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# The effect of graded monetary reward on cognitive event-related potentials and behavior in young healthy adults

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**Abstract**

Temporal correlates of the brain circuit underlying reward processing in healthy adults remain unclear. The current study investigated the P3 and contingent negative variation (CNV) as putative reward-related temporal markers. The effect of sustained monetary reward on these event-related potentials and on behavior was assessed using a warned reaction-time paradigm in 16 young healthy subjects. Monetary reward (0, 1 and 45 cents) varied across blocks of trials. While the CNV was unaffected by money, P3 amplitude was significantly larger for 45 than the 1 and 0 cent conditions. This effect corresponded to the monotonically positive subjective ratings of interest and excitement on the task (45 > 1 > 0). These findings suggest a difference between the P3 and CNV; the P3 is sensitive to the sustained effect of relative reward value, while the CNV does not vary with reward magnitude.


*Keywords:* ERP; Reaction time; Monetary reward; P3; CNV

## 1. Introduction

Reward processing is complex and involves the contribution from multiple interacting brain regions. Numerous functional neuroimaging studies in humans have helped to spatially define this neural mesocorticolimbic dopaminergic reward circuitry that encompasses the ventromedial prefrontal cortex, orbitofrontal cortex, anterior cingulate, nucleus accumbens, midbrain (e.g., substantia nigra and ventral tegmentum), amygdala and the hippocampus (for review, see Goldstein and Volkow, 2002; Kelley and Berridge, 2002). Further, neuroimaging studies have contributed to the functional dissociation of these regions based on their specific roles in reward processing (e.g., expectancy and probability, outcome and magnitude, valence) (Breiter et al., 2001; Elliott et al., 2000; Knutson et al., 2005). However, current functional neuroimaging studies lack the temporal resolution to provide the precise chronological delineation of such reward-related activity. This can be attained through the use of event-related potentials (ERPs). Surprisingly, relatively few studies have employed ERPs to investigate intact reward processing; therefore, its temporal correlates remain to be determined.

One well-studied ERP component that seems to play a role in reward processing is the P3 (or P300), a positive wave usually peaking between 300 and 600 ms post-stimulus with largest amplitude at centroparietal scalp sites (Sutton et al., 1965). The major factors affecting P3 amplitude include stimulus probability and task relevance (Squires et al., 1977). Stimuli with high emotional value, informative feedback stimuli and target stimuli also elicit larger P3s than stimuli that do not have these properties (Johnson, 1988; Picton, 1992; Pritchard, 1981). We therefore expected the P3 to be elicited by a monetary feedback manipulation; indeed, the P3's involvement in monetary reward, and specifically in marking reward's magnitude, has been previously documented (Begleiter et al., 1983; Homberg et al., 1981; Otten et al., 1995; Ramsey and Finn, 1997; Yeung and Sanfey, 2004). For example, Ramsey and Finn (1997) used a

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visual discrimination task where subjects were instructed to respond to target stimuli in a neutral condition (no monetary incentive) vs. an incentive condition (monetary gain of 50 cents for correct responses and loss of 50 cents for incorrect responses). Greater amplitude and shorter latency of the P3 was reported in the incentive condition as compared to the neutral condition. In a recent study, Yeung and Sanfey (2004) revealed a double dissociation between the P3 and feedback negativity (a negative component occurring 200 to 300 ms after a feedback stimulus) such that reward magnitude (small: 6–11 cents vs. large: 32–40 cents) was reflected by the P3, but not by feedback negativity, and reward valence (win or loss) was reflected by feedback negativity only.

Unlike most previous studies, the current investigation was designed to induce sustained anticipation of graded monetary reward. This design allowed for comparisons between different amounts of money, which could highlight the role of the P3 in processing of relative reward and not only in processing reward's absolute value (i.e., reward vs. no reward). We were interested in inspecting sustained (blocked) and not event-related (rapidly alternating) anticipation of reward, because of our interest in the examination of relative reward processing in a real-world context, where emotional/motivational information is more likely to occur in a sustained fashion over several minutes, rather than alternating rapidly with information of a different emotional tenor (Compton et al., 2003). Our interest in sustained reward was further guided by the prospect of future studies utilizing functional magnetic resonance imaging (fMRI), where signal-to-noise ratio is higher in blocked vs. event-related designs (for a direct comparison, see Mechelli et al., 2003), a concern that is particularly relevant in studies of clinical populations (e.g., with a psychopathology that affects reward processing such as drug addiction).

