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Can event-related potentials serve as neural markers for wins, losses, and near-wins in a gambling task? A principal components analysis

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ABSTRACT

Originally, the feedback related negativity (FRN) event-related potential (ERP) component was considered to be a robust neural correlate of non-reward/punishment processing, with greater negative deflections observed following unfavourable outcomes. More recently, it has been suggested that this component is better conceptualised as a positive deflection following rewarding outcomes. The current study sought to elucidate the nature of the FRN, as well as another component associated with incentive-value processing, the P3b, through application of a spatiotemporal principal components analysis (PCA). Seventeen healthy controls played a computer electronic gaming machine (EGM) task and received feedback on credits won or lost on each trial, and ERPs were recorded. The distribution of reward/non-reward outcomes closely matched that of a real EGM, with frequent losses, and infrequent wins and near-wins. The PCA revealed that feedback elicited both a frontally maximal negative deflection to losses, and a positive deflection to wins (which was also sensitive to reward magnitude), implying that the neural generator/s of the FRN are differentially activated following these outcomes. As expected, greater P3b amplitudes were found for wins compared to losses. Interestingly, near-wins elicited significantly smaller FRN amplitudes than losses (with no differences in P3b amplitude), and may contribute to the maintenance of gambling behaviours on EGMs. The results of the current study are integrated into a response profile of healthy controls to outcomes of varying incentive value. This may provide a foundation for the future examination of individuals who exhibit abnormalities in reward/punishment processing, such as problem gamblers.

1. Introduction

The neural mechanisms involved in the processing of reward and non-reward/punishment are of particular relevance to addictive disorders, such as problem gambling, as abnormalities in incentive value processing are believed to be one of the causal factors in such disorders. For example, problem gamblers may be hyposensitive to non-reward/punishment (e.g., Reuter et al., 2005) and thus, the repeated detrimental losses experienced during gambling activity are not perceived to be averse; they may be hypersensitive to reward (e.g., Hewig et al., 2010; Oberg et al., 2011) and pursue wins at the expense of high costs; or they may be hyposensitive to reward (e.g., Blum et al., 2000) and engage in thrill-seeking behaviour (such as trying to obtain large wins) in order to reach the same level of excitement associated with smaller wins in non-problem gamblers.

A particularly valuable index of incentive value processing is the feedback related negativity (FRN), an apparently robust and reliable event-related potential (ERP) component sensitive to valence manipulations. The FRN is maximal at fronto-central scalp sites and there is consensus that medial frontal cortical areas, especially the anterior cingulate cortex (ACC), are involved in its generation (Bellebaum and Daum, 2008; Miltner et al., 1997; Nieuwenhuis et al., 2004). Because of potential links to reward mechanisms through activation of the mesencephalic dopamine system (Holroyd and Coles, 2002), the FRN has major significance, particularly for gambling behaviours, as it provides a window through which the effects of reward and non-reward outcomes within the brain might be usefully examined.

Recently, there has been debate regarding the nature of this ERP component; specifically, whether it is best conceptualised as a negative deflection following unfavourable outcomes or as a positive deflection following favourable outcomes. Earlier conceptualisations of the FRN were that it is a component characterised by greater negative responses 250–350 ms following feedback that signals monetary losses compared to gains (San Martin et al., 2010; Toyomaki and

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Murohashi, 2005; Yeung et al., 2005), or the least desired of two possible outcomes within a certain context (e.g., zero credits elicit larger FRNs than wins when the alternative outcome is to gain credits, compared to when the alternative is to lose credits; Gehring and Willoughby, 2002; Holroyd et al., 2004), during tasks that resemble gambling activity. Subjective expectancy of an outcome has also been shown to affect the FRN, with larger amplitudes associated with unexpected compared to predicted negative outcomes, although this effect appears to be more subtle and may not always follow objective probabilities of such events (Hajcak et al., 2005, 2006). Whilst the link between FRN and valence appears consistent, manipulations of incentive value magnitude have yielded equivocal results. Specifically, some studies suggest that larger losses (compared to smaller losses) and smaller gains (compared to larger gains) yield larger FRN magnitudes (e.g., Bellbaum et al., 2010; Holroyd et al., 2004), whilst others have found no magnitude effects (e.g., Gu et al., 2010; Hajcak et al., 2006; Yeung and Sanfey, 2004).

While the negative deflection to unfavourable outcomes described above has been reported in a wide variety of circumstances, including simulated gambling (Hewig et al., 2007), guessing tasks (Hajcak et al., 2006; Hajcak et al., 2005, 2007), time estimation tasks (Holroyd and Krigolsen, 2007; Miltner et al., 1997; Nieuwenhuis et al., 2005), and learning tasks (De Pascalis et al., 2010), the true nature of the FRN remains somewhat unclear, as this component is commonly superimposed on large amplitude P300 responses that occur immediately after it. It has been proposed that the reduced amplitude FRN observed following win outcomes may not be an actual attenuated response to these events, but is rather driven by larger P300 amplitudes following favourable outcomes (Yeung and Sanfey, 2004). Furthermore, the relative contribution of negative and positive outcomes to the FRN remains unclear due to the fact that many studies have employed the computation of a difference waveform to measure FRN magnitude (e.g., Dunning and Hajcak, 2007; Foti and Hajcak, 2009; Hajcak et al., 2007; Holroyd et al., 2008; Miltner et al., 1997), and other recent research has suggested that, rather than a negative deflection to non-reward outcomes, the FRN is better conceptualised as a positive deflection that is greater following reward compared to non-reward outcomes (Foti et al., 2011; Holroyd et al., 2003, 2008).

