Learning and Instruction 32 (2014) 73–80

Contents lists available at ScienceDirect

Learning and Instruction

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

Construction play and cognitive skills associated with the development of mathematical abilities in 7-year-old children

Swiya Nath*, Dénes Szücs*

Centre for Neuroscience in Education, Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge, CB2 3EB, UK

ARTICLE INFO

Article history:
Received 16 May 2013
Received in revised form
17 January 2014
Accepted 19 January 2014
Available online 11 February 2014

Keywords:
Mathematics
Construction play
Visuospatial memory
Lego

ABSTRACT

Construction play is thought to develop logico-mathematical skills, however the underlying mechanisms have not been defined. In order to fill this gap, this study looks at the relationship between Lego construction ability, cognitive abilities and mathematical performance in 7-year-old, Year 2 primary school children ($N = 66$). While studies have focused on the relationship between mathematics performance and verbal memory, there are limited studies focussing on visuospatial memory. We tested both visuospatial and verbal working memory and short term memory, as well as non-verbal intelligence. Mathematical performance was measured through the WIAT-II numerical operations, and the word reading subtest was used as a control variable. We used a Lego construction task paradigm based on four task variables found to systematically increase construction task difficulty. The results suggest that Lego construction ability is positively related to mathematics performance, and visuospatial memory fully mediates this relationship. Future work of an intervention study using Lego construction training to develop visuospatial memory, which in turn may improve mathematics performance, is suggested.

1. Introduction

Children learn through play. Construction play is defined by Piaget as activities producing symbolic products, and is thought to develop logico-mathematical knowledge (Wolfgang & Phelps, 1983). However, the mechanisms of how construction play can develop logico-mathematical skills are not defined. Baddeley's (1986, 2000) influential memory model differentiated between verbal and visuospatial memory systems. Ever since, there has been high interest in analysing the relationship between memory systems and learning. Previous studies on construction play and mathematics have focused on the relationship with verbal memory (Richardson & Richardson, 2011), but there are no studies on construction play and visuospatial memory, which may be more relevant. In fact, there is a general paucity of research on visuospatial memory, in comparison to the research on verbal memory (Raghubar, Barnes, & Hecht, 2010). In this study we analyse the relationship between construction play and mathematics performance and test whether visuospatial memory is a mechanism mediating this relationship.

2. Construction play, spatial ability, and mathematics performance

Studies analysing the relationship between construction play and cognitive abilities have focused on spatial ability (Caldera et al., 1999; Connor & Serbin, 1977; Robert & Heroux, 2004). Spatial ability has been further divided into static (fixed objects) or dynamic (movement of objects), and intrinsic (comparison within an object) or extrinsic (comparison between objects) (Uttal et al., 2013).

Studies have found correlations between construction play and spatial abilities. Connor and Serbin (1977) first asked undergraduate students to categorize toys as masculine or feminine, and then analysed play preferences of children according to the categorization. They found boys playing with masculine activities (blocks, and large motor toys) were correlated with higher performance of spatial ability as measured by the Wechsler Preschool and Primary Scale of Intelligence Block Design and Preschool Embedded Figures Test (EFT). However for girls, they did not find significant relationships between cognitive development and play preferences for either masculine or feminine activities (Connor & Serbin, 1977). In a study with older children (9-year-old), past experience in playing with Lego did not correlate with any of the spatial measures. There was a negative relationship between the mental rotation ability, and the number of errors and the time taken to

* Corresponding authors.
E-mail addresses: sn413@cam.ac.uk (S. Nath), ds377@cam.ac.uk (D. Szücs).

0959-4752/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.learninstruc.2014.01.006

construct the Lego model (Brosnan, 1998). Similarly, in another study, although preference for construction play was not significantly correlated with any of the spatial tests, accuracy on the structured block play was correlated with Block Design and Copying Blocks, but not with the Children's EFT (Caldera et al., 1999). In 9 and 12-year-old children, construction play was significantly related to Water Level tasks and Block Design but not EFT (Robert & Heroux, 2004). It is important to note that two of the studies (Brosnan, 1998; Caldera et al., 1999) correlating construction ability and spatial ability found that accuracy, rather than preference for construction play, was positively correlated with spatial ability. The other studies only looked at preference of construction play, but did not have a measure to test accuracy in construction ability.

