The contribution of cool and hot executive function to academic achievement, learning-related behaviours, and classroom behaviour

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RUNNING HEAD: COOL AND HOT EXECUTIVE FUNCTION AND ACADEMIC ACHIEVEMENT

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Abstract

The primary aim of this study was to examine whether individual differences in cool and hot executive functions (EF) were associated with children's transition to school, in terms of both academic performance and classroom behaviour. Children between 5- and 7-years-of-age (*N* = 90) completed performance based assessments of cool and hot EF as well as verbal ability. Teachers reported on children's reading and numeracy performance, learning-related behaviours, hyperactivity, and aggression. Results revealed that EF, in particular working memory, was associated with reading and numeracy performance and that this relation was mediated by learning-related behaviours. EF was not associated with hyperactive or aggressive behaviour. The findings strengthen the evidence base for the importance of EF in early academic performance and underscore its potential to be a beneficial part of early education curriculum and a target for early intervention for successful transition to school.

Key Words: *executive function, early academic achievement, learning-behaviours, aggression, early childhood*

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Early childhood is characterised by marked gains in children's cognitive and social development (Beauchamp & Anderson, 2010); important foundations for a successful transition to school (Blair, 2002). It is likely that young children's executive function (EF) skills are important for a successful transition to school as EF has been associated with both academic achievement (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009) and social functioning (O'Toole, Monks & Tsermentseli, 2017; Poland, Monks, & Tsermentseli, 2016). EF refers to a set of higher-order neurocognitive skills that are necessary for goal directed behaviour (V. Anderson, 1998). Although there is no definitive consensus on the organisation of EF, it is generally agreed that it encompasses skills such as inhibition, working memory and cognitive flexibility (Miyake et al., 2000). Until relatively recently, the role of emotion and motivation in EF was largely neglected (Peterson & Welsh, 2014). However, over the past decade there has been a rising interest in the role of emotion and motivation in EF, leading researchers to pay greater attention to the role of EF in affectively charged and social situations.

Paving the way for this more affective view of EF, was the proposed conceptual distinction between cool and hot EF (Zelazo & Müller, 2002). Cool EF refers to the more purely cognitive skills (e.g. inhibition, working memory, cognitive flexibility) associated with the dorsolateral prefrontal cortex (DL-PFC) and elicited by emotionally neutral problems. Hot EF, on the other hand, denotes the more affective EF processes related to the ventromedial prefrontal cortex (VM-PFC) and is evoked by emotionally significant problems. A growing body of literature has identified the cognitive skills that encompass cool EF and numerous assessments of cool EF have been developed (e.g. Go/No-Go, Stroop or Tower of London tasks; Anderson, Anderson, Jacobs, & Spencer-Smith, 2008). The most commonly assessed hot EF skill is delay of gratification (the ability to resist the temptation for immediate reward and wait for a greater reward; Kim, Nordling, Yoon, Boldt, & Kochanska, 2014; Masten et al., 2012; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011), an ability that is often considered reflective of effortful control (Allan & Lonigan, 2011). A further skill that is often proposed to reflect hot EF is affective decision making, the ability to make decisions in a context of risk and uncertainty (Kerr & Zelazo, 2004; Zelazo & Müller, 2002).

EF and Academic Achievement

Several lines of research have provided support for the role of EF in children's early school success. First, teachers report that a substantial number of children show adjustment problems in their transition to school, which they attribute to children's difficulties following directions and controlling attention (Rimm-Kaufman, Pianta, Cox, Carolina, & Hill, 2006). Second, numerous studies have found a link between children's cool EF skills and academic achievement. For example, children who showed poor EF performance between 3- and 5-years-old demonstrated substantial impairments in multiple aspects of academic readiness, including vocabulary, reading, problem-solving and overall teacher rated academic ability (Willoughby, Magnus, Vernon-Feagans, & Blair, 2016). Intervention studies have also shown that fostering EF abilities can have a positive impact on children's school adjustment (Bierman et al., 2008; G. Duncan et al., 2006). Together, this evidence endorses the foundational role that EF plays in children's academic adjustment at school (Blair & Raver, 2015; Ursache, Blair, & Raver, 2012).

EF and Learning-Related Behaviours

EF is also important for learning-related behaviours, i.e. behaviours that support learning such as working independently and persisting with challenging tasks (Blair, 2002). Studies have found that children who have superior cool EF demonstrate more positive learning-related behaviours, are more engaged and attentive, and participate more in lessons (Brock et al., 2009; Garner & Waajid, 2012). In contrast, the link between hot EF and learning-related behaviours is less well understood. Superior hot EF skills are associated with greater social and emotional understanding (Brock et al., 2009; Garner & Waajid, 2012; Mann et al., 2016). Children who demonstrate high social and emotional competence are better able to understand and manage their own emotions and are also more skilled at developing and maintaining peer relationships (Denham, 2006). Greater social and emotional competence has been linked to more positive attitudes toward school and higher academic achievement (Razza & Raymond, 2015). However, to date, there has only been one study that has directly investigated the relation between hot EF and learning-related behaviours among young children. Brock and colleagues (2009) failed to find an association between hot EF and learning-related behaviours, but only delay of gratification was assessed as a measure of hot EF.

