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

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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.

Keywords: Executive function; Processing speed; Intelligence; Preterm birth.

Highlights

- Children born very preterm are at risk of cognitive deficits
- We examined executive function, processing speed and intelligence in this sample
- Executive functioning fully mediated intelligence deficits in preterm-born children
- Processing speed partially mediated intelligence deficits in preterm-born children

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

Children born very preterm (VP; less than 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, Craddock, & 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., 2017). 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., M. Anderson, 1992, 2001; Brydges, Reid, Fox, & M. 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 $r = .42$ to $r = .63$), 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 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, & M. 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; Nettelbeck 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 (M. Anderson, 2017; M. Anderson, Nettlebeck, & Barlow, 1997; Davis & M. 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 (M. Anderson, 1989, 1995; M. Anderson, Nettlebeck, & Barlow, 1997; M. Anderson, 1989, 1985 M. 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 et al., 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 M. 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., M. Anderson, 1992; 2001; 2017; Demetriou et al., 2014). M. Anderson's theory of the minimal cognitive architecture underlying intelligence and cognitive development (M. 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 *SD*s, 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; P. 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 (M. 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.

Method

Participants

A total of 302 children participated in the study. This sample comprised 204 children born VP at less than 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 children (44 male, 54 female; *M* = 7 years 3 months, *SD* = 5 months, range = 6 years 2 months – 8 years 0 months) were also included and recruited from local primary schools. The preterm group was significantly younger in terms of both chronological age ($t(300) = 2.29$, $p = .023$) and corrected age (*M* = 6 years 11 months, *SD* = 3 months, range = 6 years 4 months – 7 years 9 months; $t(300) = 8.33$, $p < .001$)[1].

Materials

Executive Functioning.

Fruit Stroop: The Fruit Stroop task was used to measure age-related differentiation of inhibition, and was selected for this study as it does not require competent literacy. The task is comprised of four trials of speeded colour naming of six rows of seven fruit stimuli. In condition one, children are required to name coloured boxes as quickly as possible. In condition two, children are required to name the colour of seven fruits as quickly as possible. In the third condition, children are asked to recall the colour of the seven fruit that have been shaded grey as quickly as possible. In the final Stroop inhibition condition, children are required to name the colour of the seven fruits when the pictured fruit are shaded in incongruent colours. All trials are preceded by practice trials, presented on a separate sheet from stimulus materials. All trials are given a time limit of 45 seconds. The number of correct items in condition four was used as the dependent variable.

Letter-Number Sequencing: Letter-Number Sequencing (LNS) is part of the Working Memory Index of the WISC-IV (Wechsler, 2003). Children were required to mentally sort series of letters and numbers into alphabetical and ascending order, and state this transformed sequence to the administrator. The dependent variable was the raw score from this measure, which is the total number of correct trials.

Digit Span: Digit Span is also a part of the Working Memory Index of the WISC-IV (Wechsler, 2003). Children were required to recall lists of numbers of increasing length in the order they were presented, then in reverse order. The indicator of working memory was the raw score from this measure, which is the total number of correct trials.

Creature Counting: Creature Counting is a subtest of the Test of Everyday Attention of Children (TEA-Ch; Manly, Robertson, V. Anderson, & Nimmo-Smith, 1999) that measures attentional control when switching. Children are required to switch between two relatively simple activities of counting creatures in their burrows either forwards and backwards, which is cued with arrows of corresponding direction intermittently appearing in each sequence of pictures. The raw score of trials correct was submitted for analysis.

Processing Speed.

Coding: Coding is part of the Processing Speed Index of the WISC-IV (Wechsler, 2003). Children were required to write the symbol associated with a number using a provided chart with digit-symbol pairings, and complete as many items as possible within the allowed timeframe. The number of correct items was the raw score used in analyses.

Symbol Search: Symbol Search is also part of the Processing Speed Index of the WISC-IV (Wechsler, 2003). Children were required to search for and decide whether a target symbol appeared among distractors, and again complete as many items as possible within the allowed timeframe. The number of correct items was the raw score used in analyses.

Intelligence.

Cattell Culture Fair Intelligence Test (Scale 2, Cattell, 1973): The Cattell Culture Fair Intelligence Test (CCFIT) is a commonly used, nonverbal measure of gF. The task requires inductive reasoning about perceptual patterns, and consists of four timed subtests (series completion, odd-one-out, matrices, and topology), with items increasing in difficulty within each subtest. The indicator for gF was the raw score of this measure, which is the total number of correct items across all subtests.

Block Design: Block Design is a subtest from the Perceptual Reasoning Index of the WISC-IV (Wechsler, 2003). This task requires children to reconstruct patterns using blocks, with more points awarded in each trial for more accurate replications of the patterns. The indicator for gF was the raw score for this measure, which is the total number of points across trials.

Vocabulary: The Vocabulary subtest from the Verbal Comprehension Index of the WISC-IV (Wechsler, 2003) was used as a measure of gC as it assesses previously acquired knowledge. For this task, participants are required to name pictures or provide definitions for words, with more points in each trial awarded for correct and clear definitions. The indicator of gC was the raw score of this measure, which is the total number of points across trials.

Information: Information is also a subtest from the Verbal Comprehension Index of the WISC-IV (Wechsler, 2003) that was used as a measure of gC. This task also assesses previously acquired knowledge, by requiring participants to answer questions about general factual knowledge, with more points awarded for correctness and clarity. The indicator of gC was the raw score of this measure, which is the total number of points across trials.

