Advantages and disadvantages of the erp method

Electroencephalography (EEG) refers to the measurement of the electrical activity within the brain, first recorded by Berger (1929, as cited in Luck, 2005, p. 3). This electrical activity is measured by placing electrodes on the scalp, amplifying the signal, and plotting the voltage variations in the brains electrical activity during the testing session. The EEG output shows the electrical activity within the entire brain, but cognitive neuroscientists are more interested in specific neural processes. Averaging techniques allow specific neural responses to be extracted; these responses are known as Event-Related Potentials (ERPs) and represent the summation of postsynaptic potentials between individual neurons (Woodman & Luck, 2003). ERP research has identified several wave components, where the term component refers to the sequentially activated processes that are then measured on the scalp as distinct positive and negative wave patterns (Donchin, Ritter & McCallum, 1978). The current essay does not attempt to be an exhaustive discussion of all the advantages and disadvantages of the ERP method for investigating cognitive functions and dysfunctions, or all the areas where the ERP method has been used, but attempts to highlight important issues in some of the areas where the ERP technique has been applied.

The ERP method is a non-invasive, direct measure of the electrical activity in the brain, recorded through the scalp at the time of response, leading to excellent temporal resolution (Liotti, Woldorff, Perez III, & Mayberg, 2000) when compared to neuroimaging methods, such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET). In neuroimaging the temporal resolution is in terms of seconds whereas in the

ERP method the temporal resolution is in terms of milliseconds (Swick, Kutas & Neville, 1994). This allows a temporally detailed investigation of the processes underlying cognitive functions, where early components reflect sensory processing, and later components reflect higher-level cognitive processes (Woodman & Luck, 2003). Whilst neuroimaging techniques provide excellent spatial information about the neural areas activated during cognitive actions, the temporal resolution is not advanced enough to reveal the exact nature and order of the processes within these areas (Hillyard & Anllo-Vento, 1998). The ERP method also has several other advantages over neuroimaging techniques. ERP experiments are more flexible than those in neuroimaging techniques, where the measurement equipment causes constraints on testing conditions (Chein & Schneider, 2003). Additionally, the superior temporal resolution of the ERP method allows the use of mixed control and experimental trials, whereas neuroimaging techniques often rely on block designs as quick changes between conditions cannot be detected (see Menon & Kim, 1999). However, recent developments have led to the use of event-related fMRI experiments whereby mixed trials can be used (Rosen, Buckner & Dale, 1998). Compared to neuroimaging techniques, the ERP method is also cheap (Dellabadia, Bell, Keyes, Matthews & Glazier, 2002). Taylor and Baldeweg (2002) explained the advantages of the ERP technique in research with infants as it allows the understanding of the association between brain development and behavioural development. Further, the ERP method is less sensitive to movement artefacts than neuroimaging measures, making it useful when studying infants. Finally Luck (2005) explained that ERPs provide a measure between stimulus and response, allowing the understanding of the effects of precise experimental manipulations much better than behavioural responses. Due to the excellent temporal resolution of ERPs they have been widely used to investigate cognitive functions and dysfunctions.

Several ERP components have been identified and related to different cognitive processes (see Coles & Rugg, 1996). The N400 component, first observed by Kutas and Hillyard (1980), has been proposed to reflect interruptions in semantic processing, with both word (Atchley et al., 2006) and picture stimuli (Proverbio & Riva, 2009). The N400 component has been found to be larger in children than adults (Atchley et al., 2006), which may reflect increasing automaticity and easier access to memory traces about the relations between concepts as age increases (Juottonen, Revonsuo & Lang, 1996). Another component, the P600 has been proposed to reflect the processing of syntactic anomalies (Atchley et al., 2006). Investigations of the development of language suggest that ERP data provides a useful way of investigating the normal language abilities of children and adults, as well as predicting infants' future language abilities (see Molfese, Molfese & Epsy, 1999). The N400 component has also been found to be useful in the investigation of cognitive dysfunction. Friedrich and Friederici (2006) conducted a longitudinal investigation and found that the expressive language skills of 30-month old children were related to their lexical and semantic development at the age of 19-months. Children showing specific language impairments (SLI) at 30-months of age were retrospectively found to show no N400 at 19-months of age. This research shows that the N400 may be useful as a precursor for developmental language impairments. Researchers have also found that there may be a genetic contribution to SLI

(Tomblin, 1989) with the fathers of children with SLI showing larger N400 amplitudes than in control subjects suggesting that the N400 component may be useful for predicting SLI in infants (Ors et al., 2001). Olichney et al. (2002) found that a delayed and slower N400 alongside an absent or diminished Late Positive Component, was indicative of probable Alzheimer's disease (AD), whilst Kumar & Debruille (2004) highlighted how different N400 components can be observed in patients with schizophrenia compared to neurotypical controls (see also Condray, 2005). This evidence highlights the value of using ERP components in the study of language development, and in the investigation of SLI and wider cognitive deficits.

