Learning and Individual Differences 54 (2017) 30–40

Contents lists available at ScienceDirect

Learning and Individual Differences

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

The influence of memory updating and number sense on junior high school math attainment

Miao-Hsuan Yen [a,1], Cheng-Ching Han [b,1], Pei-Chi Yu [c], Tsung-Han Yang [b], Daniele Didino [d,e], Brian Butterworth [b,f,g,2], Nai-Shing Yen [b,g,*,2]

[a] Graduate Institute of Science Education, National Taiwan Normal University, Taipei, Taiwan
[b] Department of Psychology, National Chengchi University, Taipei, Taiwan
[c] Tainan Municipal Yong-Ren Senior High School, Tainan, Taiwan
[d] Department of Economics, Tomsk Polytechnic University, Tomsk, Russia
[e] Department of Psychology, Humboldt-Universität zu Berlin, Berlin, Germany
[f] Institute of Cognitive Neuroscience, University College London, London, UK
[g] Research Center for Mind, Brain, and Learning, National Chengchi University, Taipei, Taiwan

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 5 January 2017
Accepted 8 January 2017
Available online xxxx

Keywords:
Number sense
Working memory
Mathematics achievement
Approximate numerosity system
Memory updating task

ABSTRACT

The present study investigated the development and influence of working memory abilities (WM) and number sense (NS) on mathematics achievement in junior high school students (grades 7–9, $N = 267$). Math achievement was measured by three sectional examinations in a semester, NS was indicated by an approximate numerosity system task, and WM was assessed by a battery of four tasks. Developmental trends in both WM and NS task scores were observed. Memory updating (MU) in the WM tasks was found to be dominant in predicting math achievement in correlation and regression analyses. A similar pattern was observed for separate analyses across grade levels, except that in grade 7 a significant unique contribution of NS to math was observed after taking MU into account. The findings suggest that WM ability (especially that used in MU task) had greater influence on math achievement than NS.

1. Introduction

Basic mathematical ability is of critical importance for high school students. It is fundamental for learning science in school and poor mathematical ability is a serious handicap in the workplace and in daily life (Bynner & Parsons, 1997; Parsons & Bynner, 2005). A UK study found that poor levels of mathematical ability are a major cost to society (Gross, Hudson, & Price, 2009), and improvements in national levels of mathematics ability promote economic growth (OECD, 2010). The junior high school students (grades 7–9) tested in the present study were required to be competent in a wide range of mathematical topics, such as linear and quadratic equations, formulas for polynomials and square roots, similar geometrical figures, properties of triangles, and probability. Mathematics attainment has been shown to be related to a wide range of cognitive and perceptual abilities including number sense, visuo-spatial ability, and the domain-general ability to maintain and manipulate information, usually labeled working memory (WM) and executive functions (e.g., Chen & Li, 2014; De Smedt, Noël, Gilmore, & Ansari, 2013; Fazio, Bailey, Thompson, & Siegler, 2014; Raghubar, Barnes, & Hecht, 2010; for a review). Nevertheless, there is some evidence of domain-specificity in WM (Butterworth, Cipolotti, & Warrington, 1996; Iuculano, Moro, & Butterworth, 2011), and it is maintaining and manipulating numerical information that is linked to mathematical attainment, at least for 8- and 9-year-old children (Iuculano et al., 2011). However, research about the contribution of number sense (NS) and WM to math performance mainly focuses on preschool and elementary students (e.g., De Smedt et al., 2013; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Halberda & Feigenson, 2008; Iuculano et al., 2011); there is little evidence about which of these factors is of particular importance to attainment in junior high school. The aim of the present study was to investigate the role of NS and aspects of WM on individual differences in math achievement in junior high school students.

1.1. Number sense and mathematics

Number sense (NS) is the ability to represent and manipulate numerical quantities (Dehaene, 2001). It is held to reflect the operation

* Correspondence to: N.S. Yen, Department of Psychology, National Chengchi University, No. 64, Sec 2, Zhih-Nan Rd., Taipei 11605, Taiwan.
E-mail address: nsy@nccu.edu.tw (N.-S. Yen).
[1] These authors contributed equally to this work.
[2] These authors are corresponding authors.

http://dx.doi.org/10.1016/j.lindif.2017.01.012
1041-6080/© 2017 Published by Elsevier Inc.