Procedure

Children participated in a school-holiday activity program called Project K.I.D.S. (M. Anderson & Reid, 2015; Reid & M. Anderson, 2012) at Murdoch University, in collaboration with the Neurocognitive Development Unit at the School of Psychology of the University of Western Australia and the UWA Centre for Neonatal Research and Education (KEMH). Psychometric, chronometric and physiological measures were administered as part of a broader study enquiring about the cognitive, social and emotional development of children born VP as well as the typical development of school-aged children. Data reported here was derived from this larger database and includes selected subtests from measures of intelligence as well as executive functioning and processing speed tasks. All selected subtests were administered under standardized conditions. A maximum of 24 children at a time attended Project K.I.D.S. for two consecutive days over a two week period. This two-week testing session occurred in the school holidays. All testing was presented in a child-friendly manner, and each testing session lasted 25 minutes. When not in testing sessions, meals and activities (such as games and arts) were scheduled to ensure the participants enjoyed themselves and did not become fatigued. At the conclusion of each two day testing period, all participants were given a Project K.I.D.S. t-shirt as a memento of their participation.

Statistical Procedures and Analysis

All measures displayed a satisfactory level of normality without any trimming or transformation procedures. As CFA and SEM are very sensitive to outliers, univariate and multivariate outlier analyses were conducted on the ten dependent variables. Specifically, a test score was considered a univariate outlier if it was greater than 3 *SD*s from the betweensubjects variable mean, and was replaced with a value that was 3 *SD*s from the mean. This affected no more than two of the observations on any measure. No multivariate outliers were identified when using a Cook's *D* value of > 1 (Cook & Weisberg, 1982). Although Little's (1988) MCAR test was significant [$\chi^2(483) = 652.60$; $p < .001$], this is most likely due to the large number of degrees of freedom. The χ^2/df value is less than 2 (χ^2/df = 1.43), arguing that the missing data is missing completely at random. These scores were estimated using the full information maximum likelihood method.

As the preterm group was significantly younger than the full-term group, analyses were conducted twice – once using raw scores on the measures described previously, and again using corrected-age-standardised scores (Doyle & P. Anderson, 2016). As Fruit Stroop and CCFIT do not have norms for children as young as 6 years, the sample was divided into three corrected-age groups (less than 7 years, between 7 and 7.5 years, and 7.5 to 8 years corrected age), and z-scores were calculated within each group. All other measures had WISC-IV age standardised scores.

Amos 20 (Arbuckle, 2011) was used to estimate latent variable models with missing data. In both CFA and SEM, several fit indices were used to evaluate the fit of each model to the data. The χ^2/df statistic was used, because models with larger sample sizes and/or more degrees of freedom often show significant χ^2 values, despite having only marginal differences between the model and the data. χ^2/df being less than two is considered an indication of good model fit. Three other fit indices recommended by Hu and Bentler (1998) were also used: Bentler's comparative fit index (CFI), and the root-mean-square error of approximation (RMSEA). The criteria for excellent model fit based on these indices is greater than .95 and less than .05 respectively. However, models are acceptable with respective values of .90 and .10 (Blunch, 2008). Significance of correlation and path coefficients was determined by conducting χ^2 difference tests when removing an individual regression parameter. If the difference in model fit was significant, it indicated that the regression path makes a significant contribution to model fit. This method is more reliable than using test statistics that are based upon comparing standard errors of parameters (Gonzalez & Griffin, 2001).

Results

Descriptive Statistics

Descriptive statistics of the raw and standardised scores of the ten measures are presented in Tables 1 and 2 respectively, and the correlations between the measures being studied after outlier analysis are presented in Tables 3 and 4. As predicted, the VP group performed significantly worse on all measures regardless of whether raw or age-standardised variables were analysed, with medium to large effects of preterm birth evident, though these effect sizes were generally a little lower in the standardised measures (see Tables 1 and 2).

Latent Variable Analyses

Using standardised scores to account for between-groups age differences, a CFA was conducted to determine whether birth group and the four cognitive constructs were related to each other. The correlations between constructs ranged from $r = -.32$ to $r = .87$ (all $p < .001$; see Table 5 for CFA factor correlations). Despite some very high correlations, alternative model testing found that the full five-construct model was the best fit for the data (i.e. attempting to combine, say, EF and gF into a single factor resulted in significantly worse model fit). The model fit statistics for this model were excellent [$\chi^2(35) = 59.57$, $p = .006$, $\chi^2/\text{df} = 1.70$, CFI = .97, RMSEA = .048].

Given the high degree of relatedness between birth group and the four cognitive factors, a mediation model was tested using structural equation modelling. In this model, birth group predicted both gF and gC, whilst EF and processing speed acted as mediators between birth group and the intelligence factors. Additionally, the residual variances of EF and processing speed were allowed to correlate with each other in case there was common variance between the two constructs that birth group did not account for. This was also done for the residual variances of gF and gC.

Figure 1 shows the final SEM mediation model. To test whether the relationship between birth group and intelligence is mediated by EF and/or processing speed, the birth group-gF and birth group-gC regression paths were removed from the model, one at a time, given that the birth group-gF and birth group-gC correlations were both statistically significant in the CFA model. Removal of these paths did not significantly worsen model fit (birth group-gF $\Delta\chi^2 = 0.93$, $\Delta df = 1$, $p = .33$; birth group-gC $\Delta\chi^2 = 2.57$, $\Delta df = 1$, $p = .11$), therefore, any association between birth group and the two intelligence factors is completely accounted for by EF and/or processing speed. That is, the relationship between preterm birth and intelligence was fully mediated by EF and/or processing speed.

