Learning and Instruction 40 (2015) 79–88

Contents lists available at ScienceDirect

Learning and Instruction

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

Spontaneous focusing on numerosity and the arithmetic advantage

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ARTICLE INFO

Article history:
Received 28 April 2014
Received in revised form
16 August 2015
Accepted 7 September 2015
Available online 20 September 2015

Keywords:
SFON
Arithmetic
Symbolic mathematics
Nonsymbolic number skills
Children

ABSTRACT

Children show individual differences in their tendency to focus on the numerical aspects of their environment. These individual differences in 'Spontaneous Focusing on Numerosity' (SFON) have been shown to predict both current numerical skills and later mathematics success. Here we investigated possible factors which may explain the positive relationship between SFON and symbolic number development. Children aged 4–5 years ($N = 130$) completed a battery of tasks designed to assess SFON and a range of mathematical skills. Results showed that SFON was positively associated with children's symbolic numerical processing skills and their performance on a standardised test of arithmetic. Hierarchical regression analyses demonstrated that the relationship between SFON and symbolic mathematics achievement can be explained, in part, by individual differences in children's nonsymbolic numerical processing skills and their ability to map between nonsymbolic and symbolic representations of number.

1. Introduction

For many children, the development of symbolic number knowledge (i.e. knowledge of number words and Arabic numerals) is a long and arduous process. Learning the number sequence by rote may happen very early on – children typically begin counting around the age of two – but it can take years to grasp the meanings of the words in the count list. While some children start school with a range of numerical skills (from counting, matching and ordering sets, to adding and subtracting small numbers), others have yet to understand that the last word in their count list represents the numerosity of the set as a whole (e.g. Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006). In other words, they have yet to acquire the cardinal principle of counting (Gelman & Gallistel, 1978).

Recent research has highlighted the role of informal numerical experiences in the acquisition of formal symbolic number knowledge. In particular, Hannula and colleagues have demonstrated that preschoolers show individual differences in their tendency to focus on numerical information in informal everyday contexts. These individual differences in 'Spontaneous Focusing on Numerosity' (SFON) are related to children's counting skills (Hannula & Lehtinen, 2005; Hannula, Räsänen, & Lehtinen, 2007) and they predict later arithmetical success (Hannula, Lepola, & Lehtinen, 2010; Hannula-Sormunen, Lehtinen, & Räsänen, 2015; McMullen, Hannula-Sormunen, & Lehtinen, 2015).

1.1. Spontaneous focusing on numerosity (SFON)

SFON is a recently-developed construct which captures an individual's spontaneous focusing on the numerical aspects of their environment (e.g. Hannula & Lehtinen, 2005). The term "spontaneous" is used to refer to the fact that the process of "focusing attention on numerosity" is self-initiated or non-guided. That is, attention is not explicitly guided towards the aspect of number or the process of enumeration. The idea is that "SFON tendency indicates the amount of a child's spontaneous practice in using exact enumeration in her or his natural surroundings" (Hannula et al., 2010, p.395).

The measures used to assess children's SFON differ from typical enumeration measures. Firstly, children are not guided towards the numerical aspects of the tasks; researchers are careful to ensure that the numerical nature of the tasks is not disclosed. Secondly, the tasks always involve small numerosities so that all children have sufficient enumeration skills to recognise the numbers in the activities. This is important for ensuring that the tasks capture individual differences in focusing on numerosity rather than individual differences in enumeration skills. To demonstrate that SFON tasks are not measures of individual differences in accuracy of number recognition skills per se, previous studies have included guided

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http://dx.doi.org/10.1016/j.learninstruc.2015.09.005

focusing on numerosity (GFON) versions of the tasks. Hannula and Lehtinen (2005) and Hannula et al. (2010) showed that low-SFON children could perform the tasks when guided towards numerosity, thus their low-SFON scores can be interpreted as not focusing on numerosity rather than not having sufficient skills needed to perform the tasks.

1.2. The relationship between SFON and numerical skills

In a three-year longitudinal study, Hannula and Lehtinen (2005) tracked preschool children's counting skills together with their SFON. Results showed that children's SFON, measured at 4, 5, and 6 years, was significantly associated with the development of number word sequence production, object counting and cardinality understanding. Path analyses revealed a reciprocal relationship suggesting that SFON both precedes and follows the development of early counting skills.

Follow-up work demonstrated the domain specificity of SFON as a predictor of children's numerical skills. In another longitudinal study, Hannula et al. (2010) measured children's SFON together with their spontaneous focusing on a non-numerical aspect of the environment, namely, ‘Spontaneous Focusing on Spatial Locations’ (SFOL). Findings showed that SFON in preschool predicted arithmetic skills, but not reading skills, two years later in school. This relationship could not be explained by individual differences in nonverbal IQ, verbal comprehension or SFOL.

