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Impulsive personality dimensions are associated with altered behavioral performance and neural responses in the monetary incentive delay task

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ABSTRACT

Individual differences in dimensions of impulsivity personality including disinhibition and sensation seeking modulate approach responses to reinforcing stimuli, such as drugs and money. The current study examined the effects of monetary incentive on both behavioral performance and electrophysiological activity among individuals varying in disinhibition and sensation seeking. The monetary incentive delay (MID) task was completed under electroencephalogram (EEG) recording. Behavioral data showed that higher disinhibition and sensation-seeking were associated with lower performance accuracy. Event-related potential (ERP) data showed that high reinforcement cues elicited a larger late positive component (LPC) than other conditions among high disinhibition participants, indicating its strong emotional influence. Additionally, in the neutral incentive condition, the feedback-related negativity (FRN) elicited by correct outcomes was larger than that elicited by incorrect outcomes in the high disinhibition group only. This novel finding indicates that high disinhibition participants were less likely to expect correct outcomes compared to incorrect outcomes in the neutral incentive condition. Finally, the P3 component elicited by outcome presentation showed an interaction between two impulsivity dimensions; when disinhibition level was low, the P3 was larger among high than low sensation seeking participants.

1. Introduction

Risk-related behaviors, such as drug use, gambling, and risky sexual activity, occur in contexts in which the consequences may be reinforcing, punishing, or both, and the probabilities of the outcomes are uncertain (Loewenstein et al., 2001). For example, the chemical composition of drugs, which determines both reinforcing efficacy and the possibility of untoward response (e.g., allergic reaction, overdose) is often unpredictable, particularly if drugs are acquired from an unknown or illicit source. Uncertain adverse legal and social consequences are also associated with drug possession (Macleod et al., 2004). Gambling is defined by uncertain financial consequences (Fiorillo et al., 2003). Health risks associated with risky sexual behavior are often difficult to predict (Hill et al., 1997). It is clear that the decision to engage in risk-related behaviors reflect a confluence of approach and avoidance processes.

Individual differences in the probability of engaging in risk-related behavior have been associated with impulsivity (Martin and Potts, 2009), which is characterized by the increased seeking of immediate reward, a reduced delay tolerance, and an inability to plan ahead (Diekhof et al., 2012). High impulsive individuals are at increased health risk due to their participations in risky activities, such as illegal drug abuse, skydiving, and sexual experimentation (Dalley et al., 2011; Ersche et al., 2010; Jiang et al., 2009; Joseph et al., 2009). Higher levels of impulsivity are associated with hypersensitivity to reward but hyposensitivity to punishment; in other words, both approach and avoidance processes play important roles in impulsivity (Bari and Robbins, 2013). There is a growing consensus that impulsivity is a multidimensional construct, but the precise number of its facets is still debated (Gullo et al., 2014). In this paper, we follow the suggestion of

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two-factor theoretical models (e.g., Dalley et al., 2011; Dawe et al., 2004) and decompose impulsivity into two global dimensions, which are labeled as disinhibition (or 'rash impulsiveness') and sensation seeking based on our previous studies (Harvanko et al., 2016; Perry et al., 2010). Disinhibition refers to a tendency to engage in rash, spontaneous behavior regardless of potential risk or harmful outcomes (Dalley et al., 2011), while sensation seeking is defined as a tendency to seek out novel and thrilling experiences along with the willingness to take risks (Ersche et al., 2010; Fischer and Smith, 2004). Disinhibition and sensation seeking modulate the influence of drug on behavioral performances, including the enhanced attention toward drug-related cues, the inability to resist drug cravings, and the lack of forethought about negative consequences (Dalley et al., 2011; Harvanko et al., 2016; Kelly et al., 2006; Marusich et al., 2011). Our previous research has demonstrated that individual difference in response to reinforcing stimuli such as food, drugs, and money, is linked to impulsive personality dimensions (e.g., Jiang et al., 2009; Joseph et al., 2009; Kelly et al., 2006; Martin et al., 2007; Perry et al., 2010). The purpose of this study is to investigate the relationship between behavioral performance on a task involving both reinforcing and avoidance consequences and individual differences in disinhibition and sensation seeking.

To test brain responses to incentive stimuli among individuals varying in impulsivity, we applied a version of the monetary incentive delay (MID) task (Knutson et al., 2001; Knutson et al., 2000), which is adapted from non-human primate research on motivation (Schultz et al., 1998) and has been examined extensively in human studies (for a review, see Balodis and Potenza, 2014). This task was designed to investigate the effect of monetary gains and losses on cognitive function by providing various incentive cues (Samanez-Larkin et al., 2007). In this task, participants are asked to respond as quickly as possible to the appearance of a target. Prior to target presentation, incentive cues indicate the context of the current trial, that is, whether participants could earn money or avoid losses by responding within a limited time window. The MID task has been used successfully to examine individual differences (e.g., depression, alcohol dependence, ageing) in incentive processing (Bjork et al., 2004a, 2004b, 2008; Joseph et al., 2015; Knutson et al., 2008; Samanez-Larkin et al., 2007).

