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The contribution of spatial ability to mathematics achievement in middle childhood

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ABSTRACT

Strong spatial skills are associated with success in science, technology, engineering, and mathematics (STEM) domains. Although there is convincing evidence that spatial skills are a reliable predictor of mathematical achievement in preschool children and in university students, there is a lack of research exploring associations between spatial and mathematics achievement during the primary school years. To address this question, this study explored associations between mathematics and spatial skills in children aged 5 and 7 years. The study sample included 12,099 children who participated in both Wave 3 (mean age = 5; 02 [years; months]) and Wave 4 (mean age = 7; 03) of the Millennium Cohort Study. Measures included a standardised assessment of mathematics and the Pattern Construction subscale of the British Ability Scales II to assess intrinsic–dynamic spatial skills. Spatial skills at 5 and 7 years of age explained a significant 8.8% of the variation in mathematics achievement at 7 years, above that explained by other predictors of mathematics, including gender, socioeconomic status, ethnicity, and language skills. This percentage increased to 22.6% without adjustment for language skills. This study expands previous findings by using a large-scale longitudinal sample of primary school children, a population that has been largely omitted from previous research exploring associations between spatial ability and mathematics achievement. The finding that early and concurrent spatial skills contribute to mathematics achievement at 7 years of age highlights the potential of spatial skills as a novel

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target in the design of mathematics interventions for children in this age range.

Introduction

Recent studies have proposed the use of spatial ability training as a means to improve both spatial and mathematics achievement in children. The prospective benefits of such an intervention would be significant for many countries including the UK. From an educational perspective students from the UK typically perform at or below the average level of their international counterparts in assessments of mathematics and science (Mullis, Martin, Foy, & Arora, 2012; Organisation for Economic Co-operation and Development [OECD], 2013). Improving Science, Technology, Engineering and Mathematics (STEM) success is also a particularly pertinent economic issue. STEM-related industries contribute over 400 billion pounds to the UK economy per year (Centre for Economics and Business Research [CEBR], 2015; also see Berressem, 2011) yet over 39% of firms in need of STEM employees have reported difficulties recruiting suitably qualified candidates (Confederation of British Industry [CBI], 2013). Spatial ability has been identified as a reliable predictor of adult achievement in STEM domains in many large-scale ($N > 500$) longitudinal studies following both normative and intellectually gifted populations through adolescence and adulthood (Shea, Lubinski, & Benbow, 2001; Wai, Lubinski, & Benbow, 2009). For example, it has been reported that students who pursue STEM careers and complete STEM degrees at both undergraduate and masters level have higher spatial ability scores at 13 years (Wai et al., 2009). If effective, spatial training interventions could offer a promising alternative to traditional attempts at improving STEM achievement, and could in turn confer both educational and economic benefits.

The theory that spatial training interventions could improve mathematical ability is supported by findings that spatial ability is malleable and changeable, that changes and improvements in spatial ability are durable over time and that improvements in certain spatial skills transfer to other non-trained spatial skills (Ehrlich, Levine, & Goldin-Meadow, 2006; Uttal et al., 2013). Spatial training interventions have demonstrated improvements in spatial skills as early as in primary school children (Bruce & Hawes, 2015; Taylor & Hutton, 2013; Uttal et al., 2013). However, few studies with children have investigated the transfer of spatial training gains to mathematical domains. Cheng and Mix (2014) were among the first to report significant gains in a mathematical calculation task following spatial skill training in children aged 6–8 years. However, these gains were specific to missing term problems and were not observed on number fact or multi-digit calculation problems. Furthermore, subsequent results from Hawes, Moss, Caswell, and Poliszczuk (2015) failed to demonstrate improvements in non-verbal arithmetic or missing number problems following a similar spatial training intervention. Taken together, these findings suggest a need for further investigation of the associations between spatial cognition and mathematics achievement in children, in order to best design effective training interventions.

Understanding spatial cognition

Spatial cognition as described by Hart and Moore (1973) is 'the knowledge and internal or cognitive representation of the structure, entities, and relations of space; in other words, the internalised reflection and reconstruction of space in thought" (p. 248). Despite almost half a century of research, attempts to define sub-divisions within spatial cognition have led to the emergence of many contrasting typologies (Linn & Petersen, 1985). This study will adopt Uttal et al.'s. (2013) top-down model of spatial typology which has gained significant endorsement and popularity owing to the convincing neurological, behavioral and linguistic evidence supporting it (Chatterjee, 2008; Palmer, 1978;