Journal of Experimental Child Psychology 116 (2013) 380–391

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

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

Visual sustained attention and numerosity sensitivity correlate with math achievement in children

Giovanni Anobile [a,*], Paolo Stievano [b], David C. Burr [a,c]

[a] Department of Neuroscience, Psychology, Pharmacology, and Child Health, University of Florence, 50139 Florence, Italy
[b] Azienda USL 12, Toscana, 55049 Viareggio, Italy
[c] CNR Neuroscience Institute, 56100 Pisa, Italy

ARTICLE INFO

Article history:
Received 21 February 2013
Revised 7 June 2013
Available online 7 August 2013

Keywords:
Attention
Numerical cognition
Numerosity perception
Number line
Math achievement
Developmental dyscalculia

ABSTRACT

In this study, we investigated in school-age children the relationship among mathematical performance, the perception of numerosity (discrimination and mapping to number line), and sustained visual attention. The results (on 68 children between 8 and 11 years of age) show that attention and numerosity perception predict math scores but not reading performance. Even after controlling for several variables, including age, gender, nonverbal IQ, and reading accuracy, attention remained correlated with math skills and numerosity discrimination. These findings support previous reports showing the interrelationship between visual attention and both numerosity perception and math performance. It also suggests that attentional deficits may be implicated in disturbances such as developmental dyscalculia.

Introduction

Educational problems are often related to the inability to sustain attention even when there are no apparent cognitive impairments (Zentall, 1993). Attention acts as a filter to select and maintain relevant information while suppressing irrelevant distracters, improving the efficiency with which information arriving from the environment is acquired and processed and then memorized and learned (Posner & Rothbart, 2005). Recent studies have demonstrated a causal link between visual attention and reading acquisition; serial search and spatial cueing facilitation predict future reading acquisition in children (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012). Furthermore, they showed that

* Corresponding author.
E-mail address: giovannianobile@hotmail.it (G. Anobile).

0022-0965/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jecp.2013.06.006

playing action video games improved both children's attentional skills and their reading speed (Franceschini et al., 2013).

The current research raises a simple and relevant question: What is the relationship between visual attention and perceptual capacities in general and the acquisition of math skills? Using a correlational approach, we tested whether visual sustained attentional capacity of children, as well as perceptual tasks related to the perception of number, correlates with formal school-acquired and nonsymbolic numerical skills after controlling for potential confounding variables such as age, nonverbal IQ, gender, and reading accuracy.

Although humans are the only species with a linguistically mediated code for numbers, humans share a nonverbal representation of numerical quantities with many animal species (Dacke & Srinivasan, 2008; Pepperberg, 2006; see Nieder, Diester, & Tudusciuc, 2006, for a review). In addition, human infants (Feigenson, Dehaene, & Spelke, 2004; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005), including newborns (Izard, Sann, Spelke, & Streri, 2009) and cultural groups with no words for numbers or any mathematic formal system (Dehaene, Izard, Spelke, & Pica, 2008; Gordon, 2004), can reliably discriminate numerical quantities. Whereas the representation of integers is exact, estimation of numerical quantities is approximate, with a certain degree of error associated with number estimation. Numerosity perception obeys Weber's law (Whalen, Gallistel, & Gelman, 1999), meaning that discrimination thresholds increase with stimulus intensity. Weber fraction reflects the *precision* with which two numerical quantities can be discriminated, an index of "number acuity."

A growing amount of evidence links the ontogenetically inherited nonverbal system with the culturally invented and linguistically mediated number code (Feigenson, Libertus, & Justin, 2013). Number acuity, which improves during development (Halberda & Feigenson, 2008), correlates with formal mathematics achievement (Mazzocco, Feigenson, & Halberda, 2011) and predicts math skills years later (Halberda, Mazzocco, & Feigenson, 2008). Even if the causal direction of influence has not been demonstrated, is clear that numerosity representation plays a key role in the acquisition of formal mathematical ability (Mazzocco et al., 2011; Piazza, 2010).

Number and space are intrinsically interconnected (Hubbard, Piazza, Pinel, & Dehaene, 2005). Conceptions of how numbers map onto space develop during school years (Booth & Siegler, 2006; Siegler & Booth, 2004; Siegler & Opfer, 2003); kindergarten children represent numbers in space in a compressed, seemingly logarithmic scale (e.g., placing the number 10 near the midpoint of a 1–100 scale). The scale becomes progressively more linear over the first 3 or 4 years of schooling. Interestingly, dyscalculic children (those who suffer from a specific mathematical learning disability) show poor number acuity (Piazza et al., 2010) and a more logarithmic representation of the number line than controls (Ashkenazi & Henik, 2010; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008).

Like space representation, attention correlates with many aspects of numerosity and number processing. We recently demonstrated that*subitizing* (the errorless and rapid apprehension of collection of items up to four) strongly depends on visual, auditory, and haptic attention (Anobile, Turi, Cicchini, & Burr, 2012; Burr, Turi, & Anobile, 2010). Attention training (through video game playing) increases the subitizing range (Green & Bavelier, 2003), and under attentional load small numbers (inside the errorless subitizing range) become susceptible to adaptation (Burr, Anobile, & Turi, 2011). In line with these results, the event-related potential (ERP) component P2p, a signature of numerosity processing, emerges in the subitizing range under dual-task conditions (Hyde & Wood, 2011). In addition, the capacity to map number onto space requires attention; we recently showed that visual attentional load leads to a logarithmic-like number line mapping (Anobile, Cicchini, & Burr, 2012). Merely looking at numbers causes a shift in covert attention to the left or right side, depending on number magnitude (Fischer, Castel, Dodd, & Pratt, 2003). The connection between attention and number processing also finds support from recent functional magnetic resonance imaging (fMRI) studies of neural correlates of visual enumeration under attentional load. Ansari, Lyons, van Eimeren, and Xu (2007) showed that the temporal–parietal junction (rTPJ), an area thought to be involved in stimulus-driven attention (Corbetta & Shulman, 2002), is activated during a comparison task of quantities. This evidence reveals a strong connection among the representations of numbers, space, and attention.

Despite the growing number of studies demonstrating the relationship between attention and acquisition of reading skills (Franceschini et al., 2012, 2013), surprisingly few studies have examined