Event-related potential (ERP) reflects the summation of post-synaptic potentials time-locked to an event of interest, collecting from the electrodes placed at the scalp (Amodio et al., 2014). ERP biomarkers are useful tools to aid our understanding of brain mechanism associated with incentive processing (Kamarajan et al., 2008; Martin and Potts, 2004) and they are valuable for investigating individual difference in this process (Martin and Potts, 2004, 2009). In the current study, three ERP components are selected as electrophysiological measures, not only because of their importance in the processing of incentive stimuli (San Martín, 2012), but also because of the results of previous studies which used the MID task for ERP research (Broyd et al., 2012; Pfabigan et al., 2015). According to their sequence in time, these components are feedback-related negativity (FRN), P3, and late positive component (LPC), respectively.

A dominant theory is that the FRN represents the decoding of reinforcement value of outcome feedback, such that unfavorable outcomes elicit a larger FRN than favorable outcomes (Holroyd and Coles, 2002; Nieuwenhuis et al., 2004). However, recent studies based on the predicted response outcome (PRO) model contend that the FRN reflects the unexpectness/surprisingness of an event regardless of its favorableness, which means the amplitude of this component is generally larger for unexpected events than for expected ones (Ferdinand et al., 2012). This viewpoint has received lots of support in the recent literature (Garofalo et al., 2014; Hauser et al., 2014; Sambrook and Goslin, 2014; Talmi et al., 2013).

Following the FRN peak, the P3 is a well-studied component that has been associated with various cognitive functions including attention allocation, memory updating, and stimulus evaluation (Polich, 2007; Polich and Criado, 2006). Generally, the interpretation of the P3 function is highly context-dependent. In decision-making studies, the P3 has often been linked to the motivational significance of the ongoing event (Nieuwenhuis et al., 2005; San Martín, 2012). Heightened P3 amplitudes indicate stronger motivational impact of an outcome (Polezzi et al., 2010). Consistent with this interpretation, the P3 amplitude increased in individuals who attributed more meaning to outcomes (De Bruijn et al., 2004) or showed stronger desire for rewards (Zheng et al., 2010).

Finally, although not typically studied in the context of decision-making, the LPC is also sensitive to the processing of incentive stimuli. This component, which emerges in a relatively late time window, is suggested to reflect sustained emotional experience to a stimulus (Hajcak et al., 2009; Hajcak and Olvet, 2008). In decision-making studies, reward-predicting cues elicit a larger LPC than non-reward cues. The same LPC pattern was observed when comparing outcome feedback following reward cues with that following non-reward cues. Lastly, emotional up-regulation strengthens the aforementioned effects (Langeslag and van Strien, 2013; Pornpattananangkul and Nusslock, 2015). These findings indicate that the LPC amplitude increases as a function of emotional experience to incentive stimuli (Pornpattananangkul and Nusslock, 2015).

Broyd et al. (2012) first examined the ERPs in the MID task and suggested that the ERP components generally showed their typical patterns. Specifically, the FRN was larger following monetary loss, and the P3 was enhanced in both incentive conditions (gain/loss) than the neutral condition (Broyd et al., 2012; see also Flores et al., 2015; Novak and Foti, 2015). In contrast, Pfabigan et al. (2014) reported that the P3 elicited by gain cues was larger than both loss and neutral cues, while the latter two condition showed no difference (see also Vignapiano et al., 2016). Additionally, Pfabigan et al. (2015) found that the FRN elicited by the neutral outcome is sensitive to its unexpectedness modulated by cues. Finally, the LPC elicited by MID feedback denoting monetary gain or successfully avoiding monetary loss is larger than non-reward feedback (Broyd et al., 2012). In short, the validity of the FRN, P3, and LPC as neural makers of incentive processing has been established with the MID task. Most relevant to the current study, Novak et al. (2016) discovered that in the MID task, sensation seeking scores were positively correlated with the outcome-FRN amplitude, but negatively correlated with the cue-P3 amplitude across incentive conditions. However, only the P3 elicited by cues and the FRN and P3 elicited by outcomes were analyzed. A more comprehensive analysis of ERP signals during the course of the MID task may lead to novel findings about impulsivity dimensions.

We expected to observe individual difference on MID task performance as a function of both disinhibition and sensation seeking status. First, participants high in disinhibition might find it difficult to inhibit behavioral reactions at inappropriate timepoints (see also Goudriaan et al., 2008). In addition, high disinhibition participants may also show a larger FRN in response to MID feedback because they tend to act rashly without consideration of consequences, and therefore would be more likely to receive unexpected feedback. This hypothesis is supported by the positive correlation between the FRN amplitude and disinhibition in previous research (Balconi and Crivelli, 2010). Meanwhile, both incentive cue processing and outcome evaluation would vary based on sensation seeking status. Specifically, we predicted that high incentive cues and/or outcomes would induce stronger motivational impact (indicated by a larger P3) and emotional feelings (indicated by a larger LPC) of incentive stimuli among high sensation seeking participants.

2. Methods

2.1. Participants

Advertisements for experimental participants placed in local newspapers and on flyers distributed throughout the local community