While there have been several studies investigating the role of P3 in reward processing, less attention has been directed to the CNV (contingent negative variation), a slow component typically elicited in Go/No-go paradigms and associated with expectancy in the human brain (Walter et al., 1964). In warned S1–S2 Go/No-go paradigms, the CNV develops early in response to the warning stimulus (S1), having a frontal distribution (the orienting, "O", wave); its latter part develops immediately preceding the target stimulus (S2), having a centroparietal distribution (late expectancy, "E", wave). We were particularly interested in this later CNV component, which is anticipatory in nature, further related to motor response preparation or the readiness potential of the motor potential complex (Rohrbaugh et al., 1986) and to motivation (Cant and Bickford, 1967).

However, although preparation to and anticipation of reward are core mechanisms in reward processing (Knutson et al., 2001; Volkow et al., 2003), this slow ERP component has not been frequently targeted in the study of reward processing and conflicting results abound to date. Thus, while some studies point to a role of the CNV in reward processing (Boyd et al., 1979; Pierson et al., 1987), other studies suggest otherwise (Lumsden et al., 1986; Sobotka et al., 1992). For example, Pierson et al. (1987) conditioned subjects to associate one tone with monetary gain (reward) and another tone with loss of money (punishment); a third tone was not associated with reward or punishment (neutral stimulus). Following the conditioning phase, they found that CNV amplitude differed between rewarding conditioned stimuli and neutral or punishing conditioned stimuli. Other evidence supporting the relationship between the CNV and reward derives from animal literature; Boyd et al. (1979) examined the CNV in the squirrel monkey and found that it varied as a function of reward (but not consistently in the same direction across all animals). Conversely, Sobotka et al. (1992) manipulated reward and punishment contingencies such that subjects were instructed whether they could potentially win or lose money (25¢) on each trial. To win money (on reward trials) or avoid losing money (on punishment trials), subjects had to press or release a button faster than a specified response time, while responding slower resulted in either no monetary gain or loss of money, respectively. While the CNV was larger for trials on which subjects had faster response times, it did not vary with reward or punishment.

The purpose of the current study was to investigate cognitive ERPs, especially the P3 and CNV, evoked by warning (S1) and target (S2) stimuli in a Go/No-go paradigm and their modulation by magnitude of sustained monetary reward (high, low and none as baseline) in the intact brain. Event-related potential variations were interpreted in conjunction with behavioral measures (including reaction time, accuracy and self-reported interest and excitement ratings) in 16 healthy young subjects. While we hypothesized the P3 to be modulated by reward magnitude (high > low > none), our analyses of the CNV were more exploratory in nature.

## 2. Materials and methods

### 2.1. Participants

Subjects were 16 college students (age: $M=21.56$, S.D. $=1.9$; education: $M=14.9$, S.D. $=2.05$; sex: 56% female; race: 56% Caucasian; handedness: 88% right) free of neurological disorder by self-report. Subjects were given a basic monetary fee ($5) for participating and the opportunity to earn additional money ($20) based on the ERP task performance. All procedures were undertaken in accordance with the Stony Brook University Committee on Research Involving Human Subjects (Institutional Review Board).

### 2.2. Task

A blocked design (sustained activation) was selected over an event-related paradigm (rapid alternation) as most appropriate for examining the continuous electrophysiological activation induced by predictable and constant monetary reward. Prior behavioral studies have demonstrated that emotional/motivational stimuli become more potent when they are grouped together into blocks, rather than when they are intermixed with neutral trials (Holle et al., 1997; see also Compton et al., 2000; Dalgleish, 1995).