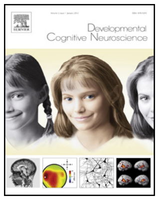
Developmental Cognitive Neuroscience 9 (2014) 93–105

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn



Age-related changes in error processing in young children: A school-based investigation

Jennie K. Grammer *, Melisa Carrasco, William J. Gehring, Frederick J. Morrison

University of Michigan, United States

ARTICLE INFO

Article history:
Received 20 August 2013
Received in revised form 31 January 2014
Accepted 2 February 2014

Keywords:
Error-related negativity
Executive function
Response inhibition
School-aged children
Error positivity

ABSTRACT

Growth in executive functioning (EF) skills play a role children's academic success, and the transition to elementary school is an important time for the development of these abilities. Despite this, evidence concerning the development of the ERP components linked to EF, including the error-related negativity (ERN) and the error positivity (Pe), over this period is inconclusive. Data were recorded in a school setting from 3- to 7-year-old children ($N = 96$, mean age = 5 years 11 months) as they performed a Go/No-Go task. Results revealed the presence of the ERN and Pe on error relative to correct trials at all age levels. Older children showed increased response inhibition as evidenced by faster, more accurate responses. Although developmental changes in the ERN were not identified, the Pe increased with age. In addition, girls made fewer mistakes and showed elevated Pe amplitudes relative to boys. Based on a representative school-based sample, findings indicate that the ERN is present in children as young as 3, and that development can be seen in the Pe between ages 3 and 7. Results varied as a function of gender, providing insight into the range of factors associated with developmental changes in the complex relations between behavioral and electrophysiological measures of error processing.

1. Age-related changes in error processing in young children

The transition to elementary school is characterized by rapid growth in the development of executive functioning (EF) skills, including response inhibition, working memory, and attention control. During this important developmental period, children also face increasing demands in academic domains, and there is growing evidence for the importance of EF for children's academic achievement (e.g., McClelland et al., 2007), particularly for those growing up in poverty (Raver et al., 2011). Although it is clear that early childhood is an important time for the development of EF, evidence concerning age-related behavioral and neurological changes associated with these abilities across the transition into elementary school in diverse groups of children is lacking. An increasing number of studies have contributed to the understanding of EF in childhood by examining the electrophysiological correlates of conflict-resolution and response-inhibition including the error related negativity (ERN) and the error positivity (Pe) (for a review, see Tamnes et al., 2013). Building on this work, in an effort to understand the neurological changes associated with EF across the school transition, this investigation examined the age-related changes in the ERN and Pe in preschool and elementary school-aged children.

1.1. The development of executive skills

Development of the group of skills identified as executive function has received increasing attention from both basic and applied researchers (Anderson, 2002; Duckworth

* Corresponding author. Tel.: +1 718 862 1765.
E-mail address: jennie.grammer@gmail.com (J.K. Grammer).

http://dx.doi.org/10.1016/j.dcn.2014.02.001
1878-9293/

and Seligman, 2006; Luciano, 2003; Zelazo et al., 2004). Developmental researchers have focused on the emergence and growth of executive functioning from infancy to early adulthood (Welsh, 2001). Along with educational researchers, they have sought to understand the interplay between maturational and environmental factors in shaping development of executive skills as well as in the growing concern about the role of variability in children's self-control (including gender differences) on American children's poor academic achievement, emerging even before children start school (Duckworth and Seligman, 2006; Matthews et al., 2009; McClelland et al., 2000). From a different perspective, neuroscientists have long noted that brain areas subserving basic cognitive functions such as attention and memory are distinct from those that integrate and coordinate these abilities (e.g., Luria, 1966). More recent studies have explored how these skills differ in children and adults (Welsh et al., 2006). Cognitive scientists have been analyzing the underlying components of executive functioning (attentional control/flexibility, working memory, response inhibition, planning) to ascertain their structure and function (Miyake et al., 2000; Zelazo et al., 2004).

