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Playing number board games supports 5-year-old children's early mathematical development

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ABSTRACT

The study examined effects of playing number games (linear number board game, circular number board game, and nonlinear numerical activities) on the development of number knowledge and early arithmetic. A passive control group was also included in the design. 114 5-year-old preschool children participated. Four tasks (number line estimation, counting, naming Arabic numbers, and arithmetic calculation) were used as dependent measures. Children assigned to an intervention participated in six 10-min sessions during a period of three weeks. Children playing the linear number board game improved their performance on the number line estimation task, while children playing the other games did not. Furthermore, children playing the linear number board game showed a substantial enhancement of their calculation performance. The positive effects of playing linear number board games support the representational mapping hypothesis. The finding concerning calculation provides support to the assumption that a linear representation is important for early arithmetical learning.

1. Introduction

At an early age, before entering school, children start to develop mathematical skills (Fuson, 1992; Gasteiger, 2012; Ramani & Siegler, 2011). These early and informal skills are important since children entering school with a mathematical foundation to stand on benefit in further learning, not only in mathematics, but also in science, literacy and technology (Duncan et al., 2007). However, when entering primary school, children's mathematical knowledge varies (Anders, Grosse, Rossbach, Ebert, & Weinert, 2013; Duncan et al., 2007). This variation can be problematic since some children may not possess sufficient basic skills that later enable them to acquire adequate mathematical and arithmetical skills. Thus, to ensure children's early development in mathematics they must be supported in a conscious way already in preschool to promote later, more complex learning and understanding in mathematics (Cross, Woods, & Schweingruber, 2009; Gasteiger, 2012; Hannula & Lehtinen, 2005). Today, there is an increased attention to the importance of young children's mathematical learning and development during the preschool period (Cross et al., 2009; Gasteiger, 2012; Östergren & Träff, 2013).

The present study is based on the assumption that humans are born with two core number representation systems (Feigenson, Dehaene, & Spelke, 2004; Piazza, 2010). The first system, the *Approximate Number System* (ANS), constitutes the intuitive sense of numbers and represents large approximate quantities via an analogue magnitude (Mazzocco, Feigenson, & Halberda, 2011a, Mazzocco, Feigenson, & Halberda, 2011b; Piazza, 2010). The precision of the ANS develops during childhood

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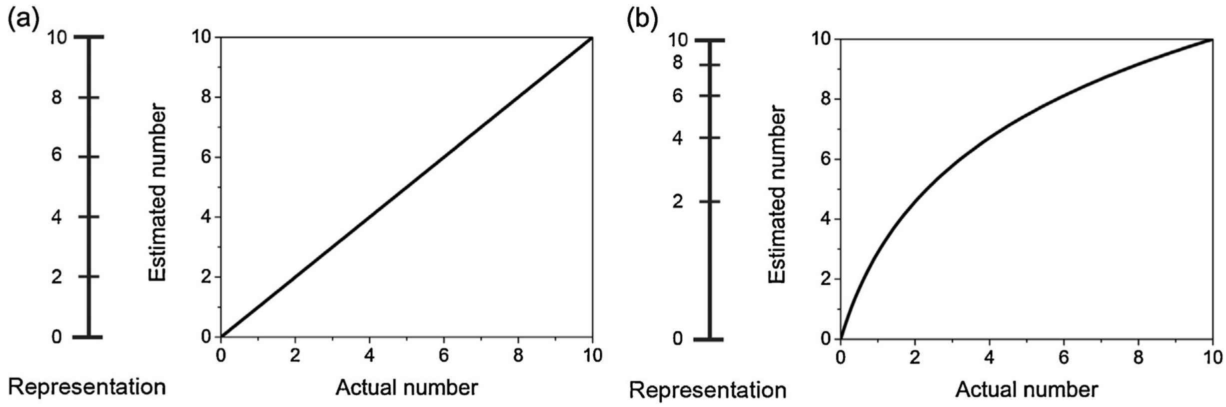

Fig. 1. Illustration of (a) a linear estimation pattern and (b) a logarithmic estimation pattern on a 0–10 number-to-position estimation task.

and functions throughout life (Feigenson et al., 2004; Mazzocco et al., 2011b). The second system is the *Object Tracking System* (OTS) for precise representation of small sets of objects (Feigenson et al., 2004; Piazza, 2010). Piazza (2010) concludes that it is mainly the ANS that is related to numerical development.

