Learning and Individual Differences 39 (2015) 150–157

Contents lists available at ScienceDirect

Learning and Individual Differences

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

The sense of small number discrimination: The predictive value in infancy and toddlerhood for numerical competencies in kindergarten

Annelies Ceulemans [a,*], Daisy Titeca [a], Tom Loeys [b], Karel Hoppenbrouwers [c], Sofie Rousseau [d], Annemie Desoete [a,e]

[a] Department of Experimental Clinical and Health Psychology, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium
[b] Department of Data Analysis, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium
[c] Environment and Health Unit, University of Leuven, Kapucijnenvoer 35 blok d — box 7001, 3000 Leuven, Belgium
[d] Parenting and Special Education Research Unit, University of Leuven, Leopold Vanderkelenstraat 32 — box 3765, 3000 Leuven, Belgium
[e] Department of Speech Therapists, Artevelde University College, Voetweg 66, 9000 Ghent, Belgium

ARTICLE INFO

Article history:
Received 28 February 2014
Received in revised form 19 February 2015
Accepted 28 March 2015

Keywords:
Early numerical competencies
Habituation task
Manual search task
Small number discrimination

ABSTRACT

Extending previous research on the predictive value of large *number discrimination*, this study explored the role of infants' and toddlers' small number discrimination for numerical competencies in kindergarten (NCK). Although no significant relationship could be found between number discrimination in infancy (8 months, T1) and NCK (48 months, T3), the predictive value of toddlers' number discrimination (24 months, T2) for NCK could be demonstrated at least for some NCK. The finding that only toddlers' small number discrimination related to NCK raised thoughts about the task, age, set size, stability and development of number discrimination or other influencing factors. Future research should study all small set sizes (not only 1 vs. 3) and a broader range of NCK in a larger sample. Nevertheless, whereas infants' small number discrimination might be too early to predict NCK, performance in toddlerhood might be addressed in the future to establish a measure to detect at-risk mathematical development.

1. Introduction

Infants are found to non-verbally discriminate between sets with a different number of items. This so-called *number discrimination* (e.g., Xu & Arriaga, 2007) has frequently been studied as an innate sense of quantity that develops without or with little verbal input early in life (Butterworth, 1999; Dehaene, 1997; Jordan & Levine, 2009).

Research on number discrimination is remarkable, as it shows that even infants are already able to (non-verbally) discriminate between numerosities (e.g., Cordes & Brannon, 2009a,b; Starr, Libertus, & Brannon, 2013a; Xu, 2003). The precise nature and underlying processes of this ability, however, remain a topic of an abundance of studies. As yet, studies on number discrimination were mainly restricted to concurrent group results (e.g., Xu, Spelke, & Goddard, 2005). This means that attention was mainly given to the group performances on different number discrimination tasks of children overall without mapping any individual differences in the specific ability to discriminate numerosities between children in a studied sample. Only recently, these individual differences were studied (Libertus & Brannon, 2010) and furthermore related for the first time to later numerical competencies (Starr, Libertus, & Brannon, 2013b). One of the main findings of this latter study was that the performance on a number discrimination task administered in infancy (i.e., 6 months of age) significantly predicted later math scores in kindergarten (i.e., 3.5 years). Administered items covered counting and numeral literacy, number-comparison facility and basic calculation (Starr et al., 2013b). Furthermore, number discrimination performance also predicted children's mastery of cardinality in particular as children who understood the exact meaning of the number words 'one' to 'six' in kindergarten performed significantly higher on number discrimination in infancy than children who only understood a subset of those number words (Starr et al., 2013b). As such data of this pioneering study pointed toward a developmentally primary role of the preverbal ability to discriminate numerosities already from infancy on. Nevertheless, it should be noted that this finding concerned *large* as opposed to *small* number discrimination, with the latter being another format of this ability and the focus of the current study. Overall, small number discrimination has been connected with object files and large number discrimination with analog magnitudes as underlying systems of number discrimination (Feigenson,

