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Response monitoring during typical development

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ABSTRACT

This study was conducted to gain a more comprehensive understanding of the normative development of response monitoring. We examined response monitoring under both relatively simple and more cognitively demanding conditions by measuring behavioral modifications that occurred in the presence of error and conflict. Eighty-nine participants between 4 and 24 years of age were administered two tasks (i.e., Simon and go/no-go). Data were analyzed using *t*-tests and hierarchical regression. We found that children (4–10 years of age), adolescents (11–17 years of age), and young adults (18–24 years of age) demonstrated significant reaction time slowing in the presence of *either* error *or* conflict, and that the magnitude of the slowing in these relatively simple conditions decreased with age. Under more cognitively demanding task conditions, adolescents and young adults demonstrated additional slowing beyond what they exhibited when task conditions were relatively simple. In contrast, children did not show any additional slowing in response to more cognitively demanding task conditions. The findings suggest that older individuals more efficiently modify their behavior in response to subtle changes in task demands.

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1. Response monitoring during typical development

Response monitoring refers to behavioral modifications that are made to enhance performance upon detection of error or conflict. For example, after realizing an error on a math test, a child might take more time to complete the remaining problems. Similarly, during a soccer game, a child might wait to advance toward the goal because of conflict between scoring a goal and receiving an off-side penalty. Both instances would involve response monitoring.

The modifications in behavior that occur in the presence of error or conflict are thought to reflect the recruitment of cognitive control, or the temporary allocation of attentional resources to reduce the influence of distracting information. Cognitive control increases the likelihood of correct responding (Botvinick, Braver, Barch, Carter, & Cohen, 2001; see also Egner & Hirsch, 2005).

In the laboratory, response monitoring is often assessed using tasks that induce errors and response conflict. For example, during a traditional go/no-go task, participants are instructed to press a response key when a target stimulus appears, but to withhold responding when a non-target stimulus appears. Errors occur when a key press is made in response to a non-target; conflict occurs when a non-target stimulus is presented because of competition between the prepotent (i.e., making a button press) and alternative response tendencies (i.e., withholding a response).

Measuring response monitoring in the laboratory typically involves recording RT on trials that immediately follow errors, and/or trials that immediately follow conflict. This is done to assess how the recruitment of cognitive control influences responding. Indeed, research has shown that RT on "post-error trials" is slower than RT on trials that follow correct responses, a phenomenon referred to as post-error slowing (Falkenstein, Hoorman, Christ, & Hohnsbein, 2000; Gehring & Fencsik, 2001; Gehring, Goss, Coles, Meyers, & Donchin, 1993; Gehring & Knight, 2000; Hajcak, McDonald, & Simons, 2003; Hester, Foxe, Molholm, Shpaner, & Garavan, 2005; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Rabbitt, 1966; Swick & Turken, 2002). Similarly, behavioral modifications occur following conflict trials such that RT is faster on subsequent conflict trials but slower on subsequent non-conflict trials. These behavioral modifications are thought to reflect the recruitment of cognitive control in the presence of conflict, which enhances processing of conflicting information on subsequent trials (Botvinick et al., 2001; Kerns, 2006).

Neuroanatomically, response monitoring is believed to be subserved by frontal brain regions. Specifically, the anterior cingulate is thought to detect or react to the occurrence of errors and conflict, signaling the need for cognitive control. In turn, the prefrontal cortex is thought to implement cognitive control, resulting in behavioral modifications to enhance performance (e.g., slowing; Botvinick et al., 2001; Carter et al., 1998; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000).

1.1. Response monitoring in children

The anterior cingulate and prefrontal cortices continue to mature during childhood (for reviews, see Casey, Giedd, & Thomas, 2000; Casey, Tottenham, Liston, & Durston, 2005; Lenroot & Giedd, 2006). Research examining the development of response monitoring during this time period has shown that like adults, children as young as 7 years of age demonstrate post-error slowing across a range of tasks including go/no-go (Araujo et al., 2009; Wiersema, van der Meere, & Roeyers, 2007), stimulus response compatibility (Friedman, Nessler, Cycowicz, & Horton, 2009), flanker (Davies, Segalowitz, & Gavin, 2004a,b; Ladouceur, Dahl, & Carter, 2004, 2007), and choice RT (Hogan, Vargha-Khadem, Kirkham, & Baldeweg, 2005).

Less clear is how response monitoring emerges and matures during development. Several studies have found no relationship between age and the magnitude of post-error slowing from childhood to early adulthood (Araujo et al., 2009; Davies et al., 2004a; Ladouceur et al., 2004, 2007; Wiersema et al., 2007). However, other studies have provided evidence of ongoing maturation in response monitoring using more cognitively demanding tasks that require greater cognitive control. For example, Friedman and colleagues (2009) administered a stimulus response compatibility task to children (9–10 years of age), young adults (21–27 years of age), and older adults (66–78 years of age), and examined separately the behavioral modifications that occurred under relatively simple versus more cognitively demanding conditions. That is, they examined behavioral modifications that occurred in the presence of *either* error