To describe children's numerical cognition and early mathematical development, Von Aster & Shalev (2007) presents a four-step developmental model. The model states that the mental number line is a result of an experience-dependent, neuroplastic development and not only the result of an intact core system (Von Aster & Shalev, 2007). The developmental model describes the development of numerical cognition in four steps. The first step contains the two core systems of numbers; ANS and OTS that provide the basic meaning of numbers such as subitizing and approximation that develops during infancy. Von Aster & Shalev (2007) argue that this part "... is a necessary precondition for children to learn to associate a perceived number of objects or events with spoken or, later written Arabic symbols..." (p. 870). Thus, it lays the foundation for later acquisition and development of the symbolic number system. The second step focuses on the verbal number system and is developed during the preschool period. In the third step, the Arabic number system is connected to the former two steps. Finally, in the fourth step, the number line is developed during the school period and children's arithmetical thinking is further developed. The first three steps are thus important preconditions for the development of a mental number line and arithmetical thinking (Von Aster & Shalev, 2007). The core system of numbers and Von Aster and Shalev's developmental model gives support to the importance of using numerical activities to develop children's knowledge in mathematics with focus on numerical magnitudes and development of the mental number line.

The range of the mental number line expands during the (pre)school period and with increasing age and experience the number line representation seems to change becoming more linear (Feigenson et al., 2004; Laski & Siegler, 2007; Siegler & Booth, 2004; Siegler & Opfer, 2003). When the understanding of magnitude (core system) is combined with the symbolic and spatial-ordinal properties of number, children's number line representations develop. The ability to make accurate mental number line representations and possess knowledge about numbers are strong predictors of both arithmetical performance and mathematical skills when children enter school (Booth & Siegler, 2006; Siegler & Booth, 2004; Östergren & Träff, 2013).

Siegler & Lortie-Forgues (2014) describes the integrated theory of numerical development proposing that "...the continuing growth of understanding of numerical magnitudes provides a unifying theme for numerical development" (p. 144). This means that the understanding of real numbers is progressively broadened, which is also described in Von Aster & Shalev's (2007) developmental model. All real numbers possess a magnitude and can be ordered on the number line. The ability to accurately represent and arithmetically combine magnitudes of real numbers is central for the numerical development. Therefore, the mental number line can be described as a structure that gradually extends to include whole numbers in different numerical ranges (Siegler & Booth, 2004; Siegler & Lortie-Forgues, 2014; Siegler & Opfer, 2003) and later fractions and decimals (Siegler & Lortie-Forgues, 2014). The integrated theory (Siegler & Lortie-Forgues, 2014) resembles the idea that the number line of whole numbers expands to rational numbers while learning mathematics (Case et al., 1996).

Numerical magnitudes can be represented in different ways (Ramani & Siegler, 2008; Siegler & Opfer, 2003). Two common ways are the *logarithmic* and the *linear representation* of the mental number line (Laski & Siegler, 2007; Siegler & Opfer, 2003). The spatial distance between numbers is equal and constant in the linear representation (see Fig. 1a) whereas the spatial distance between numbers in the logarithmic representation decreases with increasing number (see Fig. 1b). That is, larger numbers are spatially positioned closer together than smaller numbers in the logarithmic representation (Feigenson et al., 2004; Siegler & Opfer, 2003). With increasing age and experience of numbers, a change from a logarithmic to a (more) linear representation occurs. This typically happens at different times for different numerical ranges as depicted in Table 1 (Feigenson et al., 2004; Laski & Siegler, 2007; Siegler & Booth, 2004; Siegler & Opfer, 2003). The linear representation of numbers seems to be an important part in the development of numerical knowledge and learning in mathematics (Booth & Siegler, 2008; Ramani & Siegler, 2008; Siegler & Ramani, 2009).