Intelligence 68 (2018) 101–108

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Executive functioning (fully) and processing speed (mostly) mediate intelligence deficits in children born very preterm

Christopher R. Brydges[a,b,*], Corinne L. Reid[c], Catherine Campbell[d], Noel French[d,e], Mike Anderson[b]

[a] School of Psychological Science, University of Western Australia, Perth, Western Australia, Australia
[b] School of Psychology & Exercise Science, Murdoch University, Perth, Western Australia, Australia
[c] School of Health in Social Science, University of Edinburgh, Edinburgh, UK
[d] Neonatal Clinical Care Unit, King Edward Memorial Hospital, Perth, Western Australia, Australia
[e] State Child Development Centre, West Perth, Western Australia, Australia

ARTICLE INFO

Keywords:
Executive function
Processing speed
Intelligence
Preterm birth

ABSTRACT

Children born very preterm (< 32 weeks gestational age) are known to be at increased risk of neurocognitive impairments, in domains including executive functioning, processing speed, and fluid and crystallised intelligence. Given the close association between these constructs, the current study investigated a specific model, namely whether executive functioning and/or processing speed mediates the relationship between preterm birth and intelligence. Participants were 204 children born very preterm and 98 full-term children, who completed a battery of tasks measuring executive functioning, processing speed, and fluid and crystallised intelligence. Independent-samples *t*-tests found significantly poorer performance by children born preterm on all measures, and a confirmatory factor analysis found preterm birth to be significantly related to each of the cognitive domains. A latent-variable mediation model found that executive functioning fully mediated the associations between preterm birth and both fluid and crystallised intelligence. Processing speed fully mediated the preterm birth-fluid intelligence association, but only partially mediated the preterm birth-crystallised intelligence association. Future research should consider a longitudinal study design to test whether these deficits and mediating effects remain throughout childhood and adolescence.

1. Introduction

Children born very preterm (VP; < 32 weeks gestation) have increased risks of brain injury (Cooke & Abernethy, 1999; Maalouf et al., 1999; Stewart et al., 1999), potentially resulting in neurocognitive deficits, academic underachievement and behavioural problems (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, & Oosterlaan, 2009; Bhutta, Cleves, Casey, Cradock, & Anand, 2002). For example, there is an increased risk of poorer executive function, intelligence and speed of processing following very preterm birth (Brydges et al., 2018). Given that these three cognitive domains – executive functioning (EF), processing speed, and intelligence – are commonly considered to be related to each other in both adults (e.g., Friedman et al., 2006; Redick, Unsworth, Kelly, & Engle, 2012) and children (e.g., Anderson, 1992, 2001; Brydges, Reid, Fox, & Anderson, 2012), it is possible that lower intelligence associated with preterm birth is at least partially mediated by EF and/or processing speed. It is this hypothesis that we will test in this study.

Executive functioning is a broad umbrella term associated with higher-order cognitive functioning and goal-directed behaviour (Miller & Cohen, 2001). Successful executive functioning is associated with performance on complex tasks (Miyake et al., 2000) and academic outcomes (St Clair-Thompson & Gathercole, 2006). Conversely, deficits in EFs, which are commonly observed in children born VP (P. Anderson & Doyle, 2003), are associated with academic underperformance and behavioural problems (Aarnoudse-Moens et al., 2009). One commonly accepted model of executive functions is the ‘unity and diversity’ model proposed by Miyake et al. (2000). Miyake et al. tested 137 young adults on multiple measures of three commonly theorised executive functions (prepotent response inhibition, updating of working memory, and task shifting), and extracted latent variables of these three constructs by using confirmatory factor analysis (CFA). The resultant model displayed moderately strong inter-factor correlations (range $r = 0.42$ to $r = 0.63$), implying that these constructs are related yet distinct from each other. As such, this model proposes that there is a general, domain-free ability underlying all executive processes, as well as several

* Corresponding author at: School of Psychological Science, University of Western Australia, 35 Stirling Highway, Perth, WA 6009, Australia.
E-mail address: christopherbrydges@gmail.com (C.R. Brydges).

https://doi.org/10.1016/j.intell.2018.03.013
Received 24 November 2017; Received in revised form 13 February 2018; Accepted 30 March 2018

independent abilities specific to each single executive function (Friedman & Miyake, 2017; Miyake & Friedman, 2012). The general, common ability causes each single executive function to correlate with each other, whereas the specific abilities cause each function to be separable from each other. Attempts to replicate this model in children, however, have been mixed. A growing body of research has suggested that that structure of executive functions though early to mid-childhood, up to around the age of 9 years, appears to be unitary (i.e. a one-factor model of executive functioning is the best fit of the data; Brydges, Fox, Reid, & Anderson, 2014a; Brydges et al., 2012; Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011; Willoughby, Wirth, Blair, & Greenberg, 2012). However, from around the age of 10 years the individual executive functions differentiate themselves from each other, so that the Miyake et al. (2000) model of executive functions is observed (i.e. children display 'unity and diversity'; Brydges, Fox, Reid, & Anderson, 2014b; Duan, Wei, Wang, & Shi, 2010; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Shing, Lindenberger, Diamond, Li, & Davidson, 2010; Wu et al., 2011).