EF, Learning-Related Behaviours and Academic Achievement

Children’s behaviour in the classroom has been found to influence achievement (Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008). For example, learning-related behaviours (e.g. memory for instructions, independent work) at 4- to 5-years-old predicted achievement through to 7- to 8 years-of-age (McCellend et al., 2000). Learning-related behaviours may therefore mediate the link between EF and academic achievement. Findings regarding the mediating role of learning-related behaviours in the relation between EF and academic achievement are mixed. Higher levels of involvement in learning and sequential learning behaviours as well as lower disengagement from the classroom mediated the link between cool EF and achievement in literacy and maths among 4-year-old children (Nesbitt, Farran, & Fuhs, 2015). In contrast, other research has failed to find support for the role of learning-related behaviours as a mediator between cool EF and maths achievement in a sample of 4- and 5-year-old children (Brock et al., 2009).

EF and Classroom Behaviour

Children’s peer directed behaviour also forms an important component of their transition to school (Denham, 2006). EF has been found to be related to children’s social development (Beauchamp & V. Anderson, 2010; Yeates et al., 2007). Poor EF performance, particularly inhibition, is linked to increased hyperactive and aggressive behaviour in young children (Berlin & Bohlin, 2002; Masten et al., 2012; Poland et al., 2016; Utendale, Hubert, Saint-Pierre, & Hastings, 2011). In contrast, understanding of the role of hot EF in children’s hyperactive and aggressive behaviour is limited. Social problem solving is likely to occur in motivationally and emotionally significant environments and as a result may require hot EF abilities (Zelazo & Müller, 2002). Findings regarding the predictive role of hot EF in aggression, however, have been mixed. Some studies have reported that poor hot EF is associated with aggression in children between the ages of 2- and 5-years (Di Norcia et al., 2015; Garner & Waajid, 2012; Kim et al., 2014), whereas other research has failed to find a relation beyond that of cool EF in children 3- to 6-years-of-age (Poland et al., 2016; Willoughby et al., 2011).

Rationale for the Study

Children who transition to school with few difficulties demonstrate better academic abilities, learning-related behaviours and fewer behaviour problems than children who experience challenges transitioning to school (Blair, 2002). EF has been linked to these domains. Despite a strong body of evidence linking EF and academic abilities, learning-related behaviours, and disruptive behaviour in children, the literature is hindered by two central limitations. First, research has tended to focus on the broad construct of EF and neglected the role of individual EF skills. Specific EF skills have been associated with academic achievement. For instance, inhibition has been found to be a significant predictor of early maths and reading ability (Blair & Razza, 2007). In addition, greater cognitive flexibility and inhibition were associated with better numeracy, literacy and vocabulary skills in 4-year-olds (R. Duncan, Mcclelland, & Acock, 2017). However, other research has found that although improvements in working memory and cognitive flexibility between 5- and 6-years-old predicted academic achievement, improvement in inhibition was not related to academic achievement (Vandenbroucke, Verschueren, & Baeyens, 2017) Understanding the link between specific EF skills and academic achievement will provide greater insight into the role that EF plays in children's successful transition to school.

Second, studies exploring the link between hot EF skills and academic achievement, learning related behaviours and disruptive behaviour, particularly during early childhood, are limited. Research exploring this relation has typically focused on the role of delay of gratification. Delay of gratification was not associated with numeracy or reading skills in 5- to 6-year-old children (Brock et al., 2009). Added to this, delay of gratification at 3- and 4-years-old did not predict numeracy and reading performance at 5-, 6-, and 8-years-old (Kim et al., 2014). However, the role of other aspects of hot EF, such as affective decision making, in academic performance has not yet been investigated. The role of hot EF in academic achievement is therefore currently poorly understood. It is possible that only cool EF may be associated with academic achievement in early childhood and not hot EF. However, this is difficult to determine when the relation between a wider range of hot EF skills and academic achievement has not been investigated. Added to this, greater exploration of the links between EF, learning-related behaviours and academic achievement will elucidate the underlying mechanisms of the relation between EF and academic achievement. Examining the role of hot EF in aggressive and hyperactive behaviour will also elucidate the role that affect plays in classroom adjustment.

Study Goals

This study will explore whether individual differences in cool and hot EF are one source of variance in 5- to 7-year-old children's academic performance, learning-related behaviour and classroom behaviour. Added to this, the present study will examine potential indirect relations between EF and academic performance and classroom behaviour via learning related behaviours. This research will therefore increase knowledge about pathways to successful transitions to school and the role that affective as well as cognitive skills play in this transition. Due to the considerable body of literature indicating that cool EF is associated with academic achievement (Brock et al., 2009; Garner & Waajid, 2012), learning-related behaviours (R. Duncan et al., 2017), and hyperactive and aggressive behaviour (Berlin & Bohlin, 2002; Poland et al., 2016), it was predicted that better cool EF performance would predict greater school readiness, including greater reading and numeracy abilities, better learning-related behaviours, and lower hyperactive and aggressive behaviour. Hypotheses regarding specific cool EF skills were not proposed due to the mixed findings of previous studies (Berlin & Bohlin, 2002; Masten et al., 2012; Poland et al., 2016; Utendale et al., 2011). Based on the link between hot EF and positive attitudes toward school (Blair & Raver, 2015), it was hypothesised that hot EF would be positively associated with learning-related behaviours, but would not be directly related to academic performance. Findings regarding the role of hot EF in young children's behaviour have been mixed and as a result specific hypotheses concerning the relation between hot EF and aggressive and hyperactive behaviour were not proposed. Finally, it was predicted that learning-related behaviours would mediate the link between cool and hot EF and academic achievement as prior research has found a relation between both EF achievement and reading and numeracy abilities as well as between learning-related behaviours and achievement (Nesbitt et al., 2015). A conceptual diagram of the proposed pathways is presented in Figure 1.