As in the investigation of language, the ERP method has been useful for investigating the theories of, and cognitive processes underlying memory. Curran (2000) investigated the two pathways of recognition memory; recollection and familiarity, proposed by Atkinson & Juola (1973). Curran (2000) found that the FN400 component was different for the familiarity-based and recollection-based recognition of words supporting the dual-processing theory for two dissociable pathways of recognition memory. Schott, Richardson-Klavehn, Heinze and Düzel (2002) used the ERP technique to examine differences in implicit and explicit encoding, as well as the differential effects of deep and shallow levels of processing (Craik & Lockhart, 1972) on these memory systems. Their results supported Schacter's (1987) proposal that implicit and explicit memory operated as separate systems, as the ERP data revealed distinct neural correlates for implicit and explicit encoding. The results also supported findings that shallow and deep levels of processing effect implicit and explicit memory differently (see Toth, Reingold & Jacoby, 1994). Rugg et al. (1998) used ERPs and discovered three functionally dissociable neural correlates activated when previously studied words were presented, with one of the correlates activated when words were implicitly recognised, providing further evidence for the structural and functional dissociation of explicit and implicit memory. The P300 component, proposed to reflect the maintenance of immediate memory and the allocation of attentional resources (Polich & Herbst, 2000), has been found to have longer latencies with cognitive impairments. The P300 has been used as a clinical predictor of possible AD and for examining the increasing memory deficits associated with the advancement of AD (St. Clair, Blackburn, Blackwood & Tyrer, 1988; Ball, Marsh, Schubarth, Brown & Standburg, 1989). As in language, ERP data is both extremely useful for investigating the normal time course of the cognitive processes in memory, and also in predicting and monitoring memory dysfunction.

The ERP method has also been used to investigate cognitive theories of attention. Early components such as the N100 and P100 suggest that visual attention selection occurs early in processing (Heinze, Luck, Mangun & Hillyard, 1990; Mangun, Hillyard & Luck, 1993) having a tendency to operate on locations over objects (Hillyard & Münte, 1984). ERP research has also suggested that attention to locations and objects are associated with different scalp distributions of the N100 component and so may be mediated by separable neural systems (He, Humphreys, Fan, Chen & Han, 2008). Mangun and Hillyard (1987, as cited in Cave & Bichot, 1999, p. 216) found that the amplitudes of the P100 and N100 components decreased as the location of the target stimulus from the attended location increased, suggesting that early attention operates over a gradient, and not a spotlight as suggested by Posner, Snyder and Davidson (1980). The research on attention using ERPs has served to improve psychologists' understanding of attention and the temporal patterns of the processes underlying attention. Importantly due to the superior temporal resolution of the ERP method it has been possible to investigate early attention effects that neuroimaging techniques are not able to investigate. Studies of attentional deficits have also been conducted using the ERP method. The N100 has been found to be decreased in schizophrenic patients alongside diminished P200 and P300 components (Boutros et al. 1997), aiding in the prediction and classification of schizophrenia. The P300 is an important component in the investigation of attentional deficits, and has been found to be different in people with Attention Deficit Hyperactivity Disorder (ADHD). Sawaki & Katayama (2006) found that higher P300 amplitudes had a positive association with higher ratings on ADHD measures. The larger P300 amplitude was proposed to reflect inefficient attention allocation in individuals with ADHD. The P300 has also been found to be sensitive to angry face stimuli in maltreated children, indicating that these children may allocate attention differently to non-maltreated children (Pollak, Klorman, Thatcher & Cicchetti, 2001). Taylor and Baldeweg (2002) summarised evidence showing that the common treatment for ADHD, methylphenidate, normalised the P300, N200 and P200 components leading to improved attentional resource allocation in individuals with ADHD, showing that the ERP method could also be used to examine the effects of treatments on cognitive dysfunction. ERP data has therefore been useful for examining cognitive functions and dysfunctions in language, memory and attention, allowing the investigation of the waveforms relating to the processes involved in language, memorised and forgotten items, attended and unattended items, and several cognitive deficits.

