of them a re a bit unusual. Would you like to turn the pages or shall I? (*Begin task*).

Thank you, now we're finished!.

At the End

Thank you for taking part in this study. I really appreciate your help. Do you have any questions about anything you have done today? This will tell you a little more about what the study is about (*give debrief sheet*). You can also claim your travel back at public transport rate, if you fill in here how far you've travelled today and send it back in this envelope (*give travel form*).

(*For older participants only*): If you enjoyed taking part in this study today and would like to help out another time, there are always opportunities for taking part in research at the university. Do you think that is something you might be interested in doing again? (*If yes*) We are putting together a database of older people like yourself, who have said they might like to take part in research studies from time to time. Here is some information about this for you to read in your own time, along with two consent forms. Should you be interested, just fill out the consent forms, keep one for yourself and send the other one back to us in this envelope. Someone will then contact you with information about other studies from time to time, and you can decide whether or not you would be interested. (*Give volunteer panel information and consent forms*).

Finally, if you know anyone who might be taking part in this research at some time, I would ask you please not to tell them anything about what you have done today, as this would prime them before they did the tasks.

Thanks again for coming today. (*Direct back to car, or if going for a hair wash, escort to the salon*).

APPENDIX L

Study: **A Study of Attention and Awareness**
Researcher: **Kate Radley, Trainee Clinical Psychologist**

Theoretical Background

The ability to attend to and to be aware of the world around us, and our own performance, are examples of 'executive function'. Evidence suggests that the front parts of our brain, the frontal lobes, play an important part in supporting these executive skills.

Recently, neuroscientists have discovered that it is possible to measure electrical activity over the front parts of the brain during performance of these types of executive skills. For example, when we perform simple motor tasks, if we make a mistake, there is a specific electrical activity in the brain associated with doing so. This pattern of activation, known as the error-related negativity (ERN), allows us to measure an individual's awareness and attention on a task.

Little is known about how healthy aging affects the electrical activity associated with being aware of making an error. In addition, little is known about the relationship between this electrical measure of awareness of error and people's own reports of their performance and their ability to attend to the motor task.

Methodology

The present study therefore required two groups of healthy participants, aged 18-30 and 65+, in order to examine error awareness using the ERN and from self report measures and measures of attention. This was examined by assessing attention (using the Test of Everyday Attention), awareness using ERN measures (through use of electrodes and ERP equipment), and explicit awareness using behavioural/observational measures (use of video and self-report). We will analyse the results in terms of accuracy, speed of response, and how people respond to having made a mistake (usually by slowing down). The study is a between groups design (comparing older participants and younger controls).

Study: **Awareness of Function and Aging**
Researcher: **Kate Radley, Trainee Clinical Psychologist**

Theoretical Background

There is evidence to suggest that skills such as planning, attention and awareness decline naturally with normal aging (West, Murphy, Armilio, Craik & Stuss, 2002). The ability to carry out these skills is known as 'executive function', and we know that the part of the brain responsible for this is the frontal lobes (Tisserand & Jolles, 2003).

However, the difficulty in obtaining a measure of an individual's awareness has also been noted. Current methods of measuring awareness in studies (for example, using patients with dementia as participants) involve examining the discrepancies between predictions of carers, predictions of participants, and actual performance. However, these can be affected by anxiety or denial (Clare, 2003).

Recently however, neuroscientists have discovered that the waveform in the brain associated with making an error, the error-related negativity (ERN), also allows us to measure awareness and attention through error processing. Research using this technique has found normal aging to be associated with smaller ERN amplitude and slower responding following an error (Band & Kok, 2000). However, the relationship between normal aging, executive function and the ERN has yet to be explored in detail.

Methodology

The present study therefore required two groups of healthy participants, aged 18-30 and 65+, in order to examine changes in awareness and attention with normal aging. This was examined by assessing attention (using the Test of Everyday Attention), implicit awareness using ERN measures (through use of electrodes and ERP equipment), and explicit awareness using behavioural/observational measures (use of video and self-report). Factors such as accuracy, response time and post-error slowing on the computer task will also be examined. The study is a between groups design (older participants versus younger controls), and associations between awareness and performance on tasks carried out by each participant will also be examined.

References

Band, G.P.H. & Kok, A. (2000). Age effects on response monitoring in a mental-rotation task. *Biological Psychology, vol. 51, pp 201-221*

Clare, L. (2003). Managing threats to self: awareness in early stage Alzheimer's disease. *Social Science and Medicine, vol. 57, pp 1017-1029*

Tisserand, D.J. & Jolles, J. (2003). On the Involvement of Prefrontal Networks in Cognitive Aging. *Cortex, vol. 39, pp 1107-1128*

West, R., Murphy, K.J., Armilio, M.L., Craik, F.I.M. & Stuss, D.T. (2002). Lapses of Intention and Performance Variability Reveal Age-Related Increases in Fluctuations of Executive Control. *Brain and Cognition, vol. 49, pp 402-419*

APPENDIX M

Psychology and Aging

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Schulz, R. (Ed.). (2000). *Handbook on dementia caregiving: Evidence-based interventions for family caregivers.* New York: Springer.

Faschingbauer, T. R., Zisook, S., & DeVaul, R. A. (1987). The Texas Revised Inventory of Grief. In S. Zisook (Ed.), *Biopsychosocial aspects of bereavement* (pp. 111–124). Washington, DC: American Psychological Association.

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