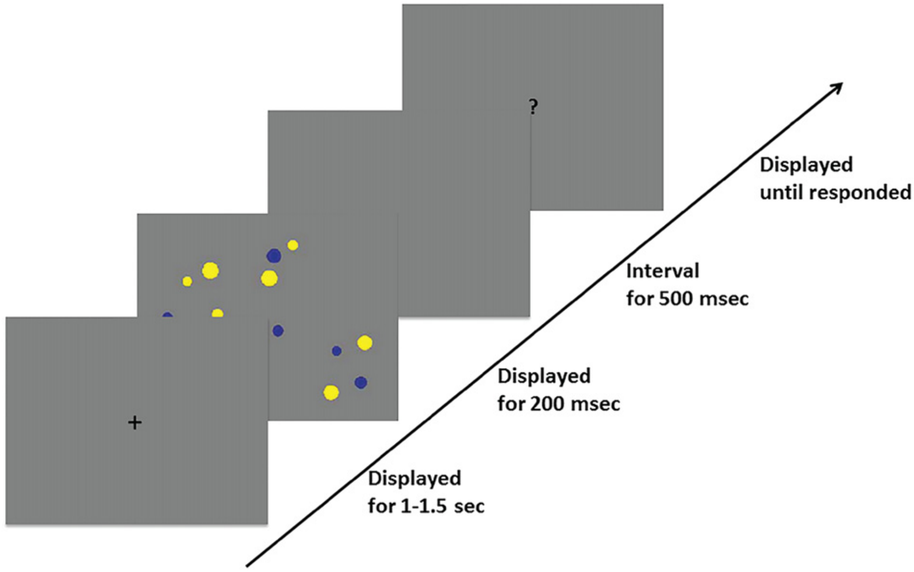

Fig. 1. Experimental procedure for the number sense (NS) task (an example based on the paradigm used by Halberda et al. (2008)).

of the Approximate Number System (ANS, sometimes called the Analogue Magnitude System), which makes approximate estimates of the numerosity of a visual display and maps them onto compressed overlapping analog representations. The operation of NS is present in human infants and in many other species (Nieder & Dehaene, 2009). In the literature, NS is typically assessed by the ability to select the larger of two arrays of dots, often with the spreading areas of the dots controlled. One standard procedure requires selecting the more numerous of two intermixed arrays of blue and yellow dots (see Fig. 1). Typically, individual differences are assessed psychometrically in terms of the proportional differences in quantities between two sets of dots an individual can reliably discriminate, as in Halberda, Mazzocco, and Feigenson (2008). Halberda and Feigenson (2008) documented an increasing trend in NS acuity from age 3–6 years to adulthood. Similarly, from a large online assessment from age 11–85 years, Halberda, Ly, Wilmer, Naiman, and Germine (2012) observed developmental improvement peaking around 30 years old.

Halberda et al. (2008) were the first to discover that an individual's psychometric function, called numerical acuity (here expressed as an "internal Weber fraction" to capture the idea that the internal neural representations of numerosity are log compressed), correlates with arithmetical ability. Sixty-four children, aged 14 years and without learning disabilities, participated in their study. Sets of math achievement tests were collected annually from their kindergarten years up to grade 6 (ages 5–11). Positive correlations were observed between numerical acuity assessed at 14 and mathematics test scores in each of the early years, suggesting that NS was highly associated with math achievement. In addition to the retrospective correlation found by Halberda et al. (2008), Libertus, Feigenson, and Halberda (2011) also documented a positive correlation between numerical acuity and math ability in 200 children aged 3–5 years. Similarly, Mazzocco, Feigenson, and Halberda (2011) found that numerical acuity measured in children aged 3 or 4 years can predict math performance two years later (see also Gilmore, McCarthy, & Spelke, 2010).

These studies suggest a stable relationship between NS and school mathematics performance from children aged 3–11 years[3]. However, whether NS is still relevant in the later stages in school has remained unclear. The relationship between NS and mathematics performance was not consistently observed in the literature. For instance, Libertus, Odic, and Halberda (2012) observed a positive correlation between NS acuity and test scores in the Quantitative section of the Scholastic Aptitude Test (SAT). In the large online assessment, Halberda et al. (2012) also found that NS precision correlated with self-reported mathematics performance in school and SAT-Quantitative scores. However, Wei, Yuan, Chen, and Zhou (2012) showed that while spatial abilities correlated with advanced math concepts of undergraduate students, basic numerical processing did not. Several other studies failed to find the significant correlations between approximation skills and math achievement from childhood to adulthood (e.g., De Smedt et al., 2013; Inglis, Attridge, Batchelor, & Gilmore, 2011; Iuculano, Tang, Hall, & Butterworth, 2008).

The inconsistencies in the contribution of NS to math achievement may result from different measures of NS used in particular studies. Inglis and Gilmore (2014) compared four major measures of NS acuity (Weber fraction, accuracy, and numerical ratio effect – consisting of accuracy and RT), and found that accuracy measure was more reliable than Weber fraction, which was better than the two measures for numerical ratio effect. However, in the review of De Smedt et al. (2013), no patterns associated with differences in measures emerged from studies with positive and negative results. In addition, inconsistent findings may stem from the fact that NS was assessed by various types of approximation tasks in different studies. For instance, Xenidou-Dervou, De Smedt, van der Schoot, and van Lieshout (2013) found that the contribution of non-symbolic approximation to math achievement in preschoolers was mediated by symbolic approximation. Mundy and Gilmore (2009) found that the mapping ability between symbolic and non-symbolic numerical representations predicted math attainment in children aged 6–8 years, above and beyond symbolic and non-symbolic tasks alone.

In junior high school, students start learning a wide range of complicated mathematical concepts and dealing with mathematical problems involving problem solving beyond simple calculations (Best, Miller, & Naglieri, 2011). Although a correlation between NS precision for junior high school students and their self-reported math performance in school was observed in the online study of Halberda et al. (2012), the relationship between NS and math performance has mainly been investigated with either younger children or adults as reviewed above (see

[3] It should be noted that in the study of Halberda et al. (2008), NS acuity was assessed at age 14 and correlated with math achievement assessed annually from ages 5–11.