The ERP method has many uses in the investigation of cognitive functions and dysfunctions. However, there are important limitations that must be considered. One of the main aims of " cognitive neuroscientists is to explain the neural basis of…cognitive functions" (Garavan, Ross, Murphy, Roche & Stein, 2002, p. 1820). The ERP method allows for the study of the temporal nature of the processes involved in a particular cognitive function, but the spatial resolution is poor (Woodman & Luck, 2003). Luck (2005) explains that neuroimaging techniques have a spatial resolution in the millimetre range, which cannot be matched by electrophysiological methods. Hillyard and Anllo-Vento (1998) explained that even though ERP data reflects temporal activation patterns within specific neural sites, the localisation of these sites through ERP can only ever be an approximation. The " inverse problem" in ERP measurement (Luck, 2005, p. 33-34) refers to the fact that by knowing a location and the orientation of a set of neurons it is possible to predict their scalp distribution. However, by knowing a scalp distribution it is not possible to calculate the location and orientation of neurons. For example Schott et al. (2002) found that explicitly recalled items processed under deep levels of processing elicited a scalp distribution over the right frontal electrodes, but this does not mean that the generation site of this wave was necessarily in the right frontal lobes. The difficulties in localising particular waves to a specific neural structure occur due to the fact that there are a near infinite number of possible generation sites for any one voltage distribution.

However, computer programs like the brain electrical source analysis (BESA), allow for more solid inferences about spatial localisation from ERP data. BESA calculates a set of neuron locations and orientations that best fits the voltage distribution found in the data and the model created by the program to explain this distribution (Luck, 2005). Techniques like BESA are widely used in ERP research to try and localise the neural generators of ERP waves (see Liotti et al., 2000; Gehring, Himle & Nisenson, 2000). However, despite these methods, at present the only way to assess spatial information is through the use of neuroimaging methods. By combining neuroimaging data with ERP data it is possible to understand both the temporal course of activations related to cognitive processes and the underlying cortical generation sites. In their investigation of Stroop performance Liotti et al. (2000) found that the wave patterns created due to colour-word incongruence were distributed around the Anterior Cingulate Cortex (ACC). By combining this with the considerable PET evidence suggesting that the ACC is the neural site subserving Stroop incongruence (Carter, Mintun & Cohen, 1995; Derbyshire, Vogt & Jones, 1998), it was possible for Liotti et al. (2000) to understand both the brain-behaviour relationship and the precise timings of the processes involved in Stroop task performance. Additonally, Anokhin, Heath and Myers (2004) suggested that the combination of ERP and fMRI data would allow for the greatest understanding of the processes and neural areas involved in ADHD.

There are other disadvantages in using ERPs to investigate cognitive functions and dysfunctions. Firstly, there is a lack of standardisation in ERP methodology. Although the 10-20 electrode placement system (Jasper, 1958, as cited in Coles & Rugg, 1996, p. 3) is commonly used by researchers, several variations on this system permitting the use of more electrodes have been proposed (see Oostenveld & Praamstra, 2001) to promote standardisation in ERP studies. This standardisation is important as the use of too few electrodes may lead to difficulties when applying procedures such as BESA (Michel et al., 2004). Michel et al. suggested sampling from the entire scalp when attempting spatial localisation from ERP data to avoid incorrect conclusions. The drawback of using larger numbers of electrodes to measure the entire scalp is the increase of interference and noise, which must be appropriately dealt with. From a developmental viewpoint, care must also be taken as ERP recordings not only measure cognitive development but also reflect changes in skull density, and neuron growth (Nelson & Monk, 2001). Molfese, Molfese and Kelly (2001) highlighted the problematic nature of the use of the 10-20 system on infants. Differences in head size and brain development between children and adults means that the electrodes do not overlay the same brain regions in both these populations raising issues about the validity of comparing data obtained from infants and adults, such as in language research and research concerning the development of attentional deficits.