* Corresponding author at: Department of Experimental Clinical and Health Psychology, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium. Tel.: +32 9 264 94 14; fax: +32 9 264 64 89.
E-mail addresses: Annelies.Ceulemans@UGent.be (A. Ceulemans), Daisy.Titeca@UGent.be (D. Titeca), Tom.Loeys@UGent.be (T. Loeys), karel.hoppenbrouwers@med.kuleuven.be (K. Hoppenbrouwers), Sofie.Rousseau@ppw.kuleuven.be (S. Rousseau), Annemie.Desoete@UGent.be (A. Desoete).

http://dx.doi.org/10.1016/j.lindif.2015.03.009
1041-6080/

Dehaene, & Spelke, 2004; Xu, 2003; and see Cantrell & Smith, 2013 for a review).

The object-file system allows an exact representation of a limited number (up to three) of items (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Leslie, Xu, Tremoulet, & Scholl, 1998; Trick & Pylyshyn, 1994) and the analog magnitude system allows an approximate representation of a larger (from four on) set of items (Feigenson et al., 2004). In the latter case discrimination is ratio-dependent: with a larger ratio numerosities are easier to discriminate. For example, Xu and Spelke (2000) demonstrated that 6-month-olds discriminate differences at a 1:2 ratio (8 vs. 16) but not at a 2:3 ratio (8 vs. 12).

Nonetheless, the claim that small numbers are only processed by object-files is tentative since the successful discrimination of small from large numerosities (Cordes & Brannon, 2009a) and the finding that number discrimination is ratio-dependent regardless of set size (Starr et al., 2013a) are incompatible with this assumption. Moreover, one should acknowledge that young children probably have access to both systems but that the system they rely on might depend on the paradigm that is used (Feigenson & Carey, 2003).

Reviewing literature on small number discrimination three paradigms step into the limelight: the habituation (Clearfield & Mix, 1999; Cordes & Brannon, 2009b; Xu et al., 2005), the manual search (Feigenson & Carey, 2003, 2005) and (only) recently the numerical change detection paradigm (Libertus & Brannon, 2010). Habituation can be described as learning which reflects a changing responsiveness toward reiterated information leading children to less heed stimuli which are repeatedly shown (Bornstein, Pêcheux, & Lécuyer, 1988). The paradigm relies on a preference for novelty (e.g., Colombo & Mitchel, 2009) which is in this case a new number of items. Like the name suggests, the manual search task relies on how children search for a certain amount of objects which are being hidden after presentation (Feigenson & Carey, 2003). Reaching/searching for objects is an action aimed at retrieving individual objects. Therefore, children are less prone to draw attention on the perceptual features (i.e., size, color, and shape) and give attention to the number of objects (Feigenson & Carey, 2005). Recently, the numerical change detection paradigm was developed by Libertus and Brannon (2010) based on a paradigm initially created by Ross-Sheeby, Oakes, and Luck (2003) to test infants' visual short-term memory. By means of two peripheral offered streams of rapidly changing images (relying on infants' preference for numerical change above constant numerosity) it was modified to test infant's ability to detect numerical changes.

Regarding small number discrimination, the numerical change paradigm is assumed to activate the analog magnitude system (Starr et al., 2013a), whereas the manual search task would prompt the use of the object-file system (e.g., Barner, Thalwitz, Wood, Yang, & Carey, 2007; Feigenson & Carey, 2003, 2005). Divergent findings on small number discrimination emerge with failure for set size 1 vs. 2 (Xu et al., 2005) and success for 2 vs. 3 (Cordes & Brannon, 2009b) as well as for 1 vs. 3 (Ceulemans et al., 2012), however, leaves the question on which system is triggered by this habituation paradigm unresolved.