To determine which of EF and processing speed (or both) mediated the birth group-intelligence relationship, further testing was conducted. Removal of the birth group-EF ($\Delta\chi^2 = 34.41$, $\Delta df = 1$, $p < .001$), EF-gF ($\Delta\chi^2 = 41.63$, $\Delta df = 1$, $p < .001$), and EF-gC paths ($\Delta\chi^2 = 65.15$, $\Delta df = 1$, $p < .001$) all significantly worsened model fit, indicating that these paths are significant and that EF mediates the birth group-intelligence relationship. Of note, when the EF-gF and EF-gC paths were removed, the birth group-gF path remained nonsignificant, but the birth group-gC path increased to statistical significance, implying that processing speed is fully mediating the birth group-gF relationship, but only partially mediating the birth group-gC relationship. The same procedure was then conducted with the processing speed factor. Removal of the birth group-speed ($\Delta\chi^2 = 30.45$, $\Delta df = 1$, $p < .001$) and speed-gF ($\Delta\chi^2 = 8.39$, $\Delta df = 1$, $p = .004$) paths both significantly worsened model fit, indicating that these paths are also significant and that processing speed mediates the birth group-gF relationship. However, removal of the speed-gC path did not significantly worsen model fit ($\Delta\chi^2 = 1.65$, $\Delta df = 1$, $p = .20$), implying that processing speed does not mediate the birth group-gC relationship. Additionally, when the speed-gF and speed-gC paths were removed, the birth group-gF and birth group-gC paths remained nonsignificant, implying that EF fully mediates the birth group-intelligence relationship.

Lastly, the correlations between residual variances were tested for significance. The EF-speed residual correlation was significant ($\Delta\chi^2 = 36.80$, $\Delta df = 1$, $p < .001$), but the gF-gC residual correlation was not ($\Delta\chi^2 = 0.67$, $\Delta df = 1$, $p = .41$). The final model fit statistics were excellent [$\chi^2(39) = 65.40$, $p = .005$, $\chi^2/df = 1.68$, CFI = .97, RMSEA = .047; Figure 1].

These results were almost all replicated with the raw data. The correlations between constructs ranged from $r = -.40$ to $r = .93$ (all $p < .001$; see Table 6). Again, despite some very high correlations, alternative model testing found that the full five-construct model was the best fit for the data. Furthermore, in the mediation analyses, removal of the birth group-intelligence paths did not significantly worsen model fit (birth group-gF $\Delta\chi^2 = 0.00$, $\Delta df = 1$, $p = 1.00$; birth group-gC $\Delta\chi^2 = 0.68$, $\Delta df = 1$, $p = .41$), therefore, any association between birth group and the two intelligence factors is completely accounted for by EF and/or processing speed. Removal of the birth group-EF ($\Delta\chi^2 = 66.52$, $\Delta df = 1$, $p < .001$), EF-gF ($\Delta\chi^2 = 33.33$, $\Delta df = 1$, $p < .001$), and EF-gC paths ($\Delta\chi^2 = 61.49$, $\Delta df = 1$, $p < .001$) all significantly worsened model fit, indicating that these paths are significant and that EF mediates the birth group-intelligence relationship. When the EF-gF and EF-gC paths were removed, the birth group-gF and birth group-gC paths remained nonsignificant, implying that processing speed is fully mediating the birth group-intelligence relationship before accounting for age. Removal of the birth group-speed ($\Delta\chi^2 = 45.48$, $\Delta df = 1$, $p < .001$) and speed-gF ($\Delta\chi^2 = 5.19$, $\Delta df = 1$, $p = .023$) paths both significantly worsened model fit, indicating that these paths are also significant and that processing speed mediates the birth group-gF relationship. In contrast to the age-corrected analyses, however, removal of the speed-gC path also significantly worsened model fit ($\Delta\chi^2 = 4.81$, $\Delta df = 1$, $p = .028$), implying that processing speed mediates the birth group-gC relationship when age is not accounted for. Additionally, when the speed-gF and speed-gC paths were removed, the birth group-gF and birth group-gC paths remained nonsignificant, implying that EF fully mediates the birth group-intelligence relationship. The EF-speed residual correlation was significant ($\Delta\chi^2 = 69.21$, $\Delta df = 1$, $p < .001$), but the gF-gC residual correlation was not ($\Delta\chi^2 = 0.01$, $\Delta df = 1$, $p = .91$). The final model fit statistics were excellent [$\chi^2(38) = 65.12$, $p = .004$, $\chi^2/df = 1.72$, CFI = .97, RMSEA = .049].

Discussion

The current study aimed to examine the direct and indirect effects of preterm birth on neurocognition. Independent-samples t-tests found that children born VP performed significantly worse than their term-born peers on all tasks, and a CFA found that preterm birth was associated with EF, processing speed, gF, and gC. However, an SEM found that EF fully mediated the associations between preterm birth and the two intelligence constructs. Processing speed also fully mediated the relationship between preterm birth and gF, but only partially mediated the relationship between preterm birth and gC.