Regardless of the actual response pattern, investigation of the latent spatial and temporal characteristics of this feedback related ERP component (whether it be a negative deflection to non-reward or a positive deflection to reward) in healthy controls using a principal components analysis (PCA) will allow a more reliable and accurate account of the neural correlates associated with incentive value processing. This will encourage the future examination of whether these responses differ in individuals who display deficits in outcome evaluation, such as those with gambling problems.

Typically examined as a global component, the P300 (called the LPC in many studies), has also been shown to be sensitive to various aspects of incentive value on tasks that simulate gambling (Bellbaum et al., 2010; Hajcak et al., 2007). The inverse relationship between probability and P300 amplitude has been well established (Donchin and Coles, 1988), although the understanding of these results is subject to different interpretations (see Gonsalvez et al., 2007; Verleger, 1988). Nevertheless, studies that have controlled for event probability have demonstrated that the P300 remains sensitive to win and loss outcomes (e.g., Hajcak et al., 2007; Wu and Zhou, 2009; Yeung et al., 2005; Zhou et al., 2010), although the pattern of these results is somewhat variable. Some studies report a double dissociation between the FRN and P300, showing the FRN to be affected by valence but not reward magnitude, with the opposite pattern for the P300, regardless of whether the outcome is of positive or negative valence (Sato et al., 2005; Yeung and Sanfey, 2004). In contrast to this, other research has demonstrated that the P300 is influenced by valence, with wins eliciting larger amplitudes than losses (Hajcak et al., 2007; Toyomaki and Murohashi, 2005). Because the P300 is established to be a complex comprising several sub-components, it is possible that different subcomponents are independently sensitive to valence and magnitude. For instance, stimulus salience is known to affect the P3b and win events may elicit larger P3bs on account of their greater salience than losses. Therefore, it is of value to determine which of the sub-components of the P300 are affected by win and loss outcomes.

By using a spatiotemporal PCA, the current study sought to examine the latent nature of both the FRN and the LPC ERP subcomponents, that may not be perceptible using traditional ERP data extraction methods, in response to manipulations of valence and magnitude within a simulated electronic gaming machine (EGM; also called a 'poker' or 'slot' machine) task. EGMs typically deliver a large number of win and loss outcomes in a short period of time and are of particular clinical significance to problem gambling. Compared with other gambling activities, a high percentage of gamblers seeking treatment report addiction to EGMs (see Dowling et al., 2001), and EGM gambling is associated with a faster progression of addiction (Breen and Zimmerman, 2002) and more severe symptoms (Petry, 2003). In the current study all key EGM outcomes were of interest, including large and small wins, losses, and near-wins (see Method Section 2.2.2. for details on these outcomes). Traditional ERP research has shown near-wins to be less aversive (Luo et al., 2011) and more rewarding than losses (Qi et al., 2011), and neuroimaging research has shown that, while these outcomes are rated as more unpleasant than losses, they increase motivation to gamble by recruiting reward related brain circuitry (Clark et al., 2009). The current study sought to examine whether the latent neural correlates of incentive value processing are differentially activated for these outcomes compared to losses, in order to evaluate their role in the development and maintenance of gambling behaviours.

In summary, the current study sought to utlilise a PCA to parse two ERP components previously found to index various aspects of incentive value processing from overlapping data, and to evaluate their capacity to discriminate between win, loss, and near-win outcomes, as well as rewards of different magnitudes.

2. Method

2.1. Participants

Seventeen undergraduate psychology students (7 male, 10 female, $M_{age} = 18.7$ years; $SD = 4.8$, age range = 18–23 years) from the University of Wollongong participated in the experiment in return for course credit. No participants reported using nicotine, alcohol, or prescription/illicit drugs in the two hours prior to testing, or a history of severe brain injury or seizures. Written informed consent was obtained from all participants, who were advised that participation was entirely voluntary, and that they could withdraw from the study at any time. The study's protocol was approved by the University of Wollongong Human Research Ethics Committee.

2.2. Materials

2.2.1. Recording equipment

EEG was recorded from a 19-site electrode cap (comprised of tin electrodes fitted in the standard international 10–20 system layout) using NuAmps 2.0 software (NeuroScan Compumedics, USA). The electrodes were referenced to linked ears and grounded by a cap electrode located mid-way between Fpz and Fz. Vertical eye movement (vEOG) was monitored with two tin cup electrodes: one placed 2 cm above and the other 2 cm below the left eye. Horizontal eye movement (hEOG) was monitored with two tin cup electrodes placed adjacent to the outer canthus of each eye. Impedance was less than 5 kΩ for cap electrodes and less than 3 kΩ for EOG and reference electrodes. Scalp EEG potentials were amplified ×20,000, EOG