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REWARD CONTINGENCIES AND THE RECALIBRATION OF TASK MONITORING AND REWARD SYSTEMS: A HIGH-DENSITY ELECTRICAL MAPPING STUDY

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Abstract—Task execution almost always occurs in the context of reward-seeking or punishment-avoiding behavior. As such, ongoing task-monitoring systems are influenced by reward anticipation systems. In turn, when a task has been executed either successfully or unsuccessfully, future iterations of that task will be re-titrated on the basis of the task outcome. Here, we examined the neural underpinnings of the task-monitoring and reward-evaluation systems to better understand how they govern reward-seeking behavior. Twenty-three healthy adult participants performed a task where they accrued points that equated to real world value (gift cards) by responding as rapidly as possible within an allotted timeframe, while success rate was titrated online by changing the duration of the timeframe dependent on participant performance. Informative cues initiated each trial, indicating the probability of potential reward or loss (four levels from very low to very high). We manipulated feedback by first informing participants of task success/failure, after which a second feedback signal indicated actual
Q4 **magnitude of reward/loss. High-density EEG recordings allowed for examination of event-related potentials (ERPs) to the informative cues and in turn, to both feedback signals. Distinct ERP components associated with reward cues, task-preparatory and task-monitoring processes, and reward feedback processes were identified. Unsurprisingly, participants displayed increased ERP amplitudes associated with task- preparatory processes following cues that predicted higher chances of reward. They also rapidly updated reward and loss prediction information dependent on task performance after the first feedback signal. Finally, upon reward receipt, initial reward probability was no longer taken into account. Rather, ERP measures suggested that only the magnitude of actual reward or loss was now processed. Reward and task-monitoring processes are clearly dissociable, but interact across very fast timescales to update reward predictions as information about task success or failure is accrued. Careful delineation of these processes will be useful in future investigations in clinical groups where such processes are suspected of having gone awry. © 2014 Published by Elsevier Ltd. on behalf of IBRO.**

Key words: reward, punishment, task monitoring, EEG, ERP, motivation. Q5

INTRODUCTION

It could reasonably be argued that all activity undertaken by an organism is in the service of achieving reward, either in the short or long term. Organisms must determine the potential value of a reward and develop and adjust reward expectations depending on environmental contingencies, and monitoring of ongoing activity and calibration of task effort and preparation occur in the context of these reward expectations and are adjusted based on outcomes (Ryan et al., 1983; Deci et al., 1999). There has been great interest in the neural underpinnings of both reward processing and task monitoring and how these processes and their underlying brain circuitry interact to govern reward-seeking behavior.

Functional magnetic resonance imaging (fMRI) has demonstrated the presence of at least partially distinct brain mechanisms for task monitoring and reward processing. Work has implicated the orbitofrontal and prefrontal cortices in the representation of rewarding items and reward prediction while participants performed gambling tasks (Dreher et al., 2006; Preuschoff et al., 2006) or delayed reward tasks (Kable and Glimcher, 2007). Meanwhile, the ventral striatum and anterior cingulate cortex have been implicated in task monitoring when participants made errors while bidding

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Abbreviations: BESA, Brain Electric Source Analysis software suite; CMS, Common Mode Sense; CNV, contingent negative variation; CRN, cue-related negativity; DRL, Driven Right Leg; ERN, error-related negativity; ERP, event-related potential; FRN, feedback-related negativity; RM-ANOVA, repeated measures analysis of variance; SCP, statistical cluster plot; UDTR, up-down transformed-rule.

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for rewards (Hare et al., 2008), when participants evaluate task effort needed to obtain primary rewards (Prevost et al., 2010), and when evaluating conflict between high-risk or low-risk choices (Kuhnen and Knutson, 2005).