Method

Participants

A sample of 90 children (42 boys and 48 girls) between 5- and 7-years-old (*M* = 74.09 months, *SD* = 10.25 months) and their class teachers were recruited to participate in the study. Children were recruited from two mainstream primary schools, across three Year One classes (children aged 5-6 years) and two Year Two classes (children aged 6-7 years). Both schools were located in the South East England. The first school comprised 43% Black and Ethnic Minority students and 57% White British students and 14% of students had English as an additional language. The second school comprised 97% Black and Ethnic Minority students and 3% White British and 81% of students had English as an additional language. Further, in the first school 23% of students were eligible for pupil premium and in the second school 30% of students were eligible.

Measures

Cool EF. Inhibition was assessed using a computerised version of the Fish and Shark Go/No-Go Task (Simpson & Riggs, 2006). When an image of a fish appeared on the screen children were required to press a button to catch the fish (Go trials), but when an image of a shark appeared children were required to withhold pressing the button to avoid catching the shark (No-Go trials). Each child first completed 6 practice trials (3 Go and 3 No-Go trials) and then 40 test trials (30 Go and 10 No-Go trials). The proportion of correct No-Go trials was calculated. Scores ranged from 0 (all trials incorrect) to 1 (all trials correct).

Working memory was measured using the Digit Span Backward Subtest from the WISC-III (Wechsler Intelligence Scale for Children – 3rd Edition; Wechsler, 1991). Children were required to recall a series of number sequences in reverse order (from two to eight digits). The task was stopped when children completed all of the sequences or incorrectly recalled two trials of the same span length. Children were awarded 1 point for each correct trial. Scores for each trial were summed and potential scores ranged from 0 to 14.

Cognitive flexibility was examined using the Dimension Change Card Sort (DCCS) (Zelazo et al., 2003). Children were presented with a deck of cards that consisted of red and blue rabbits and boats and two boxes in which the cards could be sorted. In the pre-switch condition, children were asked to sort the cards according to one rule (e.g. colour: “If it’s red put it here, but if it’s blue put it there.”). No feedback was provided. The researcher demonstrated two trials. The order in which dimensions were presented was counterbalanced across participants. After the child had completed six pre-switch trials, they were told to stop playing the first game and to switch to a new game. The child then completed 6 post-switch trials, which were identical to the pre-switch trials except the child was told the rules for sorting by the other dimension (e.g., shape: “If it’s a boat put it here, but if it’s a rabbit put it there.”).

Children were considered to have passed this phase of the task when they correctly sorted 5 or more cards out of 6 in that phase. To capture developmental changes across the entire age range of interest in this study children who passed the post-switch phase were given a new, more difficult version (Carlson, 2005). Children were first shown two test cards like those used in the standard version as well as two new test cards that had a star in the corner. Children were told that the star indicated that they must play a particular game (e.g., “If there’s a star, you have to play the colour game; if there is no star, you have to play the shape game”). The dimension indicated by the star was counterbalanced across participants. The researcher demonstrated two trials and the child completed 12 test trials, in which no feedback was provided. Children were considered to have passed this phase when they correctly sorted 9 out of 12 trials. Scores from the two DCCS versions were added together. Scores therefore ranged between 0 (no phases correct) to 2 (all phases correct).

Hot EF. Affective decision making was measured using the Children's Gambling Task (CGT) (Poland et al., 2016). On each trial the child selected a card from one of two decks, which when turned revealed happy faces, representing the number of beads won, and sad faces, representing the number of beads lost. One deck was advantageous and resulted in a win of 1 bead and a loss of either 0 or 1 beads (net gain of 5 beads per 10 cards), whereas the other deck was disadvantageous and resulted in a win of 2 beads, but a loss of either 0, 4, 5 or 6 beads (net loss of 5 beads per 10 cards). The beads the child won could be traded for stickers at the end of the task. There were 6 demonstration trials and 50 test trials. Whether predominately advantageous or disadvantageous decisions were made across the last three trial blocks was used as a measure of affective decision making. Scores ranged from -1 (all disadvantageous decisions) to +1 (all advantageous decisions).

Delay of gratification ability was assessed using the Gift Delay task (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996). The child was instructed not to peek while the researcher wrapped their gift. The researcher pretended to wrap the gift in a standardized manner (rifling through a plastic bag, cutting wrapping paper with scissors, folding the paper and tearing off the tape) for 60 seconds. Children received 2 points if they did not turn around, 1 point if they peeked over their shoulder and 0 points if they turned around completely.

Verbal Ability. The British Picture Vocabulary Scale 3rd Edition (L. Dunn, D. Dunn,Styles, & Sewell, 2009) was used to assess children’s receptive vocabulary. Children were required to select the picture (from four options) that best matched the word. Standardized scores according to age were used.

Mock Report Card (Pierce et al., 1999). Teachers completed a mock report card for each child in their class participating in the study to assess children's reading and numeracy ability as well as their learning-related behaviours. The first part of the report card asked Teachers to rate children's reading and numeracy performance on a scale of 1 to 5, with 1 meaning the child was performing below grade level and 5 meaning the child was performing beyond grade level. The second part of the report card consisted of 6 statements relating to learning-related behaviours (e.g. 'Follows classroom procedures'). Teachers rated children's performance in relation to each statement on a scale of 1 (very poor) to 5 (very good). Children's mean score for learning-related behaviour was used in the present study.