It was hypothesised that children born VP would have test outcomes consistent with a neurocognitive deficit (P. Anderson & Doyle, 2003). Independent-samples t-tests found that the VP group performed significantly worse than their term-born peers on all measures of EF, processing speed, and intelligence, regardless of whether raw scores or age-standardised scores were examined. Additionally, a CFA found significant correlations between birth group and all four of EF, processing speed, gF, and gC. These results are supported by a recent meta-analysis conducted by Brydges et al. (2018), who found medium to large effect sizes – comparable to those reported in the current study – of preterm birth on EF, processing speed, and intelligence[2]. Given that Brydges et al. (2018) found no association between effect size and age at assessment (a proxy measure of development), they concluded that children born VP have a specific deficit in cognition, rather than this being a consequence of a developmental delay. That is, these children, on average, suffer from impaired EF, processing speed, and intelligence, and may not catch up later in childhood /adolescence. Future research should consider examining a cohort of children born VP longitudinally through childhood and adolescence for further evidence of this, and to possibly determine if this applies to all EFs, or just to specific EFs, such as inhibition or working memory, seeing as previous research has suggested that EFs become differentiated from each other around the age of 10 years (Brydges et al., 2014b).

It was also predicted that EF and/or processing speed would mediate the associations between preterm birth and intelligence. A latent variable mediation model found that EF fully mediated the relationships between birth group and gF, and between birth group and gC. It was also found that processing speed fully mediated the birth group-gF relationship, but only partially mediated the birth group-gC relationship after age has been accounted for (before accounting for between-groups age differences, processing speed also fully mediated the birth group-gC relationship). This result is also supported by previous research, given the strong relationships between EF, processing speed, and intelligence in typically developing children (e.g., M. Anderson, 1988, 1992, 2001; 2017; Brydges et al., 2012), and the deficits in children born VP reported by Aarnoudse-Moens et al. (2009), Bhutta et al. (2002), and Brydges et al. (2018). As an aside, it was of interest that the EF-processing speed correlation in the CFA was very similar to the correlation between the residual variances of EF and processing speed in the SEM. This implies that what is common between these two constructs is *unaffected* by impairments due to preterm birth. What this commonality is – some domain-free general ability, perhaps – remains open to conjecture, and would be of great interest to cognitive and developmental psychologists.

One limitation of the current study is that the neurological sequelae of VP birth were not accounted for. That is, the neurocognitive effects of VP birth may stem from a variety of potential causes. For instance, it might be the case that prematurity (i.e. being born early) halts the typical prenatal development of the brain, or may cause other problems such as brain bleeding, which in turn results in impaired brain function. Additionally, problems may potentially arise from medical procedures (e.g., surgery or medication required to deal with breathing problems may have negative consequences on brain development; Short et al., 2003). Accounting for these causal factors may begin to shed some light on a potential cascade effect of preterm birth – preterm birth may lead to certain neurological differences, which in turn may affect cognitive processes (e.g., EF and/or processing speed), which impair intelligence.

The results of the current study have implications for the development and possible training of intelligence. Given the close associations between EF, processing speed, and intelligence (M. Anderson, 1992, 2001; 2017), recent research has examined the possibility of training EFs, particularly working memory, in an attempt to increase gF (e.g., Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). Alternatively, investigating the effectiveness of neurofeedback training in this group could be of benefit (Landes et al, 2017). Although processing speed is likely to be a biological constraint that is ‘untrainable’, EFs are likely to be subject to training a developmental change. It is possible that these training programs could be modified to be child-friendly in order to help minimise differences in EF and intelligence in children born VP, though it should be noted that results of these training programs are mixed (see Au et al., 2015, and Melby-Lervåg & Hulme, 2013, for contrasting meta-analyses).

In conclusion, the current study has provided evidence of neurocognitive deficits in EF, processing speed, and intelligence in children born VP, and of the direct and indirect effects of preterm birth on these neurocognitive domains. Performance on all tasks was impaired in the preterm group, and EF and processing speed both displayed mediating effects on the relationships between preterm birth and intelligence. Given the recent proliferation of research into cognitive training programs (e.g., Au et al., 2015; Melby-Lervåg & Hulme, 2013), future research should consider the possibility of developing child-friendly cognitive training programs in an attempt to improve EFs, and hopefully intelligence, in children born very preterm.

References

Aarnoudse-Moens, C. S. H., Weisglas-Kuperus, N., van Goudoever, J. B., & Oosterlaan, J. (2009). Meta-Analysis of Neurobehavioral Outcomes in Very Preterm and/or Very Low Birth Weight Children. *Pediatrics, 124*(2), 717-728.

Anderson, M. (1988). Inspection time, information processing and the development of intelligence. *British Journal of Developmental Psychology, 6*(1), 43-57.

Anderson, M. (1989). The effect of attention on developmental differences in inspection time. *Personality & Individual Differences, 10*, 559–563.

Anderson, M. (1992). *Intelligence and Development: A Cognitive Theory*. Oxford, UK: Blackwell.

Anderson, M. (1995). Evidence for a single global factor of developmental change—Too good to be true? *Australian Journal of Psychology, 47*, 18–24.

Anderson, M. (2001). Annotation: Conceptions of Intelligence. *Journal of Child Psychology and Psychiatry, 42*, 287-298.

Anderson, M. (2017). Binet's Error: Developmental Change and Individual Differences in Intelligence Are Related to Different Mechanisms. *Journal of Intelligence, 5*(2), 24.

Anderson, M., Nettlebeck, T., & Barlow, J. (1997). Using reaction time measures of speed of information processing: Speed of response selection increases with age but speed of stimulus categorisation does not. *British Journal of Developmental Psychology, 15*, 145-157.