Neuroimaging, however, is not ideal for examining the interaction of processes that may occur over very fast timescales. To this end, researchers have examined various components of the event-related potential (ERP), which provide temporally precise measures of information processing well-suited for the examination of reward processing and task monitoring. Work by Pedroni et al. (2011), which examined the timing and topography of reward responses, has put forth the suggestion that early processing of reward feedback results in a binary, ''Good/bad'' evaluation, while later processes take into account more detailed information. Further, their work identified different topographies for rewards and losses, suggesting a need to examine these processes in more detail. ERP components associated with reward processing include the so-called ''Correct Related Positivity,'' which arises as early as 200 to 250 ms after cues predicting reward (Holroyd et al., 2011; Yu et al., 2011), and the P300, a component that arises later between 300 and 600 ms and is usually associated with arousal and attention to task (Polich and Kok, 1995). The P300 is also sensitive to elements of reward processing, such as the magnitude and valence of the reward (Hajcak et al., 2005; Sato et al., 2005; Wu and Zhou, 2009). However, there remain open questions in this literature about these components. Work by Yeung and Sanfey (2004) suggested that the P300 is sensitive to reward magnitude alone. By investigating reward and monitoring in separate stages, we are well positioned to shed light on this question.

ERP research of task monitoring in the context of reward has focused on a component often referred to as the feedback-related negativity (FRN), a negative-going deflection in the ERP occurring approximately 200–300 ms after the receipt of external feedback (Miltner et al., 1997). Task monitoring and cognitive control in non-reward contexts has also been measured using the error-related negativity (ERN), which is believed to reflect internally generated error-monitoring signals as opposed to responses to external feedback like the FRN. However, it has been suggested that both the ERN and FRN reflect the same anterior cingulate mechanisms (Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Nieuwenhuis et al., 2004). Further, a sustained negativity called the contingent negative variation (CNV) precedes the onset of a predicted stimulus that requires a response (Walter et al., 1964). The CNV can be affected by motor or cognitive processes (Leynes et al., 1998) and the probability of having to make a specific response (Dias et al., 2003). Source analysis of the CNV has implicated not only premotor and sensory areas, but also aspects of the fronto-parietal network that may underlie evaluation of task effort (Gomez et al., 2007).

Interactions between reward processing and task monitoring have also been investigated during performance of a spatial incompatibility task, wherein participants responded using vertically oriented response keys to stimuli that appeared above or below a fixation cross. This created both spatially compatible trials and more difficult spatially incompatible trials, in a manner similar to the well-known Simon task (Simon and Wolf, 1963). When reward was contingent upon performance, the ERN and FRN amplitudes differed compared to blocks of trials when reward was not contingent upon performance (Sturmer et al., 2011). However, there is conflict in the literature about whether the FRN is purely related to monitoring of good- or bad-task outcomes regardless of reward. Some have suggested that it reflects only the salience of an unexpected response (Ferdinand et al., 2012) while others have suggested it reflects prediction errors in the context of reward (Cohen et al., 2007) and is dependent on monitoring related to details about reward (Yeung and Sanfey, 2004; Hajcak et al., 2006). Research focused upon the FRN is not alone in raising questions about the interaction of reward and monitoring. While some research has suggested that the CNV is insensitive to reward (Goldstein et al., 2006), other work has demonstrated an influence of monetary incentives (Hughes et al., 2012).

The goal of the current study was to examine reward processing and task monitoring in depth, as well as the interactions between these processes. Much of the previous work investigating these mechanisms presented the reward outcome simultaneously with task performance feedback. This potentially conflates task monitoring with aspects of reward processing. To our knowledge, no studies have expressly divided task and performance feedback in an ERP paradigm designed to examine reward and monitoring separately. Here, we designed a task to at least partially dissociate feedback about received reward from feedback about task execution. Our paradigm took the form of a speeded reaction time task wherein the presentation of a symbolic cue provided information to the participant about the upcoming probability of monetary gains or losses based upon performance. The unique manipulation of our task was that participants received immediate feedback when they responded, informing them only if they had successfully executed their response within an allotted timeframe. This allowed them to make a second prediction about the magnitude of the reward they were likely to receive. In turn, participants received a second instance of feedback informing them of the actual magnitude of their losses or gains. By systematically varying reward expectation and reward outcome, we set out to explore the interface of task monitoring and reward processing, and how the mechanisms that underlie these processes are altered as a function of differing reward contingencies. We recorded high-density EEG from a 168-channel montage, which allowed us to investigate not only the ERP components associated with reward motivation and task monitoring but to also perform source analysis in order to model the underlying neural sources.