Child Behaviour Scale (Ladd & Profilet, 1996). The CBS is a Teacher report measure that assesses children's behaviour with their peers. In the present study two subscales of this questionnaire were used: aggressive behaviour (9 items e.g. 'threatens classmates') and hyperactive-distractible behaviour (4 items e.g. 'restless, doesn't keep still'). Teachers rated how true each statement was of a child on a 3 point scale, with 0 representing not true and 2 representing often true. Mean scores for each subscale were used in the present study.

Procedure

This study received ethical approval from the University's Research Ethics Committee and adhered to BPS ethical guidelines. Informed consent was obtained from teaching staff and primary caregivers of children participating in the research. Data was collected in the Spring Term of 2017. Children completed a battery of performance-based assessments individually in a quiet area at their school. Assessments were administered by a team of three female researchers. The tasks were presented across two sessions in a fixed order: session 1: BPVS and CGT; session 2: Digit Span, DCCS, Go/No-Go, and Gift Wrap. Each assessment session lasted between 20 to 30 minutes. Session one and two were carried out approximately one week apart. Teaching staff completed the questionnaires at their own convenience during the testing phase.

Rigour of the Study

Assessments of children's cool and hot EF were widely used, reliable, and well validated measures. Test-retest reliability has been found to be good for the Fish/Shark version, exceeding .80 (Schoemaker et al., 2012). Correlations between .16 and .56 have been found between Go/No-Go tasks and other performance-based and questionnaire measures of inhibition indicating reasonable convergent validity (Duckworth & Kern, 2011; Shulz et al., 2007). High test-retest reliability has been found for both the standard (interclass correlation .78) and advanced version (interclass correlation .90) of the dimensional change card sort (Beck, Schaefer, Pang, & Carlson, 2011 Executive Function in Preschool Children: Test-Retest Reliability). Other research has found excellent reliability for the DCCS (interclass correlation .92) and excellent convergent and discriminate validity (Duckworth & Kern, 2011). Studies that have attempted to validate card sorting tasks have found that clinical child populations with frontal lesions performed worse than children with children with diffuse injuries as would be expected (Kongs, Thompson, Iverson, & Heaton, 2000).

Although the WISC-III was developed for use with children between 6- and 16-years-of-age, the digit span subtests have been successfully used with children 4- to 5-years-old (Alloway, Gathercole, Kirkwood, & Elliott, 2008; Bull, Espy, & Wiebe, 2008). In addition, the test-retest reliability for the good for the backward subtest (.64) in a study of children between 4- and 11-years-of-age (Alloway, 2007). The digit span task therefore appears to be a developmentally sensitive task of working memory in children under 6-years-of-age. Further the digit span task has been found to have good internal validity as it has been found to load onto the same factor as other measures of working memory such as, test of non-word repetition (Gatherole & Pickering, 2000).

The Gift Delay Task has been found to be reliable with an interclass correlation of .90 (Smith-Donald, Raver, Hayes, & Richardson, 2007). The Gift Delay Task has also been found to have good convergent validity with other measures of inhibition (Zelazo et al., 2013). The CGT is a relatively new measure of hot EF in contrast to the other measures and therefore assessments of its reliability and validity need to be carried out. However, the CGT is a simplified version of the IOWA gambling task which a preponderance of research has found to be a valid measures of decision making (Buelow & Suhr, 2009). The Children’s Behaviour Scale has high reliability. Cronbach’s alpa was high for the subscales (aggression = .90, hyperactive-distractible = .87).

Statistical Procedures

Analysis was carried out using SPSS v.24. The analysis was carried out in three stages. In the first stage correlations were carried out to explore the relations between all variables. Next, in order to explore the role of EF in children’s school transition, a series of hierarchical regressions were carried out. Control variables, including age, gender and verbal ability, were entered in step one to account for any confounding effects. In step two, cool and hot EF skills were entered. Separate regressions were carried out for reading, numeracy, learning-related behaviours, aggression and hyperactivity. Following this indirect relations between EF and academic achievement via learning-related behaviours was examined. A Lamberts mediation model was tested using the PROCESS macro in SPSS.

Results

Descriptive statistics are reported in Table 1 and correlations between all variables are reported in Table 2. Hierarchical regression results for academic achievement, learning-related behaviours, and classroom behaviour are reported below. One participant was missing data on some measures and therefore the final sample included 89 children.

Reading

Control variables significantly predicted children's reading ability, $R^2 = .25$, $F(3, 85) = 9.55$, $p < .001$. Verbal ability was a significant positive predictor. The addition of cool and hot EF skills significantly increased the amount of variance in reading ability explained, $\Delta R^2 = .14$, $\Delta F(5, 80) = 3.58$, $p = .01$. Working memory was a significant positive predictor. Regression results are presented in Table 3.

Numeracy

Control variables significantly predicted children's numeracy ability, $R^2 = .21$, $F(3, 85) = 7.31$, $p < .001$. Verbal ability was a significant positive predictor. The addition of cool and hot EF skills significantly increased the amount of variance in numeracy ability explained, $\Delta R^2 = .14$, $\Delta F(5, 80) = .14$, $p = .01$. Working memory was a significant positive predictor. Regression results are presented in Table 3.

Learning-Related Behaviours

Control variables significantly predicted children's learning-related behaviours, $R^2 =.19$, $F(3, 85) = 6.41$, $p < .001$. Gender was a significant predictor. Being female was associated with better learning-related behaviours. The addition of cool and hot EF skills significantly increased the amount of variance in learning-related behaviour explained, $\Delta R^2 = .11$, $\Delta F(5, 80)$

= 2.51, p = .04. Working memory was a significant positive predictor. Regression results were presented in Table 3.

