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Early mathematics achievement of boys and girls: Do differences in early self-regulation pathways explain later achievement?☆

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ABSTRACT

The degree to which a true gender gap exists in mathematics achievement is still debated, and empirically-supported explanations for any gap rarely address very early childhood self-regulatory pathways. This study examines whether mathematics achievement at 8–9 years differs by gender, how achievement is associated with self-regulatory pathways beginning at 2–3 years of age, and whether these pathways differ by gender. Participants were 5107 children involved in the nationally-representative *Longitudinal Study of Australian Children* (LSAC). Boys outperformed girls in mathematics achievement and girls generally had better early attentional and emotional regulation. Path analysis revealed that attentional regulation was directly associated with mathematics achievement from 4 to 5 years, and emotional regulation was indirectly associated. These self-regulatory pathways to mathematics achievement were not moderated by gender. We discuss the implications for further research and new approaches to early years mathematics education that embed self-regulatory support and development for all children.

1. Introduction

Mathematical skills are increasingly crucial to educational and career success across the lifespan (Geary, 2013), in part, due to a greater focus on science, technology, engineering and mathematics (STEM) education as a vital area of workforce planning to strengthen competitiveness in a global economy (Australian Workforce and Productivity Agency, 2012; National Science Foundation, 2015). This research focuses on early childhood developmental pathways to school STEM achievement, specifically mathematics. In particular, this study examines the role of attentional and emotional regulation development *across* early childhood and in to the early years of schooling. Mathematics learning draws heavily and uniquely on attentional capacities due to a focus on problem-solving, and for some children with mathematics anxiety, on emotional regulation. The extent to which these pathways differ by gender is a further important aspect of the study because later gender gaps in both math achievement (Atweh, Vale, & Walshaw, 2012), and in the STEM workforce (Healy, Mavromaras, & Zhu, 2011) are not yet well-explained leading to an uncertainty about how to address these gender disparities.

Recent research has begun to identify the role that self-regulation may play in children's learning in general; but specifically, in relation to the unique cognitive demands of mathematics (Bull & Lee, 2014; Clark, Sheffield, Wiebe, & Epsy, 2013; Hassinger-Das, Jordan, Glutting, Irwin, & Dyson, 2014; Ivrendi, 2011; von Suchodoletz et al., 2013). Self-regulation refers to an individual's capacity to regulate behaviors, emotions, and cognitions in ways that are beneficial to functioning and adaptive to environmental circumstances (McClelland, Ponitz, Messersmith, & Tominey, 2010). In this study we focus on attentional and emotional self-regulation which are specific 'bottom-up' aspects of self-regulation that underpin children's social and cognitive learning processes and are predictive of school adjustment and achievement (Blair & Dennis, 2010; Eisenberg, Valiente, & Eggum, 2010; Sawyer et al., 2014; Ursache, Blair, & Raver, 2012). Attentional regulation refers to the extent to which children persist in completing tasks and maintain their attention in the face of distractions or interruptions. Emotional regulation comprises the interplay between an individual's natural reactivity to emotion-inducing events, as well as their capacity to control these reactions (Blair, Calkins, & Kopp, 2010). These 'bottom-up' processes support the development of 'top-down' self-regulatory processes such as the executive functions, vital for complex learning (Diamond, 2013). Although it is well established that self-regulation is an

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important early precursor to all academic achievement, most of the work focussing on mathematics has been with children from 4 years of age (and not earlier), most has focussed only on 'top-down' self-regulatory capacity (executive function), and few have examined gender differences in early childhood longitudinal pathways in any detail.

In Australia, the employed STEM-qualified workforce is comprised of 72% males and 28% females (Healy et al., 2011). The situation is similar in other developed nations, with females comprising 24% of the STEM workforce in the United States (US Department of Commerce, Economics and Statistics Administration, 2011). This gender disparity can be traced through all stages of education and is undesirably low (Marginson et al., 2013). Early mathematics experiences and achievement, and the subsequent desire to engage in advanced levels of mathematics, could be one of the contributing factors to the gender disparity in STEM education and in workforce engagement. Atweh et al. (2012) argue that any gender gap in math achievement tends to emerge during the schooling years, but not before. However, few studies examine potential early childhood explanatory mechanisms for this apparent gender gap, leaving the field with limited information about when and how to intervene early to address these later gaps.