Anderson, M., & Reid, C. L. (2015). Theoretical insights from neuroscience in early childhood research. In A. Farrell, S. L. Kagan, & E. K. M. Tisdall (Eds.), *The Sage Handbook of Early Childhood Research* (pp. 148-162). London, UK: Sage.

Anderson, M., Reid, C. L., & Nelson, J. (2001). Developmental changes in inspection time: What a difference a year makes. *Intelligence, 29*, 475–486.

Anderson, P. J., & Doyle, L. W. (2003). Neurobehavioral outcomes of school-age children born extremely low birthweight or very preterm in the 1990s. *Journal of the American Medical Association, 289*(24), 3264-3272.

Arbuckle, J. L. (2011). *Amos 20 User's Guide.* Chicago: Amos Development Corporation.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin & Review, 22*(2), 366-377.

Bhutta, A. T., Cleves, M. A., Casey, P. H., Cradock, M. M., & Anand, K. J. (2002). Cognitive and behavioural outcomes of school-aged children who were born preterm: a meta-analysis. *Journal of the American Medical Association, 288*(6), 728-737.

Blunch, N. J. (2008). *Introduction to Structural Equation Modelling using SPSS and AMOS*. London: Sage Publications.

Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014a). Predictive validity of the N2 and P3 ERP components to executive functioning in children: a latent-variable analysis. *Frontiers in human neuroscience, 8,* 80.

Brydges, C. R., Fox, A. M., Reid, C. L., & Anderson, M. (2014b). The differentiation of executive functions in middle and late childhood: a longitudinal latent-variable analysis. *Intelligence, 47,* 34-43.

Brydges, C. R., Landes, J. K., Reid, C. L., Campbell, C., French, N., & Anderson, M. (2018). Neurocognitive outcomes in children born very preterm: A meta-analysis. *Developmental Medicine & Child Neurology*. Advance online publication. doi:10.1111/dmcn.13685

Brydges, C. R., Reid, C. L., Fox, A. M., & Anderson, M. (2012). A unitary executive function predicts intelligence in children. *Intelligence, 40,* 458-469.

Cattell, R. B. (1963). Theory of fluid and crystallised intelligence: a critical experiment. *Journal of Educational Psychology, 54,* 1-22.

Cattell, R. B. (1973). *Cattell Culture Fair Intelligence Test*. Champaign, IL: Institute for Personality and Ability Testing.

Cook, R. D., & Weisberg, S. (1982). *Residuals and influence in regression*. New York: Chapman & Hill.

Cooke, R. W. I., & Abernethy, L. J. (1999). Cranial magnetic resonance imaging and school performance in very low birth weight infants in adolescence. *Archives of Disease in Childhood-Fetal and Neonatal Edition*, *81*(2), F116-F121.

Davis, H., & Anderson, M. (1999). Individual differences in development – One dimension or two? In M. Anderson (Ed.), *The Development of Intelligence* (pp. 161-191). Hove, UK: Psychology Press.

Davis, H., & Anderson, M. (2001). Developmental and individual differences in fluid intelligence: Evidence against the unidimensional hypothesis. *British Journal of Developmental Psychology, 19*(2), 181-206.

Demetriou, A., Spanoudis, G., & Shayer, M. (2013). Developmental intelligence: From empirical to hidden constructs. *Intelligence, 41,* 744–749.

Demetriou, A., Spanoudis, G., Shayer, M., van der Ven, S., Brydges, C. R., Kroesbergen, E., . . . Swanson, H. L. (2014). Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modeling of 14 studies. *Intelligence, 46*, 107-121.

Doyle, L. W., & Anderson, P. J. (2016). Do We Need to Correct Age for Prematurity When Assessing Children? *The Journal of pediatrics, 173,* 11-12.

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12-year-old children. *Psychological Test and Assessment Modeling, 52*(4), 419-431.

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex, 86*, 186-204.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not All Executive Functions Are Related to Intelligence. *Psychological Science, 17*, 172-179.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science, 7,* 237-241.

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology, 54*(1), 1-34.

Gonzalez, R., & Griffin, D. (2001). Testing parameters in structural equation modelling: Every “one” matters. *Psychological Methods, 6*, 258-269.

Hale, S. (1990). A global developmental trend in cognitive processing speed. *Child Development, 61*(3), 653-663.

Hu, L., & Bentler, P. M. (1998). Fit Indices in Covariance Structure Modeling: Sensitivity to Underparameterized Model Misspecification. *Psychological Methods, 3,* 424-453.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*(19), 6829-6833.

Jensen, A.R. (1982). Reaction time and psychometric g. In H. J. Eysenck (Ed.), *A Model for Intelligence* (pp. 93-132). Berlin, Germany: Springer.

Kail, R. (1986). Sources of age differences in speed of processing. *Child Development, 57,* 969-987.

Kail, R. (1991a). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109*(3), 490-501.

Kail, R. (1991b). Processing time declines exponentially during childhood and adolescence. *Developmental Psychology, 27,* 259-266.

Kail, R. (1992). Processing speed, speech rate, and memory. *Developmental Psychology, 28*(5), 899-904.

Kail, R., & Hall, L. K. (1994). Processing speed, naming speed, and reading. *Developmental Psychology, 30*(6), 949-954.

Kail, R., & Park, Y. –S. (1992). Global developmental change in processing time. *Merrill-Palmer Quarterly, 4,* 525-541.