Working memory was the only significant independent predictor of both academic achievement (reading and numeracy) and learning-related behaviours. Therefore, the indirect relation between working memory and reading and numeracy via learning-related behaviours was explored. The analysis revealed that there was a significant indirect effect of working memory on reading ability via learning-related behaviours, b = .16, 95% CI [.08, .27]. This represented a medium effect size, k^2 = .20, 95% CI [.09, .33]. There was a significant indirect effect of working memory on numeracy ability via learning-related behaviour, b = .16, 95% CI [.08, .22]. This represented a medium effect size, k^2 = .20, 95% CI [.08, .33]. The indirect effect is illustrated in Figure 2.

Aggression

Control variables significantly predicted children's aggression, R^2 = .13, F(3, 85) = 4.20, p = .01. Age was a significant positive predictor. The addition of cool and hot EF skills did not significantly increase the amount of variance in aggression explained, ΔR^2 = .04, ΔF(5, 80) = .68, p = .64. Regression results are presented in Table 4.

Hyperactivity

Control variables significantly predicted children's hyperactivity, R^2 = .14, F(3, 85) =4.65, p = .01. Gender was a significant negative predictor. Being male was associated with increased hyperactivity. The addition of cool and hot EF skills did not significantly increase the amount of variance in aggression explained, ΔR^2 = .05, ΔF(5, 80) = 1.05, p = .39. Regression results are presented in Table 4.

Discussion

The current study examined the links between cool and hot EF abilities and academic performance, learning-related behaviours, and classroom behaviour in children 5- to 7 years-old in order to elucidate the underlying mechanisms of a successful transition to school. The present findings made three main contributions to the literature: 1) in support of the hypotheses, cool EF (working memory) significantly predicted reading and numeracy abilities as well as learning-related behaviours, but hot EF skills did not, 2) learning-related behaviours mediated the relation between working memory and reading and numeracy achievement in line with the hypotheses, and 3) neither cool nor hot EF skills predicted hyperactive and aggressive behaviour, in contrast to predictions.

In line with previous studies that have found a link between cool EF skills and academic achievement (Brock et al., 2009; Garner & Waajid, 2012; Kim et al., 2014), cool EF predicted reading and numeracy abilities, after taking into account gender and verbal ability. Interestingly, working memory was the only independent predictor of academic achievement. Many of the learning activities in the classroom will require working memory capabilities. For example, children may be required to hold a sentence in memory to be written down, while undertaking a mentally challenging task such as working out how to spell the words. The current study also found that working memory predicted learning-related behaviours. Children with greater working memory were better able to follow classroom instructions, work independently, and work in an organised fashion. Working memory is important in order for children to be able to remember classroom rules and to follow the steps of these rules when required. Children with better working memory may therefore be able to more effectively manage learning activities.

The mediation analysis revealed that there was an indirect relation between working memory and reading and numeracy ability via learning-related behaviours. Cool EF may directly influence academic achievement. Children who perform well on working memory tasks may have a unique advantage in reading and numeracy development. Working memory, for example, is required for switching between strategies (e.g. adding instead of subtracting/reading a word or sounding out the letters) and evaluating which strategy to employ to solve a given problem (e.g. whether a numeracy problem requires addition or subtraction/sounding out the letters or matching the word to a similar word) (Bull & Scerif, 2001). However, EF may also indirectly influence academic achievement via its association with learning-related behaviours. Children who demonstrate greater cool EF performance may show more positive learning related behaviours, working independently, persisting in the face of challenge, are more engaged and attentive and follow instructions (Blair, 2002; Brock et al., 2009). Children with positive learning-related behaviours may therefore be more ready to learn and may be exposed to more academically stimulating environments, whereas children with poor learning-related behaviours may be more disruptive and less engaged and may more frequently be removed from the classroom. This combination of poor EF and classroom-behaviour associated with lower academic achievement may present a particular challenge for Teachers who's attention is divided across many children.

In contrast to prior studies (Blair & Razza, 2007; R. Duncan et al., 2017), other cool EF skills including inhibition and cognitive flexibility were not associated with academic achievement. One explanation for this may be that the relation between EF and academic achievement varies with development. EF is a heterogeneous concept and although childhood is characterised by general advances in EF, individual EF skills show considerable variability in their development. For example, children show greater advances in inhibition and cognitive flexibility during early and middle childhood compared to working memory (P. J. Anderson, 2002; Senn, Espy, & Kaufmann, 2004). Working memory continues to show rapids gains into late childhood (Brocki & Bohlin, 2004). Inhibition and cognitive flexibility may consequently be associated with academic achievement in preschool period, but not during the transition to school. In line with this argument, previous research has found an association between inhibition and academic achievement at 3- to 5-years-of-age (Willoughby et al., 2016), but not between 5- and 6-years-of-age (Vandenbroucke et al., 2017). An alternative explanation surrounds the appropriateness of the tasks used to assess cool EF skills. The tasks used to assess inhibition and cognitive flexibility may not have been developmentally sensitive to these abilities in middle childhood. Indeed, children performed close to ceiling on both the Go/No-Go (inhibition) and Dimension Change Card Sort (cognitive flexibility) tasks.

