Learning and altering behaviours by reinforcement: Neurocognitive differences between children and adults

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ABSTRACT

This study examined neurocognitive differences between children and adults in the ability to learn and adapt simple stimulus–response associations through feedback. Fourteen typically developing children (mean age = 10.2) and 15 healthy adults (mean age = 25.5) completed a simple task in which they learned to associate visually presented stimuli with manual responses based on performance feedback (acquisition phase), and then reversed and re-learned those associations following an unexpected change in reinforcement contingencies (reversal phase). Electrophysiological activity was recorded throughout task performance. We found no group differences in learning-related changes in performance (reaction time, accuracy) or in the amplitude of event-related potentials (ERPs) associated with stimulus processing (P3 ERP) or feedback processing (feedback-related negativity; FRN) during the acquisition phase. However, children's performance was significantly more disrupted by the reversal than adults and FRN amplitudes were significantly modulated by the reversal phase in children but not adults. These findings indicate that children have specific difficulties with reinforcement learning when acquired behaviours must be altered. This may be caused by the added demands on immature executive functioning, specifically response monitoring, created by the requirement to reverse the associations, or a developmental difference in the way in which children and adults approach reinforcement learning.

1. Introduction

1.1. Reinforcement learning in development

The ability to learn and modify behaviours based on the positive and negative outcomes of our actions is an important skill used throughout the lifespan. This skill, known as reinforcement learning (Holroyd and Coles, 2002; Thorndike and Bruce, 1911), may be particularly valuable in the first two decades of life, affording the naïve developing child an effective method of identifying advantageous behaviours and discerning when and how learned actions should be adapted for changing contexts. Indeed, impaired reinforcement learning has been implicated in the pathology of several neurodevelopmental disorders, including Tourette syndrome and ADHD (Marsh et al., 2004; Sagvolden et al., 2005), although the precise deficits in these conditions are unclear. A thorough understanding of the typical development of reinforcement learning may help clarify these deficits, but few studies have examined this aspect of cognitive development.

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1.2. Differences in reinforcement learning across typical development

Previous studies have consistently reported performance differences between children and adults in reinforcement learning. Younger children are less accurate when learning associations between stimuli and responses (S–R associations) by positive and negative feedback than older children and adults (Baldwin et al., 2012; Crone et al., 2004). Children learn at a slower rate than adults (Crone et al., 2004) and show particular difficulties when reinforcements are inconsistent. Specifically, performance differences between children and adults increase when feedback is probabilistic and does not correctly reinforce performance 100% of the time (Eppinger et al., 2009; Hämmerer et al., 2010).

Neural processes underlying these developmental differences have been examined using EEG, particularly the feedback-related negativity (FRN) event-related potential (ERP). The FRN is a negative deflection in the waveform at ∼250 ms following feedback (Miltner et al., 1997). FRN amplitude is larger following negative than positive feedback, and in some studies positive feedback elicits a positive-going deflection in the FRN time-range, the feedback-positivity (FP) (Holroyd et al., 2008). Evidence suggests the FRN/FP is generated by prefrontal cortical regions associated with performance monitoring, and reflects the processing of dopaminergic reinforcement learning signals triggered by feedback indicating behaviour was better or worse than expected (Bellebaum and Daum, 2008; Luque et al., 2012; Oliveira et al., 2007). FRN/FP amplitudes decrease during a reinforcement learning episode, likely reflecting decreased reliance on external feedback with increasing knowledge of the to-be-learned behaviours (Eppinger et al., 2009; Holroyd and Coles, 2002).

Children show less enhancement of the FRN for negative compared with positive feedback, suggesting children are poorer at differentiating between types of feedback than adults (Hämmerer et al., 2010). The authors suggest this may explain why learning is more disrupted in children when feedback is probabilistic and difficult to discriminate. FP amplitude decreases less across learning in children than adults and ERP correlates of monitoring errors in performance differentiate less between correct and error responses in children than in adults (Eppinger et al., 2009). Based on these differences between children and adults, Eppinger et al. (2009) suggested that children have weaker internal representations of whether a response is correct or erroneous, resulting in a greater reliance on feedback processing to achieve successful performance. In a recent review of this literature, Hämmerer and Eppinger (2012) proposed that increasing reinforcement learning ability reflects developing efficiency in processing feedback, using reinforcements effectively to guide goal-directed behaviour, and building internal representations of correct behaviours, as prefrontal cortical regions mature.

However, due to the scarcity of research in this area further studies are needed (Hämmerer and Eppinger, 2012). Furthermore, previous research has not addressed an important aspect of reinforcement learning, that is, the ability to alter and re-learn behaviours following changes in reinforcements. A robust finding in the executive function literature is that children are poorer than adults in switching to new behaviours when prompted by cues (Koolschijn et al., 2011). This suggests that children will have particular difficulty with learning when reinforcement contingencies change. Furthermore, the learning tasks used previously have been complicated, with multiple feedback conditions presented for different S–R associations within task blocks, creating considerable working memory demands (Crone et al., 2004; Eppinger et al., 2009; Hämmerer et al., 2010). Crone et al. (2004) and Eppinger et al. (2009) controlled for this problem by allocating children extra response time, but nevertheless the difficulty of these tasks may have enhanced developmental differences.

1.3. The current study

The study aims were firstly to further investigate neurocognitive differences in the typical development of reinforcement learning using a simple task designed to reduce the influence of age-related performance differences on ERP correlates of learning. The intention was to ensure all participants could perform the task adequately regardless of age so that any ERP differences are more likely to reflect differences in the recruitment of neural networks underlying task performance, rather than floor or ceiling effects in one age group. Secondly, to assess developmental differences in the ability to change and re-learn acquired behaviour in response to altered reinforcement contingencies we compared children aged 9–11 years with adults aged 21 years and over. Our aim was to establish whether children differ from adults in behavioural and brain correlates of learning before they undergo the significant maturational changes that take place during adolescence. During EEG recording typically developing children and adults performed a task in which they learned four S–R associations by positive and negative feedback and then reversed the associations after an unexpected change in reinforcement contingencies. Changes in performance and feedback processing, indexed by the FRN, related to learning and reversal were examined across the task and between age groups. Additionally, changes in the P3 ERP, a positive deflection at ∼300 ms post-stimulus, were examined. P3 amplitude increases with progressing reinforcement learning in adults, which is thought to reflect increasing consolidation of to-be-learned behaviours (Rose et al., 2001). The P3 may further elucidate neurocognitive differences between children and adults, for example, children may show weaker consolidation of associations than adults reflected by smaller P3 amplitude increases with learning. We predicted children would show smaller learning-related changes in performance and ERP amplitudes during the initial acquisition of S–R mappings than adults, reflecting poorer learning ability at this age. Further, we expected children to show greater disruptions to performance and greater reliance on feedback, indexed by smaller FRN amplitude changes, when the reversal occurred.