One of the main difficulties with the ERP method comes from extracting and defining components. Many researchers measure ERP components through the amplitude and latency of the peaks and troughs of the waves. The reasoning behind the measurement of peaks and troughs for extracting components is not clear, as their timings do not necessarily relate to the temporal characteristics of the underlying neural system(s) (Coles & Rugg, 1996; Kayser & Tenke, 2003). Techniques like Principle Components Analysis, although not perfect, allow for the extraction of components, such as the ones discussed, which have been useful in furthering the understanding of the temporal processes and possible neural generation sites of cognitive functions and dysfunctions (Coles & Rugg, 1996). As well as difficulties extracting components, there are ambiguities about the cognitive processes that waves represent. The P300 is a widely investigated component (Luck, 2005), but it has been proposed to be involved in attentional resource allocation (Ravden & Polich, 1998), the maintenance of working memory (Polich & Herbst, 2000), and context updating (Donchin, 1981, as cited in Luck, 2005, p. 42). Similarly the P600 component has been found be elicited by both syntactic and semantic anomalies (van Herten, Kolk & Chwilla, 2005). Therefore care must be taken when making inferences about the exact processes that a component may reflect, as it must be acknowledged that knowing the effects of various manipulations on wave amplitudes and latencies does not necessarily lead to a clear understanding of the cognitive process reflected (Luck, 2005). Simple task changes can also lead to differences in the elicitation of wave components. Heinze et al. (1990) failed to elicit a posterior N100 component in their study of early attention selection, and proposed that this was due to differences in the task compared to research where the N100 had been elicited. This highlights that it is important to be careful when making assumptions about cognitive functions and dysfunctions, as small experimental manipulations may change, or eliminate a specific ERP component; carefully designed experiments are essential (Luck, 2005). Finally Boutros et al. (1997) highlighted that ERP component amplitudes and latencies vary along a continuum with overlaps between patients and non-patients occurring. Therefore, whilst a useful method in the investigation of cognitive dysfunction, the ERP method must be carefully combined with other clinical and behavioural measures in order to avoid misdiagnosis.

An important point for measurement in the ERP method is the need to control for background interference. In ERP studies filters are applied to eliminate background noise and movement artefacts. There are several different approaches for dealing with artefacts (see Talsma & Woldorff, 2005) but it is possible that in correcting for artefacts ERP data is distorted. These possible distortions must be acknowledged when using ERP data for making inferences about cognitive functions and dysfunctions. Luck (2005) suggests rejecting all data affected by artefacts wherever possible. Further, the use of different reference sites on the scalp can lead to problems when using ERP data. Reference sites, assumed to be constant in electrical activity across the temporal course of the ERP measurement, such as the earlobes or mastoids can be affected differentially by different experimental manipulations and electrical fields diffusing from both close and distant neural generators (Junghöfer, Elbert, Tucker & Braun, 1999). This means that the differences in reference sites used across studies may lead to differences in the interpretation of ERP components (Michel et al., 2004). Therefore care must be taken when studying cognitive functions, and in particular making inferences about cognitive dysfunctions. The combination of electrophysiological and neuroimaging methods may allow for the ultimate understanding of brain-behaviour relations as both temporal activation patterns, and underlying structural areas will be able to be studied, with the data from each helping to account for the weaknesses of the approaches alone. Rugg & Coles (1996) proposed that combinations of ERP, Magnetoencephalography, and neuroimaging techniques may allow the ultimate understanding of both the temporal and spatial properties of cognitive functions and dysfunctions. Recently the use of intracranial ERPs (iERPs) has allowed the study of cognitive processes at an excellent temporal and spatial resolution (Taylor & Baldeweg, 2002). Although iERPs are invasive, and so have mainly been used with adult patients, they hold the potential to be extremely useful in the future study of cognitive function and dysfunction in both adults and children.

The ERP technique has been to investigate several cognitive functions and dysfunctions, leading to the identification of several ERP components. The excellent temporal resolution provided by the ERP technique allows the investigation of the precise timings of the processes underlying cognitive functions. However, the poor spatial resolution provided by the ERP method means that the understanding of precise brain-behaviour relations is not possible. Care must be taken when using ERPs in the investigation of cognitive functions and dysfunctions as methodological issues, and difficulties in inferring components to exact cognitive processes can lead to misdiagnosis in a clinical setting, and difficulties in studying cognitive functions and dysfunction. The combination of ERPs and other methods may allow for the ultimate understanding of brain-behaviour relations as both temporal activation patterns, and underlying structural areas will be able to be studied. Despite some disadvantages the ERP method has proved to be an invaluable method in the investigation of cognitive functions and dysfunctions, highlighting differences in brain activity that can be used both to predict future cognitive functioning, and to identify cognitive dysfunction. With further development and combination with other methods, the value of the ERP method in investigating cognitive functions and dysfunctions can only increase.

Word Count = 3, 295.