Neither hot delay of gratification nor affective decision making were associated with academic achievement or learning-related behaviours, in support of studies that have failed to find an association between delay of gratification and reading or numeracy skills (Brock et al., 2009; Kim et al., 2014). It has been argued that hot EF may be associated with academic achievement as prior studies have found a link between emotion regulation and academic achievement (Graziano & Reavis, 2007; Howse et al., 2003). Research into the organisation of hot EF is in its infancy compared to cool EF. Hot EF may be a heterogeneous construct and only certain aspects of hot EF may be related to academic achievement; or emotion regulation may be a separate ability from hot EF. Alternatively, other studies have suggested that cool EF is more strongly associated with academic achievement whereas hot EF is more strongly related to social development (Brock et al., 2009; Garner & Waajid, 2012; Mann et al., 2016). Though, the present study failed to find a link between neither cool nor hot EF skills and aggressive and hyperactive behaviour. Greater understanding of the organisation of hot EF, or indeed if hot EF is a distinct construct, will elucidate understanding of the role of hot EF in children's development.

Hyperactivity and aggression were unrelated to cool or hot EF abilities, after taking into account gender and verbal ability. This contradicts previous research which has found a link between poor EF performance, particularly inhibition, and hyperactive and aggressive behaviour (Berlin & Bohlin, 2002; Masten et al., 2012; Poland et al., 2016; Utendale & Hastings, 2011). The unexpected lack of an association between inhibition and behaviour may reflect differences in the assessment of inhibition. In the present study children performed close to ceiling on the Go/No-Go task, meaning the task may not have been sensitive enough to the variability in children's inhibition performance to detect a relation between inhibition and hyperactive and aggressive behaviour. The present study, though, supported research which has failed to find a relation between hot EF and aggression in children 3- to 6-years-of-age (Poland et al., 2016; Willoughby et al., 2011). Understanding of the organisation of hot EF is limited and there is debate surrounding whether EF represents distinct cool and hot constructs or whether EF is used differently under affective conditions (Allan & Lonigan, 2014; Masten et al., 2012). The limited relation between hot EF and behaviour may reflect the fact that there is not a distinct hot EF construct. Greater research into the underlying construct of EF will therefore be beneficial to understanding the link between EF and behaviour.

Limitations and Future Research Directions

The present study added to the limited understanding of how multiple aspects of cool and hot EF contribute to children's transition to school, in terms of both academic and behavioural domains. However, the findings should be considered in the context of the limitations of the current study. First, although both cool and hot dimensions of EF were measured, a limited number of tasks were included. A battery including a broader range of EF tasks and multiple assessments of each EF skill may avoid issues surrounding ceiling effects and may shed greater light on the relation between individual EF skills and academic performance and behaviour. Second, academic achievement was assessed according to teacher reports, which may be subject to bias. Future research should consider the use of achievement tasks in order to assess children's actual academic abilities. Thirdly, the sample size was relatively small and the data was cross-sectional meaning that it is difficult to draw strong conclusions regarding the direction of the relation between EF and academic performance and classroom behaviour. Finally, data gathered on the socioeconomic status of the sample was not gathered. Numerous studies have reported a strong link between EF, achievement, and socioeconomic status (Noble, Norman, & Farah, 2005) and as a result socioeconomic status may influence the role of EF in school readiness. Future research should take into account the role of socioeconomic status to better understand whether the relation between EF and school readiness is the same for different socioeconomic status groups.

Conclusion

In conclusion, the present findings of a relation between EF and academic performance and learning-related behaviours strengthen the empirical evidence for the potential role of EF in early academic success. Further, the findings indicate that children's EF may interact with their learning-related behaviours in the classroom to influence academic performance. Taken together, these findings underscore the importance of EF as a candidate target for early intervention. The present study, though, indicates that cool-cognitive EF skills may be more central to academic performance than hot affective EF skills in early childhood and therefore cool EF may be a more effective target for early intervention.

Acknowledgements

The authors would like to acknowledge the schools and children who participated in this research. The authors would also like to thank Dr. Maria Pomoni and Catherine Culbert for their help with data collection.

Declaration of Interest

There was no conflict of interest.

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Table 1. Descriptive statistics for variables

	N	*M*	*SD*	Min	Max
Verbal ability	90	90.66	20.28	0	119
Inhibition	90	.89	.14	.50	1.0
Working memory	90	3.03	1.53	0	6.0
Cognitive flexibility	90	1.51	.55	0	2.0
Decision making	90	.02	.41	-1.0	1.0
Delay of gratification	90	1.58	.64	0	2.0
Reading	89	3.18	1.22	1	5.0
Numeracy	89	3.25	1.14	1	5.0
LR behaviour	89	3.56	1.05	1	5.0
Aggression	89	1.31	.41	1	2.78
Hyperactivity	89	1.45	.56	1	3.0

Note. LR behaviour = learning-related behaviour.