Further results from more recent studies have demonstrated an even longer-term role of SFON in predicting school mathematics achievement. Hannula-Sormunen et al. (2015) found that SFON in preschool is still a significant predictor of mathematics achievement at the age of 12, even after controlling for nonverbal IQ. This longer-term relationship was found not only for natural number and arithmetic skills, but for rational number conceptual knowledge as well (McMullen et al., 2015).

1.3. Why is SFON associated with a numerical advantage?

SFON is emerging as a key factor for explaining variations in children's numerical development. However, the mechanisms behind this relationship are not yet clear. In particular, we do not know why SFON provides a numerical advantage. Hannula et al. (2007) proposed that the more children focus on the numerical aspects of their environment, the more practice they acquire with enumeration and thus, the better their counting skills become. To explore this possibility, they looked at the relations between children's subitizing-based enumeration (i.e. the rapid perception of the numerosity of small sets, without counting), object counting and SFON. Regression analyses revealed a direct relationship between children's SFON and their number sequence production skills. In contrast, there was an indirect relationship between SFON and object counting that was explained by individual differences in subitizing-based enumeration skills. This provides some evidence to suggest that SFON promotes perceptual subitizing skills which in turn supports the development of children's counting skills.

Other research has investigated motivational factors in the development of children's SFON and early numerical skills. In one of the first SFON studies to be conducted outside of Finland, Edens and Potter (2013) explored the relationship between SFON and counting skills in 4-year-old children in US preschools. They obtained teacher reports of children's motivation, attentional self-regulation, persistence and interest in mathematics. They also measured children's self-selected activity choices during free-play in the classroom. In line with the results from Hannula and colleagues (e.g. Hannula & Lehtinen, 2005), Edens and Potter found a positive correlation between preschoolers' SFON and their object counting and number sequence production skills. In terms of the motivational factors, they found that teachers' reports of children's motivation and interest in mathematics were significantly correlated with children's counting skills, but not with children's SFON. Moreover, there was no relationship between children's SFON and their self-selected activity choices during free-play: High-SFON children did not choose overtly number-related activities in their classrooms. These findings suggest that SFON does not reflect children's interest in mathematics, or at least not their “overt” interest in mathematics.

Together these studies indicate that the factors underpinning the relationship between SFON and children's numerical development are more likely to be cognitive than affective. However, the precise mechanisms involved need further investigation. The current literature is sparse and somewhat limited in scope. Thus far, studies exploring the mechanisms of SFON have focused solely on its relationship with early counting skills. We do not know why SFON is related to children's later arithmetical development. We also do not know how SFON relates to more basic numerical competencies such as nonsymbolic processing skills or ‘number sense’ (Dehaene, 2001).

One possibility is that SFON works by increasing children's fluency with number symbols. High-SFON children may get more practice mapping between their newly-acquired symbolic representations of number (Arabic numerals and number words) and pre-existing nonsymbolic (approximate) representations. As children get practice with, and improve the precision of these mappings, their counting and arithmetic skills may develop. This is theoretically likely because we know from previous research that mapping ability is related to mathematics achievement (Booth & Siegler, 2008; Holloway & Ansari, 2009; Mundy & Gilmore, 2009; see De Smedt, Noël, Gilmore, & Ansari, 2013 for a review). For example, Mundy and Gilmore (2009) found that children aged 6–8 years showed individual differences in their ability to map between nonsymbolic representations (dot arrays) and symbolic representations (Arabic digits). These individual differences explained a significant amount of variation in children's school mathematics achievement.

Some initial support for this possibility comes from two recent studies. Firstly, Sella, Berteletti, Lucangeli, and Zorzi (2015) found that pre-counting children who spontaneously focused on numerosity did so in an approximate manner. Sella et al. suggest that high-SFON children might be more prone to comparing and estimating numerical sets from an early age thus improving the precision of their numerical representations. Secondly, Bull (2013) found that high-SFON children (aged 5–7 years) performed better than their low-SFON peers on a numerical estimation task, in which they had to assign a symbolic number word to a nonsymbolic array of dots. In other words, children who consistently focused on numerosity were better able to map between nonsymbolic and symbolic representations of number.

In addition to these studies, research exploring the transition from informal to formal mathematics knowledge has highlighted the role of mapping ability. In a one-year longitudinal study Purpura, Baroody, and Lonigan (2013) demonstrated that the link between children's informal and formal mathematics knowledge was fully explained by individual differences in symbolic number identification and the understanding of symbol to quantity relations. Here, informal mathematics knowledge was defined as “those competencies generally learned before or outside of school, often in spontaneous but meaningful everyday situations including play” (Purpura et al., 2013, p. 454). It is important to note that this informal mathematics is a separate construct to SFON (recall that SFON is a distinct attentional process rather than the spontaneous acquisition of mathematical skills). Therefore