Processing speed usually refers to the speed at which individuals can perform single cognitive operations such as mentally rotating an object, encoding stimuli and rehearsing items in working memory (Sheppard & Vernon, 2008; Vernon, 1983). Processing speed has been a central explanatory construct for explaining individual differences in intelligence, or g, with this research reaching its apogee in the 1980s where numerous studies reported that simple measures of both reaction time and inspection time have moderate to strong correlations with measures of IQ (Jensen, 1982; Kranzler & Jensen, 1989; Nettlebeck, 1987). Processing speed is usually found to improve with age in children (Fry & Hale, 1996, 2000; Hale, 1990; Kail, 1986, 1991a, 1991b, 1992; Kail & Hall, 1994; Kail & Park, 1992, 1994; Kail & Salthouse, 1994; Nettlebeck, 1987; Nettlebeck & Wilson, 1985), though this is not uncontested (Anderson, 2017; Anderson, Nettlebeck, & Barlow, 1997; Davis & Anderson, 1999, 2001). Part of the difficulty in interpreting the developmental research, in particular, is the acknowledgement that most speed measures are derived from tasks that probably include processes other than speed of processing that are related to both intelligence and development. This is the case for even relatively simple measures of reaction time (Rabbitt & Goward, 1994) and inspection time (Anderson, 1989, 1995; Anderson et al., 1997; Anderson, Reid, & Nelson, 2001). Because of task impurity some researchers argue for a structural equation modelling approach where constructs such as processing speed and executive functioning can be extracted as independent latent traits (the approach taken in this paper). For example, Demetriou and colleagues have attempted to tease apart the influence of processing speed, working memory and other executive functions at different points of development (Demetriou, Spanoudis, & Shayer, 2013). Their developmental model proposes shifts and cycles in development where processes of representational change interact with the development of some basic information processing capacities. While it must be acknowledged that differentiating these processes is not without difficulty (see Anderson, 2017, for a recent review and a theoretical analysis of the relationship between processing speed, executive functioning and intelligence in development) there is a consensus in the literature that the development of these processes appears to be relatively linear throughout childhood (e.g., Hale, 1990; Kail, 1991a), and, in particular, there is evidence that age-related improvements in intelligence are partially mediated by developmental improvements in processing speed (Fry & Hale, 1996, 2000). Furthermore, Fry and Hale (1996) found that age-related improvements in processing speed also accounted for most of the age-related improvements in working memory, and even when age-related differences in speed, working memory and intelligence were controlled for, individual differences in speed were predictive of working memory capacity, which was in turn predictive of fluid intelligence.

It is well established that both EF and processing speed are associated with intelligence in children (e.g., Anderson, 1992, 2001, 2017; Demetriou et al., 2014). Anderson's theory of the minimal cognitive architecture underlying intelligence and cognitive development (Anderson, 1992, 2001, 2017), posits that processing speed and EF are two separate dimensions of general intelligence. Speed is related to individual differences (IQ) and EFs are related to developmental change (mental age). While in theory these are independent dimensions of general intelligence (being grounded in quite different brain systems) in practice these dimensions work in concert to produce changing levels of fluid intelligence (Cattell, 1963) in the developing child which has a cascading effect on the development of crystallised intelligence (Cattell, 1963). For example, Brydges et al. (2012) conducted CFA and structural equation modelling (SEM) on a sample of 215 7- and 9-year old children, and found that a unitary EF factor was highly predictive of both fluid intelligence (gF; the ability to solve unfamiliar problems) and crystallised intelligence (gC; the repository of previously acquired knowledge; Cattell, 1963). Hence, it is clear that EF and processing speed are associated with intelligence. In this paper we focus on the developmental dimension and ask the central question, again using a structural equation modelling methodology: if processing speed and EF are related to both fluid and crystallised intelligence in typically developing children, to what extent is the relationship the same for children born preterm? Our hypothesis is that the relationship may differ because preterm children show significant differences in brain volume across a broad frontoparietal network (Peterson et al., 2000), the activation of which is associated with successful executive functioning (Niendam et al., 2012) and hence the effects of prematurity on intelligence might be more mediated by EF than processing speed.

The current study aimed to examine the effects of preterm birth on neurocognition. A recent meta-analysis conducted by Brydges et al. (2018) examined the effects of very preterm birth on EF, processing speed, and intelligence. It was found that preterm birth has medium effect sizes on EF and processing speed, and a large effect on intelligence (0.51 *SDs*, 0.49 *SD*s, and 0.82 *SD*s, respectively). Given the plethora of research reporting deficits in these cognitive domains (e.g., Aarnoudse-Moens et al., 2009; Anderson & Doyle, 2003; Bhutta et al., 2002; Kerr-Wilson, Mackay, Smith, & Pell, 2012) a mediation model using latent variables was created to test whether EF and/or processing speed mediated associations between preterm birth and intelligence (split into gF and gC). Based on Brydges et al. (2018), it was hypothesised that children born VP suffer from neurocognitive deficits. As such, it was predicted that these children would perform significantly worse on all measures of EF, processing speed, and intelligence. Secondly, it was hypothesised that EF and processing speed would both be related to, and predictive of, both gF and gC in our sample. Lastly, as a result of the effects of preterm birth on EF, processing speed, and intelligence observed in previous meta-analyses (Aarnoudse-Moens et al., 2009; Bhutta et al., 2002; Brydges et al., 2018; Kerr-Wilson et al., 2012) and the close relations between these constructs (Anderson, 1992, 2001, 2017) it was hypothesised that that EF and/or processing speed would mediate both the preterm birth-gF and preterm birth-gC associations.

2. Method

2.1. Participants

A total of 302 children participated in the study. This sample comprised 204 children born VP at < 32 weeks gestation ($M = 27.21$ weeks, $SD = 2.53$ weeks) recruited from King Edward Memorial Hospital (KEMH). This group had a mean birthweight of 999.80 g ($SD = 368.87$ g, range = 455 g–2360 g). The KEMH Neonatal Intensive Care Unit is within the only level 3 perinatal service in the state of Western Australia and the largest unit in the Asia-Pacific region. Children (106 male, 98 female) had a mean chronological age of 7 years 2 months ($SD = 3$ months; range = 6 years 7 months–8 years 0 months) at the time of the current study. Ninety-eight typically developing