Kail, R., & Park, Y. –S. (1994). Processing time, articulation time, and memory span. *Journal of Experimental Child Psychology, 57,* 281-291.

Kail, R., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86*(2), 199-225.

Kerr-Wilson, C. O., Mackay, D. F., Smith, G. C. S., & Pell, J. P. (2012). Meta-analysis of the association between preterm delivery and intelligence. *Journal of Public Health, 34*(2), 209-216.

Kranzler, J. H., & Jensen, A. R. (1989). Inspection time and intelligence—A meta-analysis. *Intelligence, 13,* 329–347.

Landes, J. K., Reid, C. L., Arns, M., Badcock, N. A., Ros, T., Enriquez-Geppert, S., ... & Anderson, M. (2017). EEG neurofeedback for executive functions in children with neurodevelopmental challenges. *The Cochrane Library, 12*, CD012890.

Lehto, J., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology, 21*(1), 59-80.

Little, R. J. A. (1988). A Test of Missing Completely at Random for Multivariate Data with Missing Values. *Journal of the American Statistical Association, 83*, 1198-1202.

Maalouf, E. F., Duggan, P. J., Rutherford, M. A., Counsell, S. J., Fletcher, A. M., Battin, M., ... & Edwards, A. D. (1999). Magnetic resonance imaging of the brain in a cohort of extremely preterm infants. *The Journal of pediatrics, 135*(3), 351-357.

Manly, T., Robertson, I. H., Anderson, V., & Nimmo-Smith, I. (1999). *The test of everyday attention (TEA-Ch)*. Bury St. Edmunds, UK: Thames Valley Test Company.

Melby-Hervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270-291.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions four general conclusions. *Current Directions in Psychological Science, 21*(1), 8-14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of EFs and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cognitive Psychology, 41*, 49-100.

Nettlebeck, T. (1987). Inspection time and intelligence. In P. Vernon (Ed.), *Speed of Information Processing and Intelligence* (pp. 295-346). Westport, CT: Ablex.

Nettlebeck, T., & Wilson, C. (1985). A cross sequential analysis of developmental differences in speed of visual information processing. *Journal of Experimental Child Psychology, 40*, 1-22.

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(2), 241-268.

Peterson, B. S., Vohr, B., Staib, L. H., Cannistraci, C. J., Dolberg, A., Schneider, K. C., ... & Duncan, C. C. (2000). Regional brain volume abnormalities and long-term cognitive outcome in preterm infants. *Journal of the American Medical Association*, *284*(15), 1939-1947.

Rabbitt, P., & Goward, L. (1994). Age, information processing speed, and intelligence. *The Quarterly Journal of Experimental Psychology Section A, 47*(3), 741-760.

Redick, T. S., Unsworth, N., Kelly, A. J., & Engle, R. W. (2012). Faster? Smarter? Working memory capacity and perceptual speed in relation to fluid intelligence. *Journal of Cognitive Psychology, 24*, 844-854.

Reid, C. L., & Anderson, M. (2012). Left-brain, right-brain, brain games and beanbags: neuromyths in education. In P. Adey & J. Dillon (Eds.), *Bad Education: Debunking Myths in Education* (pp. 179-198). Maidenhead, UK: McGraw-Hill Education.

Sheppard, L. D., & Vernon, P. A. (2008). Intelligence and speed of information-processing: A review of 50 years of research. *Personality and Individual Differences, 44*, 535-551.

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S.-C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. *Developmental Neuropsychology, 35*(6), 679-697.

Short, E. J., Klein, N. K., Lewis, B. A., Fulton, S., Eisengart, S., Kercsmar, C., ... & Singer, L. T. (2003). Cognitive and academic consequences of bronchopulmonary dysplasia and very low birth weight: 8-year-old outcomes. *Pediatrics, 112*(5), e359-e366.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology, 59*(4), 745-759.

Stewart, A. L., Rifkin, L., Amess, P. N., Kirkbride, V., Townsend, J. P., Miller, D. H., ... & Murray, R. M. (1999). Brain structure and neurocognitive and behavioural function in adolescents who were born very preterm. *The Lancet, 353*(9165), 1653-1657.

Vernon, P. A. (1983). Speed of information processing and general intelligence. *Intelligence, 7*, 53-70.

Wechsler, D. (2003). *Manual for the Wechsler Intelligence Scale for Children* (4th ed.). San Antonio, TX: The Psychological Corporation.

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology, 44*(2), 575-587. doi: 10.1037/0012-1649.44.2.575

Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of experimental child psychology, 108*(3), 436-452.

Willoughby, M. T., Wirth, R. J., Blair, C. B., & Greenberg, M. (2012). The measurement of executive function at age 5: Psychometric properties and relationship to academic achievement. *Psychological Assessment*, *24*(1), 226-239.

Wu, K. K., Chan, S. K., Leung, P. W. L., Liu, W.-S., Leung, F. L. T., & Ng, R. (2011). Components and developmental differences of executive functioning for school-aged children. *Developmental Neuropsychology*, *36*(3), 319-337.

Footnotes

[1] Although the mean ages are very close, the standard error of the difference is very small due to the very large sample size in the study. Hence, even though there was a mean age difference of 0.09231 years (for chronological age), the standard error of the difference was 0.04034 years, corresponding to a t value of 2.288.

[2] It should be noted that the effect sizes for the intelligence measures were slightly lower than what was reported in the Brydges et al. (2018) meta-analysis, possibly because the meta-analysis was almost entirely based upon IQ scores, rather than gF or gC measures.

