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Task- and age-dependent effects of visual stimulus properties on children's explicit numerosity judgments

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ABSTRACT

Researchers investigating numerosity processing manipulate the visual stimulus properties (e.g., surface). This is done to control for the confound between numerosity and its visual properties and should allow the examination of pure number processes. Nevertheless, several studies have shown that, despite different visual controls, visual cues remained to exert their influence on numerosity judgments. This study, therefore, investigated whether the impact of the visual stimulus manipulations on numerosity judgments is dependent on the task at hand (comparison task vs. same–different task) and whether this impact changes throughout development. In addition, we examined whether the influence of visual stimulus manipulations on numerosity judgments plays a role in the relation between performance on numerosity tasks and mathematics achievement. Our findings confirmed that the visual stimulus manipulations affect numerosity judgments; more important, we found that these influences changed with increasing age and differed between the comparison and the same–different tasks. Consequently, direct comparisons between numerosity studies using different tasks and age groups are difficult. No meaningful relationship between the performance on the comparison and same–different tasks and mathematics achievement was found in typically developing children, nor did we find consistent differences between children with and without mathematical learning disability (MLD).

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Introduction

Numerosity and its continuous visual properties are correlated in everyday life. For instance, when more marbles are added to a collection of marbles, numerosity as well as the size of the collection increases. Therefore, it is common practice that studies investigating numerosity processing manipulate the visual cues of the numerosity stimuli. These manipulations should prevent participants from relying on the visual cues when judging numerosity and, thus, allow researchers to study pure number processes. However, an increasing number of studies show that numerosity judgments are sensitive to the continuous visual properties of the numerosity stimuli. These studies show, for instance, that numerosity judgments are influenced by density (Dakin, Tibber, Greenwood, Kingdom, & Morgan, 2011; Sophian & Chu, 2008; Tibber, Greenwood, & Dakin, 2012), the size of the individual elements (Gebuis & Reynvoet, 2011b; Hurewitz, Gelman, & Schnitzer, 2006; Rousselle & Noël, 2008; Tokita & Ishiguchi, 2010), or patch size (Gebuis & Gevers, 2011; Tokita & Ishiguchi, 2010).

Only a few researchers have investigated whether and how the visual stimulus manipulations they use in their experiments affect the measurements of numerosity processing. Researchers mostly believe that the visual confounds are sufficiently controlled and collapse the data from congruent trials (e.g., the larger numerosity has larger visual cues) and incongruent trials (e.g., the smaller numerosity has larger visual cues) without further examining whether the visual stimulus manipulations in these conditions lead to different findings (e.g., De Smedt & Gilmore, 2011; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004). However, investigating the effect of the different visual manipulations in congruent and incongruent trials separately seems to be necessary because some studies have shown that participants respond to the visual properties even when controlling for the visual cues (Gilmore, Attridge, & Inglis, 2011; Inglis, Attridge, Batchelor, & Gilmore, 2011). For instance, approximately 30% of the 8-year-olds in a study by Inglis and colleagues (2011) and approximately 40% of the adults in a study by Gilmore and colleagues (2011) were removed. The performance of these participants in the congruent and incongruent conditions differed by more than 50% in accuracy, suggesting that they relied on the visual stimulus properties. Apparently, the performance on numerosity tasks is unavoidably affected by the manipulations of the continuous visual properties.

To allow comparisons across numerosity studies using different designs and including different age groups, it is essential to find out how the visual stimulus manipulations affect numerosity performance throughout development. It is not clear whether children of different ages are influenced differently by the visual stimulus properties. Infant studies have revealed inconsistent results about the effect of the visual stimulus properties on numerosity judgments. There are studies showing that infants might be more sensitive to the continuous visual properties at the expense of numerosity (Clearfield & Mix, 1999, 2001; Feigenson, Carey, & Spelke, 2002), that infants are equally sensitive to numerosity and visual cues (Brannon, Lutz, & Cordes, 2006; Cordes & Brannon, 2009; vanMarle & Wynn, 2006), and that infants prefer to attend to numerosity over visual properties (Brannon, Abbott, & Lutz, 2004; Cordes & Brannon, 2008, 2011; Xu, 2003; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005). The few studies using explicit paradigms, which examined the effects of the visual stimulus manipulations, showed a more consistent pattern of findings. These studies point to a reliance on visual cues in young children at the expense of number, which seems to decrease with increasing age (Rousselle & Noël, 2008; Rousselle, Palmers, & Noël, 2004) but remains visible even in adults (Gebuis & van der Smagt, 2011; Gilmore et al., 2011; Halberda, Mazzocco, & Feigenson, 2008). However, the age at which children could compare numerosities while the visual cues were manipulated differed. Rousselle and colleagues (Rousselle & Noël, 2008; Rousselle et al., 2004) showed that 3-year-old children were unable to compare numerosities when the stimuli were controlled for surface area, whereas 4- and 5-year-olds performed significantly above chance. In contrast, Soltész, Szucs, and Szucs (2010) observed that 4-year-olds performed at chance level when the visual properties and numerosity were manipulated inconsistently, whereas performance was above chance from 5 years onward.

Research on the impact of the visual stimulus manipulations on numerosity judgments is necessary when considering the important conclusions that are drawn from the results of numerosity studies. It is, for instance, suggested that performance on numerosity tasks is related to mathematics achievement.