There are a few studies analysing the relationship between construction ability and mathematics. In adolescents, a study analysing the relationship between block building and mathematical performance found that structural balance of a block building activity was correlated to mathematics performance (Casey, Pezaris, & Bassi, 2012). In younger children, a study found that building a model according to instructions was correlated to early maths ability in 3-year-olds (Verdine et al., 2013). Another study on the adaptiveness and complexity of construction play and mathematics performance was conducted by observing and recording construction play with manipulatives (blocks, Lego, carpentry) in a child care program with preschool children 3–4 years of age (Stannard, Wolfgang, Jones, & Phelps, 2001). They found that the correlation between the children's construction play and mathematics performance was not significant at younger years, but the correlation was significant in grade 7 (12-year-old) and beyond. The researchers suggest this as evidence that construction play in preschool can have long term effects on logico-mathematical knowledge (Stannard et al., 2001). In a subsequent study, researchers looked at the relationship between block construction and reading and mathematical abilities, using Tests of Early Mathematics and Reading Abilities in preschool children (Hanline, Milton, & Phelps, 2010). Children played once a week for 90 min and their block constructions were scored according to a 19-point scale based on the complexity and symbolic representational properties of the constructions. They did not find a relationship between block construction and mathematics performance, but with reading performance at 8 years of age (Hanline et al., 2010). These findings may be a result of the study focussing on symbolic play, defined by Piaget as transforming objects into make-believe play through motor or verbal actions (Wolfgang & Phelps, 1983), more than construction play. Both the studies mentioned found a relationship between construction ability and mathematics performance (Stannard et al., 2001) or reading performance (Hanline et al., 2010) several years after construction ability was tested. It could be that construction ability develops more complex academic skills that are not tested till later years. Nevertheless, with the time lapse between the observations of construction ability and the measures of academic performance, it is difficult to assess whether the findings relate specifically to construction ability or as a result of general cognitive development, which was not tested. Another study with children (10-year-old) found that spatial ability is uniquely correlated to scientific reasoning, when taking into account verbal and non-verbal intelligence (Mayer, Sodian, Koerber, & Schwippert, 2014). This suggests that spatial ability may be a unique underlying mechanism accounting for individual differences in academic performance.

The only study on construction play and mathematics that accounts for cognitive skills is by Richardson and Richardson (2011) who tested the relationship between Lego construction ability, spatial ability, verbal memory and mathematics performance in 3 groups of children (7–8-year-old, 10–11-year-old, and 13–14-year-old). Lego construction ability was measured using the Lego construction paradigm (Richardson, Jones, & Torrance, 2004) in which eighteen different single coloured Lego construction tasks of progressive difficultly were used (see Methodology section). Instructions were provided on a one page isometric view of the models, that children had to create with Lego blocks, while their construction time was recorded. They found significant correlations between Lego construction time and mathematical performance as well as spatial ability, but not with verbal memory. They found that in older children (10–11-year-old, and 13–14-year-old) the relationship between construction time and mathematical performance was mediated by spatial ability. Richardson and Richardson (2011) was the only study to date to analyse construction play together with mathematical performance and verbal memory. However, a control task such as linguistic performance, was not included to test whether the observed relationship with mathematics performance was domain general, or specific to Lego construction ability and mathematics development. They tested Digit Span, a measure of verbal memory, however visuospatial memory may be more relevant to construction tasks. In fact, no studies have so far measured visuospatial working memory in relation to construction tasks.

Miyake et al. analysed the relationship between spatial abilities, visuospatial memory, and executive functions. They found that although the results show a higher unique correlation between spatial abilities and executive functions, visuospatial memory accounted for some of the variance found in spatial abilities (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Taking this as theoretical support, we focused our study on the relationship between visuospatial memory and construction ability.

2.1. Verbal and visuospatial memory models, and mathematics

The Baddeley (1986, 2000) memory model describes verbal and visuospatial memory as slave systems, with the central executive as an overarching umbrella term. Verbal memory has been further subdivided into verbal short term memory (STM), defined as simple storage, while verbal working memory (WM) is thought to involve STM as well as controlled attention, which is a domain of executive functions (Miyake et al., 2001). Researchers suggest that the most parsimonious model is the one in which STM is domain specific to verbal or visuospatial domains, while WM is domain general (Alloway, Gathercole, & Pickering, 2006). In contrast, others suggest that visuospatial memory should be divided along characteristics different than that of verbal memory. For example, some suggest that a visual cache stores information about form and colour, whereas the inner scribe would store information about movement sequences (Logie & Pearson, 1997). Yet, other models divide visuospatial memory into visual or spatial domains (Mammarella et al., 2006; Passolunghi & Mammarella, 2012; Pickering, Gathercole, Hall, & Lloyd, 2001). Visual tasks require recognition of form, shape and colour of objects, whereas spatial tasks require the recognition of location, position and configuration of objects, while processing them simultaneously or sequentially (Mammarella et al., 2006).

Visuospatial working memory has been correlated with mathematics performance in several studies (Ashkenazi, Rosenberg-Lee, Metcalfe, Swigart, & Menon, 2013; Holmes & Adams, 2006; McKenzie, Bull, & Gray, 2003; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Passolunghi & Mammarella, 2012). One study analysed specific visual and spatial memory impairments and mathematics ability (Passolunghi & Mammarella, 2012). The tasks consisted of visual and spatial tasks at both simple and complex levels, and intrusion errors (test of inhibition) were also measured. Children with mathematics learning disability were selectively