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Social provocation modulates decision making and feedback processing: Examining the trajectory of development in adolescent participants

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ABSTRACT

Increasingly, research is turning to the ways in which social context impacts decision making and feedback processing in adolescents. The current study recorded electroencephalography to examine the trajectory of development across adolescence, with a focus on how social context impacts cognition and behaviour. To that end, younger (10–12 years) and older (14–16 years) adolescents played a modified Taylor Aggression Paradigm against two virtual opponents: a low-provoker and a high-provoker. During the task's decision phase (where participants select punishment for their opponent), we examined two event-related potentials: the N2 and the late positive potential (LPP). During the outcome phase (where participants experience win or loss feedback), we measured the feedback related negativity (FRN). Although N2 amplitudes did not vary with provocation, LPP amplitudes were enhanced under high provocation for the younger group, suggesting that emotional reactivity during the decision phase was heightened for early adolescents. During the outcome phase, the FRN was reduced following win outcomes under high provocation for both groups, suggesting that a highly provocative social opponent may influence the reward response. Collectively, the data argue that social context is an important factor modulating neural responses in adolescent behavioural and brain development.

1. Introduction

Adolescence is a period of major change, both behaviourally and emotionally (Blakemore and Mills, 2013; Blakemore and Robbins, 2012; Crone and Dahl, 2012). Although some aspects of cognitive and behavioural performance improve during adolescence, this period is also marked by impaired decision making and emotional dysregulation (Smith et al., 2012; Steinberg, 2008; Wahlstrom et al., 2010; Yurgelun-Todd, 2007). The apparent tension between the broad improvements observed for cognitive functioning and self-regulation from childhood to adolescence, and contrasting observations regarding affective control may be understood from several points of view. For example, adolescence may mark a period when cognitive functioning and emotional control are poorly integrated or out of step with each other developmentally (Casey et al., 2008; Steinberg, 2008). Alternatively, cognitive and affective performance during adolescence may be more contextually bound, particularly to the social context (Gardner and Steinberg, 2005). These two broad accounts are not mutually exclusive.

Recent research has begun to explore how social contexts shape adolescent decision making. In particular, the role of peer influence on cognitive and behavioural performance has been examined in a number of studies (Albert et al., 2013; Gardner and Steinberg, 2005). One domain that appears particularly prone to disruption by peer influence is feedback processing (Chein et al., 2011; Segalowitz et al., 2012). Despite a growing body of behavioural research, little is known about the neural processes that underpin socially-driven changes in cognition and behaviour throughout development, and in adolescence particularly. To that end, we employed electroencephalography (EEG) to examine the key neural processes associated with decision making and feedback processing during a competitive social task in younger (10–12 years) and older (14–16 years) adolescents. We aimed to reveal the trajectory of development across these two age groups.

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1.1. Feedback processing in adolescence

Feedback processing refers to the ability to evaluate, adapt and modify future behaviour based on certain outcomes (such as 'win' or 'loss' outcomes) (Ridderinkhof et al., 2004). Although feedback processing and feedback learning are vital for adaptive decision making (Banis et al., 2014), a number of studies indicate that adolescents make maladaptive decisions owing to deficient feedback processing. Specifically, adolescents are often reward dominant, and are biased towards reward-driven behaviour even when such behaviour is detrimental (Chein et al., 2011; Steinberg, 2008; Van Duijvenvoorde et al., 2008). Reward dominance refers to a motivational state characterized by increased approach behaviour, where individuals are hyper-responsive to personal rewards (see Gray, 1987; Quay, 1993). For example, Smith et al. (2012) report a U-shaped function between age and decision making performance on the Iowa Gambling Task. In that study, children (8 years old) and older adolescents (17 years old) performed well on the Iowa Gambling task but younger adolescents (11–13 years) performed poorly. Younger adolescents typically favoured card decks that produced high rewards but high punishments, resulting in the worst overall outcomes (large net losses). This suggests a potential developmental regression in decision making during early adolescence. This U-shaped developmental change has been previously linked to an increase in impulsivity, but remains an open area of research (Casey et al., 2008).

Interestingly, earlier work using the Iowa Gambling Task did not show an inverted U function. Using four groups of participants (aged 6–9 years, 10–12 years, 13–15 years and 18–25 years), Crone and van der Molen (2004) revealed an age-related increase in performance – or at least an increase in participant's sensitivity to consequences. Given the discrepancy between existing research studies, the younger adolescents' preference for the high reward/high punishment decks must be carefully interpreted. For example, is that preference due to an increased desire for rewards (so called 'reward dominance'), or a decreased sensitivity to losses, or an adolescent-specific processing style that leads to different expected values compared with those of children and adults, or another explanation altogether? These possibilities cannot be disentangled in the Iowa Gambling Task, suggesting that alternative tasks are needed to assess feedback processing in adolescents.