Table 1

Descriptive statistics of raw scores of the cognitive tasks for the VP group (N = 204), control group (N = 98), and all participants (N = 302) used in the analyses.

Task	VP Group		Control Group		All participants		*p*	Cohen's *d*
	M	*SD*	*M*	*SD*	*M*	*SD*		
Fruit Stroop[a]	16.37	6.94	20.23	7.49	17.56	7.33	< .001	0.53
Digit Span[b]	10.87	2.66	12.60	2.68	11.42	2.78	< .001	0.65
Letter-Number Sequencing[b]	9.44	3.53	11.96	3.80	10.23	3.80	< .001	0.69
Creature Counting[b]	2.16	2.10	3.70	2.26	2.66	2.27	< .001	0.71
Coding[b]	37.81	13.12	43.21	12.96	39.51	13.29	.002	0.41
Symbol Search[b]	20.20	8.51	27.07	6.03	22.38	8.43	< .001	0.93
CCFIT[a]	19.80	6.27	25.30	5.82	21.63	6.64	< .001	0.91
Block Design[b]	15.06	8.37	20.39	7.84	17.28	8.55	< .001	0.66
Vocabulary[b]	18.54	5.63	22.31	5.65	20.11	5.93	< .001	0.67
Information[b]	10.49	2.67	12.64	2.68	11.17	2.85	< .001	0.80

Note. [a]Total items correct. [b]Total trials correct. *p* values were obtained from independent-samples t-tests conducted on each measure between groups (two-tailed), and Cohen's *d* values are the effect sizes from these t-tests.

Table 2

Descriptive statistics of standardised scores of the cognitive tasks for the VP group (N = 204), control group (N = 98), and all participants (N = 302) used in the analyses.

Task	VP Group		Control Group		All participants		*p*	Cohen's *d*
	M	*SD*	*M*	*SD*	*M*	*SD*		
Fruit Stroop	-0.09	0.98	0.21	0.98	0.00	0.99	.023	0.31
Digit Span	8.69	2.81	10.19	2.80	9.17	2.88	< .001	0.54
Letter-Number Sequencing	8.31	2.57	9.69	2.79	8.74	2.71	< .001	0.52
Creature Counting	2.98	7.50	8.82	3.45	7.93	3.19	.001	1.00
Coding	9.00	3.39	10.21	3.81	9.38	3.57	.009	0.34
Symbol Search	9.24	3.18	11.45	2.42	9.95	3.13	< .001	0.78
CCFIT	-0.18	0.98	0.36	0.92	0.00	0.99	< .001	0.57
Block Design	9.26	2.93	10.39	2.57	9.63	2.86	.002	0.41
Vocabulary	9.34	2.98	10.88	2.70	9.84	2.98	< .001	0.54
Information	8.80	3.00	10.61	2.81	9.37	3.06	< .001	0.62

Note. p values were obtained from independent-samples t-tests conducted on each measure between groups (two-tailed), and Cohen's *d* values are the effect sizes from these t-tests.

Table 3

Correlations between birth group, raw measures of executive functioning, processing speed, and intelligence, and age (N=302)

	1	2	3	4	5	6	7	8.	9.	10.	11.
1. Birth Group	-										
2. Fruit Stroop	-.25***	-									
3. Digit Span	-.29***	.38***	-								
4. Letter-Number Sequencing	-.31***	.28***	.41***	-							
5. Creature Counting	-.32***	.32***	.45***	.33***	-						
6. Coding	-.19**	.36***	.27***	.26***	.20**	-					
7. Symbol Search	-.38***	.41***	.39***	.40***	.45***	.58***	-				
8. CCFIT	-.39***	.38***	.49***	.40***	.57***	.37***	.61***	-			
9. Block Design	-.31***	.31***	.40***	.39***	.46***	.33***	.51***	.55***	-		
10. Vocabulary	-.32***	.21**	.42***	.39***	.43***	.13	.31***	.51***	.43***	-	
11. Information	-.35***	.23***	.51***	.45***	.47***	.25***	.39***	.49***	.40***	.68***	-
12. Chronological Age	-	.25***	.11	.20**	.26***	.23***	.27***	.16**	.17*	.19**	.24***
13. Corrected Age	-	.32***	.20**	.29***	.36***	.29***	.40***	.29***	.26***	.29***	.33***

Note. *p < .05; **p < .01; **p < .001. Birth group was coded as 0 = full-term and 1 = very preterm.

Table 4

Correlations between birth group, standardised measures of executive functioning, processing speed, and intelligence, and age (N=302)

	1	2	3	4	5	6	7	8.	9.	10.	11.
1. Birth Group	-										
2. Fruit Stroop	-.14*	-									
3. Digit Span	-.24***	.35***	-								
4. Letter-Number Sequencing	-.24***	.18**	.37***	-							
5. Creature Counting	-.20**	.27***	.38***	.24***	-						
6. Coding	-.16**	.31***	.24***	.20**	.15*	-					
7. Symbol Search	-.33***	.34***	.31***	.31***	.29***	.57***	-				
8. CCFIT	-.26***	.35***	.43***	.32***	.49***	.32***	.52***	-			
9. Block Design	-.19**	.30***	.35***	.27***	.37***	.28***	.44***	.52***	-		
10. Vocabulary	-.24***	.18**	.35***	.31***	.34***	.06	.22***	.45***	.35***	-	
11. Information	-.28***	.17**	.49***	.40***	.35***	.19***	.31***	.42***	.33***	.59***	-
12. Chronological Age	-	.00	-.02	.00	.00	.12	.10	-.08	-.04	-.07	.01
13. Corrected Age	-	.05	.06	.07	.08	.17**	.22***	.04	.04	.01	.09

Note. **p* < .05; ***p* < .01; ****p* < .001. Birth group was coded as 0 = full-term and 1 = very preterm.