Table 2. Correlations between all variables

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age	-	-	.04	.02	.24*	.25*	.13	.13	.05	.01	.11	.32**	.12
2. Gender		-	.15	.05	.09	.02	-.05	.15	.23*	.12	.36***	-.14	-.35***
3. VA			-	.06	.46***	.16	.02	.10	.47***	.45***	.25*	.10	.04
4. Inhibition				-	.24*	.33***	.09	.06	.18	.10	.09	.12	.01
5. WM					-	.41***	.13	.07	.54***	.53***	.39***	.05	.03
6. Flexibility						-	.05	.05	.20	.18	.08	.15	-.11
7. ADM							-	.06	.03	.06	.03	.04	.10
8. Delay								-	.13	.08	.23*	-.05	-.16
9. Reading									-	.90***	.65***	-.21*	-.37***
10. Numeracy										-	.67***	-.21*	-.26*
11. LR behaviour											-	-.34***	-.57***
12. Aggression												-	.37***
13. Hyperactive													-

Note. VA = verbal ability, WM = working memory, ADM = affective decision making, Delay = delay of gratification, LR behaviour = learning related behaviour $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 3. Regression results for reading, numeracy and learning-related behaviours

	Reading				Numeracy				Learning-Related Behaviours			
	ΔR^2	*B*	*SE B*	*ß*	ΔR^2	*B*	*SE B*	*ß*	ΔR^2	*B*	*SE B*	*ß*
Step 1	.25***				.21***				.19***			
Age		.01	.01	.05		-.001	.01	-.01		.01	.01	.12
Gender		.40	.23	.16		.12	.22	.05		.71***	.21	.34***
VA		.03***	.01	.45***		.03***	.01	.44***		.01	.01	.19
Step 2	.14**				.14**				.11*			
Inhibition		.61	.83	.07		-.19	.80	-.02		.12	.76	.02
WM		.33***	.09	.41***		.33***	.08	.44***		.25**	.08	.37**
Flexibility		-.06	.23	-.03		-.04	.22	-.02		-.20	.21	-.11
ADM		-.06	.27	-.02		.04	.26	.02		-.05	.25	-.02
Delay		.11	.17	.06		.08	.17	.04		.25	.16	.15

Note. Gender: Males = 1 and Females = 2. VA = verbal ability, WM = working memory, ADM = affective decision making, Delay = delay of gratification, * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 4. Regression results for aggregation and hyperactivity

	Aggression				Hyperactivity			
	ΔR^2	*B*	*SE B*	*ß*	ΔR^2	*B*	*SE B*	*ß*
Step 1	.13**				.14**			
Age		.01**	.004	.31**		.01	.01	.09
Gender		-.11	.08	-.13		-.40***	.11	-.36***
VA		.002	.002	.10		.003	.003	.09
Step 2	.04				.05			
Inhibition		.39	.32	.13		.28	.44	.07
WM		-.04	.03	-.14		.02	.05	.05
Flexibility		.04	.09	.06		-.21	.12	-.20
ADM		-.01	.10	-.01		.09	.14	.07
Delay		-.06	.07	-.10		-.12	.09	-.14

Note. Gender: Males = 1 and Females = 2. VA = verbal ability, WM = working memory, ADM = affective decision making, Delay = delay of gratification, * $p < .05$, ** $p < .01$, *** $p < .001$.