Unfortunately, most relevant developmental research has occurred within non-naturalistic contexts and has focused on neutral or 'cold' cognitive tasks, rather than examining how feedback processing is engaged by, or potentially impaired by, arousing social situations. This is problematic because it may well be the case that young adolescents are particularly vulnerable to impaired decision making in affectively laden social (especially peer) contexts. Furthermore, recent findings indicate that performance monitoring does not fully develop until late adolescence or adulthood (see Blakemore and Mills, 2013; Kar et al., 2012; Tamnes et al., 2013). Further, the neural activity associated with feedback processing (as measured using functional magnetic resonance imaging) differs over the course of development. Van den Bos and colleagues suggest that brain-based developmental differences to processing feedback are not driven by valence but by the informative value of stimuli (van Den Bos et al., 2009a), and are related to IQ levels in adolescents (van den Bos et al. 2012).

An examination of feedback processing in more naturalistic and emotionally arousing social contexts is therefore critical for understanding the neurodevelopmental changes involved in cognitive function, performance monitoring and decision making between younger (10–12 years) and older (14–16 years) adolescents. In line with recommendations that the selection of age groups be narrow and theory-driven (Crone and Ridderinkhof, 2011), we attempted to select two narrow age ranges that had the potential to capture neural changes associated with feedback processing. The selection of age ranges was based on a number of factors. First, we aimed to select participants who were all secondary school-aged. This is because social relationships change after adolescents leave secondary school (at the age of 16 in the UK) for college or further training pathways. By restricting the older adolescent group to a maximum age of 16 years, this factor should have been minimized. Second, given that the young adolescent group in Smith et al.'s (2012) recent work showed poorer choices (compared to those of children or adults), the early adolescent group in the current study was recruited to roughly overlap with that group. A slightly younger age range was recruited here compared with Smith et al. (10–12 years here compared with 11–13 years) in order to ensure a sufficient separation between our two recruited groups.

1.2. Using brain imaging to study feedback processing

Because adolescence is a period of dynamic neural change (Choudhury et al., 2008), neuroimaging techniques such as EEG can be employed to help unravel changes in decision making and feedback processing. For example, the feedback related negativity (FRN) is an event-related potential (ERP) that indexes important aspects of outcome evaluation. The FRN is a negative-going frontal component that usually peaks 300 ms after the presentation of feedback (for example, a win or loss outcome) (Gehring and Willoughby, 2002). The FRN is typically larger (that is, more negative) when the outcome is poor (a bad outcome). The FRN has an anterior topography and is attributed to activation of the anterior cingulate cortex (Gehring and Willoughby, 2002; Holroyd and Coles, 2002). In adults specifically, the FRN distinguishes between outcome valences (win vs. loss) and, in some studies, the magnitude of the outcome (Dunning and Hajcak, 2007; Goyer et al., 2008). This component is thought to reflect emotional appraisal of the feedback (Hajcak et al., 2006), or violations of feedback expectancy (Bellebaum et al., 2010; Oliveira et al., 2007; Potts et al., 2006), as the FRN is larger (more negative) for worse outcomes (e.g., a loss rather than a win) and is larger (more negative) when the outcome violates the participant's expectation. Interestingly, there is evidence for an asymmetry between neural responses to wins and losses (Cohen et al., 2007). Cohen et al. demonstrated that the FRN was sensitive to the probability of reward on win trials, but not on loss trials. Specifically, FRN amplitudes were shown to be more positive when outcomes were better than expected (e.g., on win trials when the probability of a win was low). Huang and Yu recently demonstrated that a larger (more negative) FRN is associated with feedback that is 'more' than expected, rather than 'worse' than expected (Huang and Yu, 2014).

In adults, an increasing body of work reveals that the FRN is sensitive to social context. For example, the FRN has been shown to distinguish positive and negative feedback, but only when participants compete against another player, and not when playing alone (Van Meel and Van Heijningen, 2010). In other words, the FRN is increased in social contexts for adult participants. Furthermore, FRN amplitude is correlated with feelings of subjective happiness when participants compare their task winnings with another player, or compete for winnings against that player (Rigoni et al., 2010). The FRN is also influenced by factors such as social status (for example based on performance on a cognitive task) (Boksem et al., 2012). In that study, participants allocated to the low status group were more likely to evaluate and attend more to their own performance. Existing research therefore suggests that an arousing social context increases the FRN, and this increase may be linked to the heightened emotional significance of outcomes in social situations. Such modulation of feedback monitoring to take account of the