Table 5

Correlations between birth group and latent variables of standardised scores of executive functioning, processing speed, gF, and gC (N=302)

	1.	2.	3.	4.	5.
1. Birth Group	-				
2. EF	-.37	-			
3. Processing Speed	-.35	.56	-		
4. gF	-.32	.87	.68	-	
5. gC	-.34	.79	.36	.70	-

Note. All *p* < .001. Birth group was coded as 0 = full-term and 1 = very preterm.

Table 6

Correlations between birth group and latent variables of raw scores of executive functioning, processing speed, gF, and gC (N=302)

	1.	2.	3.	4.	5.
1. Birth Group	-				
2. EF	-.47	-			
3. Processing Speed	-.40	.68	-		
4. gF	-.46	.93	.77	-	
5. gC	-.42	.80	.45	.73	-

Note. All $p < .001$. Birth group was coded as 0 = full-term and 1 = very preterm.

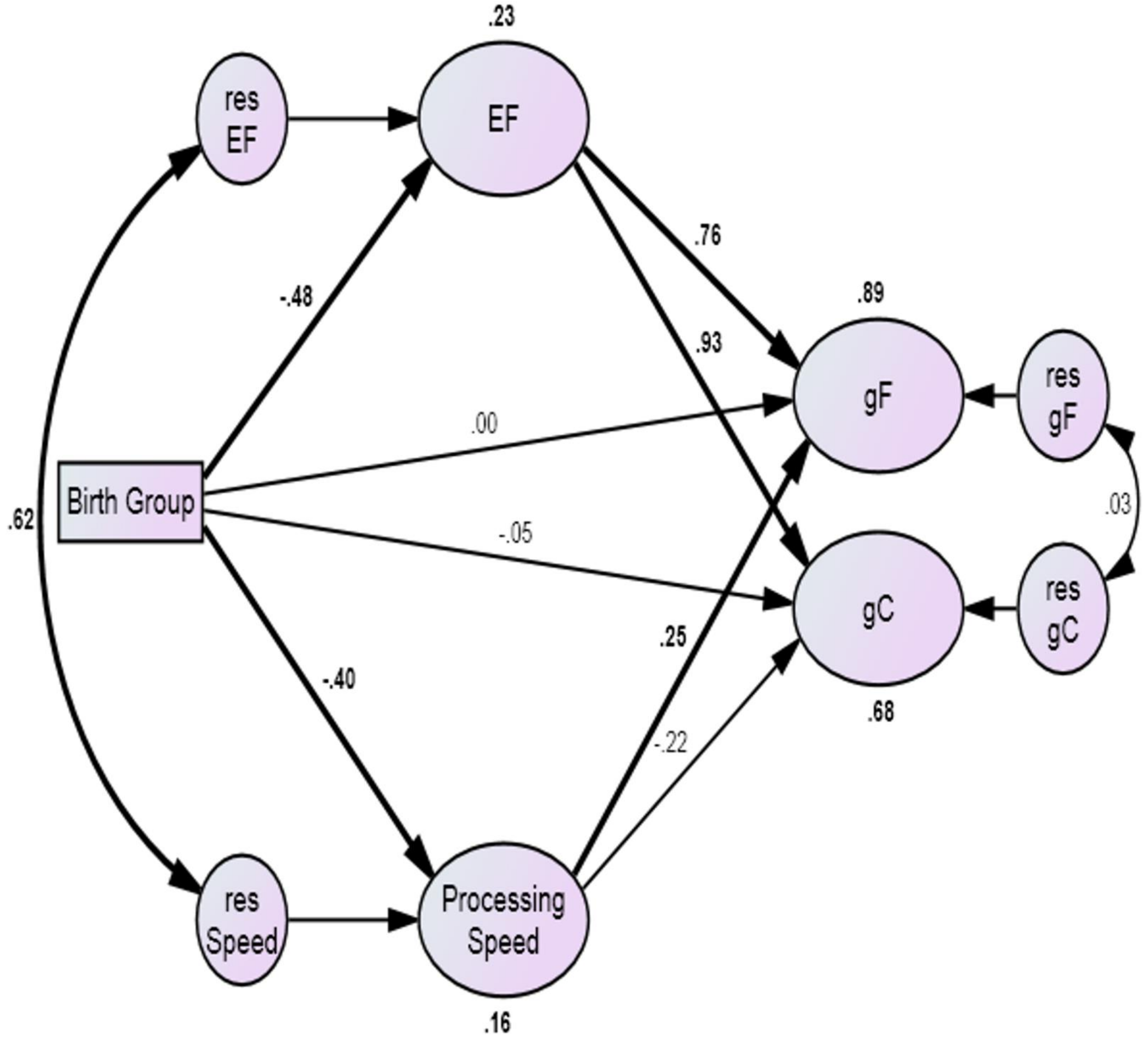

Figure 1. The final mediation model, using age-standardised measures. Straight lines indicate regression weights. Curved lines indicate correlations. Lines and values in bold indicate statistical significance ($p < .05$).