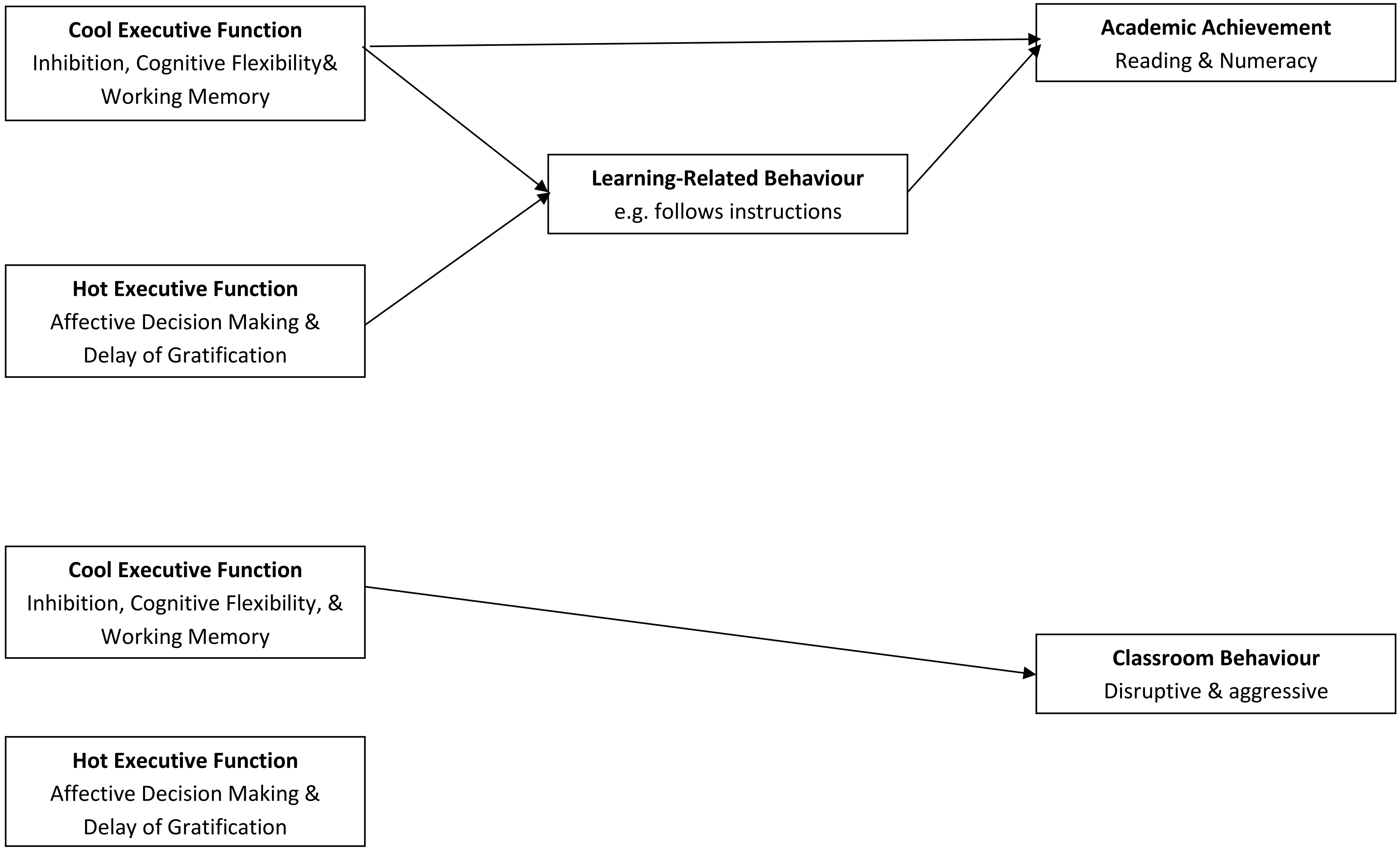

Figure 1. Hypothesised relations between cool and hot executive function, learning-related behaviours, academic achievement and classroom behaviour.

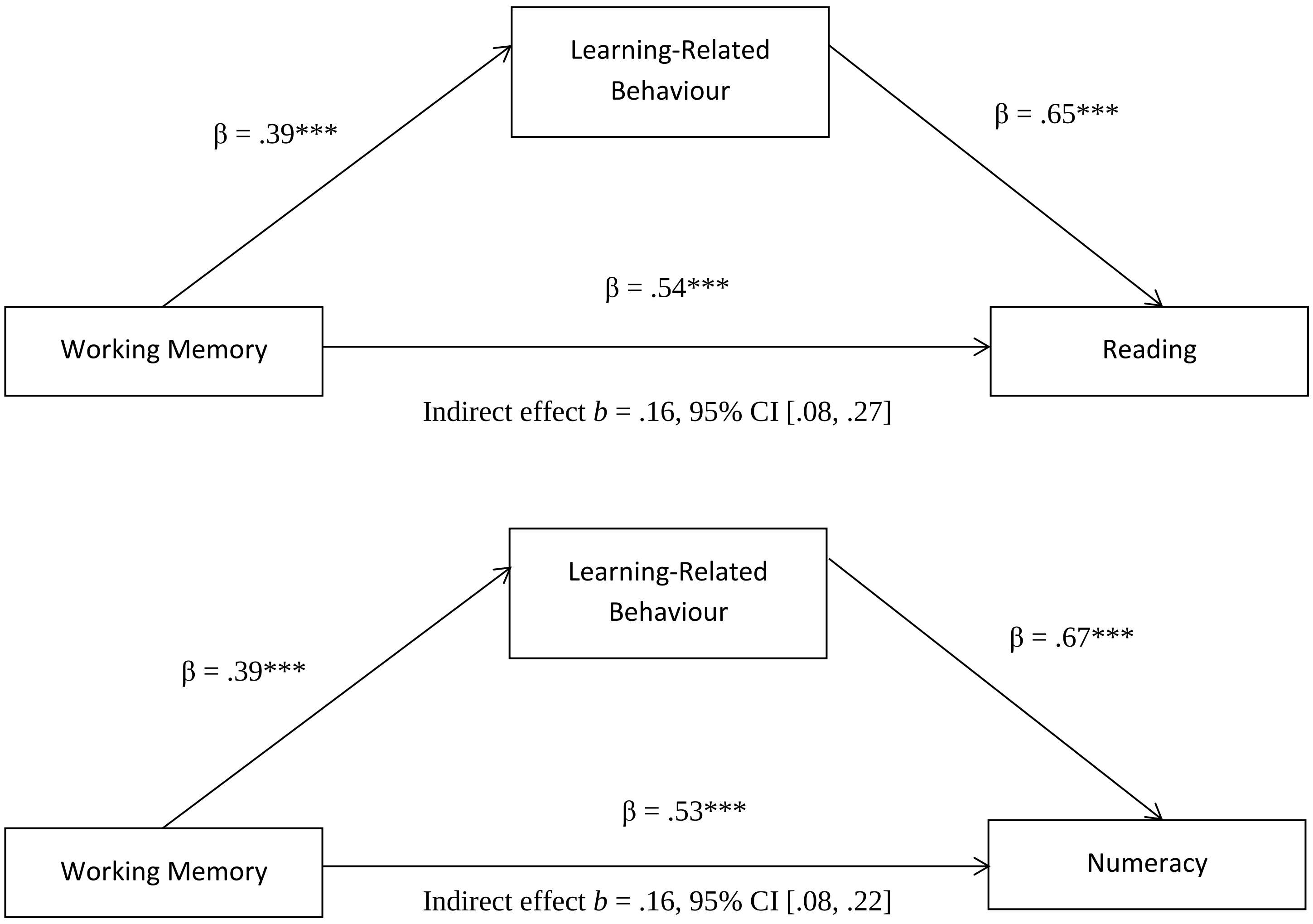
Learning-Related Behaviour
β = .39***
β = .65***
β = .54***
Working Memory
Reading
Indirect effect b = .16, 95% CI [.08, .27]
Learning-Related Behaviour
β = .67***
β = .39***
β = .53***
Working Memory
Numeracy
Indirect effect b = .16, 95% CI [.08, .22]

Figure 2. Indirect relation between working memory, learning-related behaviours, and reading and numeracy abilities