While definitions and emphases vary, there is broad agreement that executive functions refer to cognitive skills utilized for purposeful, future-oriented behavior that allow for flexible adaptation to changing task demands, including regulation of attention, inhibition of inappropriate responses, coordination of information in working memory, and organization and planning of adaptive behavior (e.g., Blair, 2002; Eslinger, 1996; Klein, 2003; Shonkoff and Phillips, 2000; Welsh, 2002; Zelazo and Frye, 1998; Zelazo et al., 2003). In older children and adults, conceptualizations of EF include inhibitory control, working memory (updating), cognitive control (Botvinick et al., 2001), and cognitive flexibility/shifting (Monsell, 2003).

There is currently a debate regarding the composition of EF in early childhood, with many positing that the composition of EF could change with development (McAuley and White, 2010). Recently, Miyake and Friedman (2012) proposed that there are aspects of EF tasks that are shared across components (reflecting unity, or a "common EF"), but also distinct, separable, components not accounted for by common EF. Uncertainty surrounding the development of EF is confounded by differential sensitivity of behavioral measurement across age and other fundamental processes (e.g., speed of processing). Regardless of this ongoing debate, three key components commonly emphasized in the study of EF in young children encompass response inhibition, working memory, and attentional control.

In addition to growing evidence regarding the composition of EF in early childhood, there is mounting evidence that the development of executive skills occurs in context. For example, growing up in poverty negatively impacts U.S. children's EF skills, as well as the neural development thought to subserve EF abilities (e.g., Noble et al., 2007; Hackman et al., 2010). Moreover, recent research indicates that chronic poverty is particularly detrimental to children's EF (Raver et al., 2013). Although the wealth of findings point to the importance of EF skills for the academic success of children in general (McClelland et al., 2007), there is reason to suspect that these skills might be particularly important for children growing up in poverty (Raver et al., 2011).

1.2. *Response monitoring*

When considering the development of children's executive skills, studies have focused on changes in ERP components that reflect a network of structures, including the anterior cingulate cortex (ACC) and lateral prefrontal cortex, involved in detecting response conflict and attention control. The ACC has been implicated in cognitive control functions, which are thought to enable the brain to adapt behavior to changing task demands and environmental circumstances (Botvinick et al., 2001; Ridderinkhof et al., 2004). These cognitive functions include processes that detect when control is needed as well as the processes that implement control by changing the focus of attention, altering response strategies, and so on. Although there is limited longitudinal data regarding the development of the ACC, evidence from cross-sectional studies conducted in adolescence and later childhood provide some evidence for relations between developmental changes in the ACC and concurrent age-related growth observed in performance monitoring (Tamnes et al., 2013).

To this end, developmental researchers have been interested in components observed when subjects process stimuli that reflect conflicting demands of the tasks including the medial-frontal N2 potentials and frontal P3 potentials that follow them (e.g., Rueda et al., 2005; Rueda et al., 2004a,b). Complementing these components are those associated with the responses to stimuli in conflict tasks: the error-related negativity (ERN), a medial-frontal negativity similar to the N2, and error positivity (Pe), a positivity similar to the P3 (Arbel and Donchin, 2009; Overbeek et al., 2005).

First identified over 20 years ago (Falkenstein et al., 1991; Gehring et al., 1993), the ERN is a response-locked negative deflection usually seen at midline frontocentral scalp locations that peaks 50–100 ms following an erroneous response in speeded choice reaction time tasks. A smaller negativity, the Correct-Response Negativity (CRN), can also been identified on correct trials at the same latency as the ERN (see Gehring et al., 2012, for a review). Because commission of an error provides an indication that cognitive control is needed, theories of the ERN have tended to argue for its role in detecting the need for or in implementing cognitive control.

The presence of the ERN is often accompanied by the Pe, a positivity reaching maximum amplitude between 200 and 400 ms after the commission of an error that usually follows the ERN (Overbeek et al., 2005). Although the functional significance of the Pe is still unclear, the Pe has been associated more frequently than the ERN with conscious awareness of having made an error (Nieuwenhuis et al., 2001). Consistent with this, the Pe is thought to capture affective responses to committing an error, awareness of having made an error, or processing related to