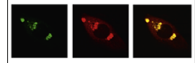


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Research Report

Modulation of the brain activity in outcome evaluation by the presence of an audience: An electrophysiological investigation

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ABSTRACT

The audience effect refers to the phenomenon that one's performance on a task is affected by the presence of others. Here we investigated how the audience effect modulates the neurocognitive signatures underlying people's evaluation of their own task performance/outcome. Participants in our study played a gambling game in two social contexts: an "audience" condition and an "alone" condition. The presence of others modulated the feedback-related negativity (FRN), which might reflect enhanced motivational significance or increased reward processing when participants were watched compared to when they were alone. We also observed increased P300 responses to outcome feedback in the audience condition, presumably reflecting more elaborative and sustained evaluation of outcomes in the audience than alone context. This audience effect on the evaluative processes complements previous observations on the social nature of outcome evaluation and extends a traditional topic in social psychology to the neuroscientific field.

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1. Introduction

The audience effect refers to the phenomenon that one's task performance is affected by the presence of others (Zajonc, 1965). This effect is thought to reflect enhanced motivational

level or attention focus induced by the presence of others (Huguet et al., 1999; Zajonc, 1965). A plethora of studies in social psychology have demonstrated the audience effect on executive functions and social behaviors in both humans and animals (Andreoni and Bernheim, 2009; Cottrell et al., 1968;

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Evans and Marler, 1991; Huguet et al., 1999; Izuma et al., 2010; Plath et al., 2008). However, it remains unclear how the audience effect modulates the neurocognitive mechanisms underlying the evaluation of one's own performance/outcome on a task. In particular, how the temporal dynamics of neural feedback processing, which are closely related to the motivational significance of an event (Gehring and Willoughby, 2002) and play a central role in guiding one's behavior (Cohen and Ranganath, 2007; Holroyd and Coles, 2002), are affected by the presence of an audience remains an open question.

In the previous decade, efforts to explore the neuropsychological signatures of outcome evaluation using the event-related potential (ERP) technique have increased considerably (Walsh and Anderson, 2012). The neurocognitive correlates of evaluative processes are consistently manifested as modulations of the feedback-related negativity (FRN) and the P300 components of ERPs by outcome valence and magnitude as well as other variables (Oliveira et al., 2007; Sato et al., 2005; Yeung and Sanfey, 2004). The FRN component evoked by unfavorable outcomes is often more negative-going than that by favorable outcomes (Hajcak et al., 2006; Miltner et al., 1997); therefore, this early ERP component is thought to reflect violations of outcome expectancy (Hajcak et al., 2007; Holroyd and Coles, 2002) or enhanced motivational significance induced by negative outcomes (Gehring and Willoughby, 2002). However, an accumulating body of the literature has shown that the FRN may reflect an enhanced positive deflection to favorable outcomes which is generated in part by the activity of reward-related brain regions (Becker et al., 2014; Carlson et al., 2011; Foti et al., 2011, 2014; Holroyd et al., 2008). In agreement with this hypothesis, the FRN amplitudes are positively correlated with hemodynamic responses in reward-related brain regions including ventral striatum and medial prefrontal cortex (Becker et al., 2014; Carlson et al., 2011). The later P300 component is thought to reflect elaborative and sustained evaluation of ongoing events (Philiastides et al., 2010; Schupp et al., 2004). The P300 amplitudes are determined by multiple factors relevant to the allocation of attention resources such as outcome magnitude and the arousal level of events (Gu et al., 2011; Olofsson et al., 2008; Wu and Zhou, 2009; Yeung and Sanfey, 2004).

Notably, recent studies have demonstrated the social nature of these evaluation-related ERP responses by showing that the FRN and the P300 components are sensitive to the social contexts in which outcomes are evaluated (e.g., Boksem et al., 2011; Li et al., 2010). For instance, the FRN and the P300 are elicited when participants are observing the outcome feedback received by other people (Leng and Zhou, 2010; Yu and Zhou, 2006), and these observational FRN and P300 are modulated by the interpersonal relations between the observer and the observed (Kang et al., 2010; Koban et al., 2010; Leng and Zhou, 2010). Furthermore, outcome feedback of social interactions (e.g., unfair treatment) also evoke FRN-like and P300 components (Alexopoulos et al., 2012; Boksem and De Cremer, 2010; Luo et al., 2014; Wu et al., 2011a, 2011b, 2012), which again are affected by social relations (Campanha et al., 2011; Wu et al., 2011a). Most importantly, it has been shown that neural responses to evaluative processes are augmented by the watching of experimenters as compared

to a control condition (Hajcak et al., 2005b; Simon et al., 2014). For instance, Hajcak et al. (2005b) reported that the error-related negativity (ERN) evoked by incorrect responses was larger when participant's performance was being evaluated by an experimenter relative to a control condition. Noteworthy, it has been proposed that ERN and FRN originate from the same system which updated the response production system applying information for both correct/incorrect responses and feedback indicating success/failure (Holroyd and Coles, 2002). The influence of social contexts on the evaluative processes is presumably attributed to the context-dependent motivational significance of outcomes or actions such that the same events could be important in some contexts but not in others (Boksem et al., 2011; Hajcak et al., 2005b; Li et al., 2010).

The primary aim of our study was to improve the understanding of the social nature of evaluative processes by unveiling how the FRN and P300 responses to outcome feedback were affected by the presence of a passive audience. Here, we asked participants to play a gambling game in two social contexts: an audience condition in which a confederate watched participants playing the game and an alone condition in which participants were left alone (Fig. 1). The experimenter was absent in both conditions to enable a real alone condition and to avoid other potential confounding factors (see also Huguet et al., 1999). We employed a card guessing task designed by Delgado and colleagues (Delgado et al., 2000) due to its simplicity, and this task has been frequently used to identify neural responses to outcome evaluation (e.g., Fareri and Delgado, 2014; Tricomi et al., 2006).

In light of previous findings, it was expected that negative feedback would evoke a more negative-going FRN than positive feedback. Importantly, the amplitudes of FRN difference wave (amplitudes of negative feedback minus those of positive feedback) were expected to be augmented by the presence of an audience, presumably due to higher motivation level in the audience condition than the alone condition. Furthermore, previous studies have reported inconsistent valence effects on the P300 amplitudes (Li et al., 2010), but many studies have consistently revealed that the P300 is sensitive to the arousal level of ongoing events (Olofsson et al., 2008). Therefore, it was hypothesized that P300 amplitudes would be generally larger in the audience condition than the alone condition irrespective of feedback valence.

2. Results

2.1. Behavioral performance

A paired *t*-test [$t(18)=0.98, p=0.40$] on RT did not reveal significant differences between the audience condition (mean \pm standard error: 693.6 ± 41.5 ms) and the alone condition (mean \pm standard error: 665.9 ± 34.0 ms).

2.2. ERP

2.2.1. FRN

The three-way repeated measures analysis of variance (ANOVA) of context (audience vs. alone) \times valence (negative

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