1.1. Math in the early years

In a seminal study of school readiness and later school achievement, Duncan et al. (2007) found a strong correlation between early math skill and later math achievement, as well as associations between early math and other competencies such as reading and writing abilities, and general school achievement. Subsequent early childhood research has focused on identifying the mechanisms involved in the development of mathematical skills in young children (Geary, 2013) so that pathways associated with poorer mathematical development might be diverted early. This research has historically progressed along two paths: those related to domain-specific precursors of mathematics achievement (De Smedt, Verschaffel, & Ghesquiere, 2009; Holloway & Ansari, 2009; Mazzocco, Feigenson, & Halberda, 2011; Schneider, Grabner, & Paetsch, 2009); and, those concerned with more domain-general precursors such as general cognitive abilities, learning behaviors, and self-regulatory skills (Bull & Lee, 2014; Willoughby, Kupersmidt, & Voegler-Lee, 2012).

1.2. Domain-specific precursors of math achievement

Research into the domain-specific precursors of math largely stem from Dehaene's (1997) description of an evolutionary number sense. At the core of number sense is a non-symbolic magnitude (quantity) representation, upon which symbolic and verbal representations develop, for example: ●●●, '3', and 'three' (Dehaene, Piazza, Pinel, & Cohen, 2003). Automatic mapping between these representations signifies the emergence of more flexible number cognitive processes and is a correlate of early math achievement. Automatic processing of number representations means that number cognitive processes occur without conscious awareness and children inherently and interchangeably understand the meaning of magnitudes ●●●, three, and 3. The presence of automatic processing between representations has been the focus of many research studies that have investigated domain-specific precursors of number development and later mathematics achievement. Specific precursors investigated have included magnitude comparison (De Smedt et al., 2009; Holloway & Ansari, 2009), the approximate (non-symbolic) number system (Mazzocco et al., 2011), as well as spatial associations and estimation (Schneider et al., 2009). However, recent research has found number sense variables to be predicted by sustained attention, and has proposed a move away from discrete explanatory factors in favour of a more complex processing network (Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2014). This has led to the recent focus on more domain-general contributors to mathematics development including self-regulation.

1.3. Domain-general precursors of mathematics achievement: self-regulation

To date, research into domain-general skills and mathematical development has had a strong focus on the developmental domain of self-regulation. Self-regulation is an umbrella term that refers to individuals' capacities to regulate their own behavior, emotions, and cognitions in ways that are beneficial to their functioning and adaptive to the circumstances in which they find themselves (McClelland et al., 2010). In this study we focus on the bottom-up self-regulatory processes of attentional and emotional and regulation. These emerge early in life and are described as automatic regulatory responses to the environment (Blair & Dennis, 2010).These bottom-up processes are fundamental to the development of top-down cognitive regulatory responses, such as executive functions, which are required for more complex learning tasks (Blair & Ursache, 2011). Executive function has been the focus of most of the self-regulation and math achievement research to date, with children generally from 4 years of age but not earlier (Bull & Lee, 2014; Clark et al., 2013; LeFevre et al., 2013; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). This has left a gap in the field in relation to the very early fundamental and bottom-up skills of attentional and emotional regulation.

In the current study we focus on pathways from early attentional and emotional self-regulation for a number of reasons. First, although number representations (e.g., ●●●, 3, and three) developed in math provide the foundation for children to engage with STEM and enable children to work with data and different representations (e.g. numbers, graphs, tables) across all STEM areas, this work also requires children to think critically and to develop flexible approaches to problem solving scenarios. There is considerable variability in children's capacity to engage in problem solving with data and representations which may be traced to children's attentional and emotional regulation capacities. For example, approaching a task requires attention to relevant information and switching between representations (pictorial-spatial-symbolic-verbal) in order to determine a strategy and recall relevant facts. Furthermore, working with complex data may create a situation where children have different emotional responses, which can influence task performance, meaning the ability to regulate emotion may be an important factor. Second, differences in these self-regulation skills emerge (and can be measured) earlier than executive function, allowing for the early identification of children at risk of poorer self-regulatory functioning and related learning difficulties. Third, these domain-general self-regulatory skills are more amenable to change through intervention (Barnett et al., 2008; Tominey & McClelland, 2011) than the domain-specific precursors of math that focus on automatic mapping between representations (Mazzocco et al., 2011). Finally, strong skills in these bottom-up areas of self-regulation are likely to support the development of the executive functions, or top-down self-regulatory processes (Blair & Ursache, 2011), critical in mathematical thinking (i.e. working memory, set shifting, and inhibition). Such skills have been positioned as both a characteristic and goal of math education in particular (De Corte et al., 2000) due to their key role in the construction of mathematical knowledge through problem-solving processes. Although some areas of math ability rely upon simple retrieval of information stored in long-term memory, the problem-solving process requires far more self-regulatory employment. As Blair and Razza (2007, p. 659) explain, problem solving "requires the individual to represent information in working memory, to shift attention appropriately between problem elements, and to inhibit a tendency to respond only to the most salient or most recent aspect of a given problem". Children who are preoccupied with managing their emotions and attention are unlikely to fully capitalise on the higher-order cognitive development opportunities presented by mathematical problem-solving tasks.