The current study tried to further disentangle the role of number discrimination in addition to earlier topic-related studies (Libertus & Brannon, 2010; Starr et al., 2013b). For this purpose, number discrimination was assessed in children at the age of 8 (infants, T1) and 24 months (toddlers, T2) using an age-appropriate task (a habituation and manual search paradigm respectively) at both time points. Up till now, number discrimination studies mostly used habituation tasks in younger infants (mostly aged 6 months up till 10 months; e.g., Cordes & Brannon, 2009b; Xu, 2003; Xu & Arriaga, 2007; Xu et al., 2005) whereas the manual search task was more often used in (older) toddlers (aged 1 to 2 years; e.g., Barner et al., 2007; Feigenson & Carey, 2003, 2005).

Furthermore, in line with Starr et al. (2013b), the following numerical competencies in kindergarten (NCK) were tested with a standardized test battery in these children at the age of 48 months (kindergarteners, T3): (procedural and conceptual) counting, with a more-in-depth test on cardinality, and arithmetic operations. In addition, general intelligence was tested. Items on procedural counting concerned children's ability to perform a mathematical task (LeFevre et al., 2006), whereas items on conceptual counting constituted the understanding of why a procedure works or is legitimate (Bisanz & LeFevre, 1992; Hiebert & Lefevre, 1986; LeFevre et al., 2006) referring to underlying principles of counting (Gelman & Gallistel, 1978). Knowing the meaning of a numeral (cardinality) as one of those principles was highlighted more in particular administering a widely used test on cardinality knowledge. Arithmetic operation exercises prompted the understanding of composition and decomposition of groups by differentiating sets and subsets (i.e., addition and subtraction; Purpura & Lonigan, 2013). As such, administered items within the scope of the current study resembled the respective abilities of counting, numeral literacy, and basic calculation assessed by Starr et al. (2013b). For all these numerical competencies the value as a predictor for later mathematics has been supported (Geary, Hamson, & Hoard, 2000; Powell & Fuchs, 2012).

Three research objectives were formulated. First, it was investigated whether performance on the habituation task (T1) related to NCK (T3). Second, this was examined for performance on the manual search task (T2) and NCK (T3). In other words, were infants' and toddlers' number discrimination performances predictive to later NCK? When a specific relationship between a number discrimination measure and a NCK-measure was significant, it was further explored whether number discrimination still had an additional value when taking into account intelligence. Finally, in the third research objective, it was studied whether number discrimination performance at 8 and 24 months of age was significantly related and could be considered as a stable measure throughout development.

Number discrimination in this study focused on small numerosities. From the age of 2 years onwards, children learn to count by acquiring consecutively the meaning of the first number words (Mix, 2009) in a first stage, which leads them to learn larger number words in a later stage. As such, investigating the predictive value of *small number discrimination* for later mathematics – even from infancy on but certainly at the critical age of 24 months – seemed to be a meaningful addition to previous research on the predictive value of *large number discrimination* (Starr et al., 2013b). Based on the findings of Starr et al. (2013b), it was expected that infant's number discrimination (T1) would relate significantly to NCK (T3). Consequently, number discrimination in toddlerhood (T2) was also expected to relate significantly to NCK (T3), since the assessed number discrimination tasks at both ages – although different in design – are assumed to tap the same ability.

In previous studies small set sizes were mainly investigated with either a habituation or a manual search task (e.g., Cordes & Brannon, 2009b; Feigenson & Carey, 2003, 2005; Xu, 2003). Since the numerical change task has only recently been used in the study of Starr et al. (2013b) to investigate small number discrimination, tasks according to the other two mentioned paradigms took precedence in the current study. Furthermore, in order to make a prediction possible between number discrimination and later outcome, at least some children needed to be able to successfully discriminate the specified numerosities. Accordingly, the small set size with the largest ratio (1 vs. 3) was chosen, since this warranted success with both tasks (Ceulemans et al., 2012; Feigenson & Carey, 2003, 2005).

In addition to previous studies, only providing binary information in terms of success or failure based on one overall task performance (Starr et al., 2013b), this study took into account successes and failures on different test trials of the tasks instead. As such, the study aimed at taking the binary information to a higher level and making it sensitive to individual differences.