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Young children's mapping between arrays, number words, and digits

Laurent Benoit [a,*], Henri Lehalle [b,*], Michèle Molina [c], Charles Tijus [b], François Jouen [b]

[a] Laboratoire Epsylon, 4 boulevard Henri IV, 34000 Montpellier, France
[b] Laboratoire CHArt, Université Paris 8, 2 rue de la liberté, 93526 Saint-Denis, France
[c] Laboratoire Palm, Université de Caen Basse-Normandie, Esplanade de la paix, 14032 Caen, France

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ABSTRACT

This study investigates when young children develop the ability to map between three numerical representations: arrays, spoken number words, and digits. Children (3, 4, and 5 years old) had to map between the two directions (e.g., array-to-digit vs. digit-to-array) of each of these three representation pairs, with small (1–3) and large numbers (4–6).

Five-year-olds were at ceiling in all tasks. Three-year-olds succeeded when mapping between arrays and number words for small numbers (but not large numbers), and failed when mapping between arrays and digits and between number words and digits. The main finding was that four-year-olds performed equally well when mapping between arrays and number words and when mapping between arrays and digits. However, they performed more poorly when mapping between number words and digits. Taken together, these results suggest that children first learn to map number words to arrays, then learn to map digits to arrays and finally map number words to digits. These findings highlight the importance of directly exploring when children acquire digits rather than assuming that they acquire digits directly from number words.

1. Introduction

As adults, we have extensive experience with three different formats in which numerical information can be conveyed: arrays, number words and digits. Researchers have explored how we internally represent information presented in each of these formats (our numerical codes) and how we map between them (Barrouillet, Camos, Perruchet, & Seron, 2004; Dehaene, 1992; McCloskey, Caramazza, & Basili, 1985; Power & Dal Martello, 1997; Seron & Fayol, 1994). Dehaene (1992) proposed a functional model of the relations between the three main codes: the analogical code (for arrays), the verbal code (for spoken number words), and the digital code (for digits).

According to Dehaene, school children and adults directly map between each of these three codes. They also use input and output procedures to map between each code and its external representation. For example, subitizing is used to map small arrays to the analogical code, while estimation procedures are used to map large arrays to the analogical code.

Curiously, there do not appear to be any developmental studies that compare when children learn to map between each of these three of the external representations (arrays, number words, and digits) and the others. The present experiment fills this gap in the literature. The novelty of this work lies largely in its focus on digits.

Prior research has focused largely on when children are able to map between arrays and number words. This work has provided two critical findings. First, 2- to 4-year-old children learn to map from arrays to number words at the same time as they learn to map from number words to arrays (Le Corre & Carey, 2007; Le Corre, Van de Walle,

* Corresponding authors.
E-mail addresses: laurent.benoit@univ-montp3.fr (L. Benoit), henri.lehalle@univ-montp3.fr (H. Lehalle).

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Brannon, & Carey, 2006; Wynn, 1990, 1992). For example, they are able to succeed the "What's on This Card?" task (Gelman, 1993; see also Meljac, 1979) which requires them to map from arrays to number words, at the same time as the "Give-a-Number" task (Wynn, 1990, 1992) which requires them to map from number words to arrays (Le Corre et al., 2006). Second, children learn the mappings for small numbers before the mappings for large numbers (Benoit, Lehalle, & Jouen, 2004; Gelman & Tucker, 1975; Wynn, 1990). For example, Benoit et al. (2004) demonstrated that 3- and 4-year-olds name small arrays (1–3) better than large arrays (4–6) when they see all the elements of the arrays at the same time.

We know considerably less about when children acquire the digit mappings. Most research on digits has focused on when children acquire the conventional rules of representations, such as place value (Sinclair, Tièche Christinat, & Garin, 1993; Tolchinsky Landsmann & Karmiloff-Smith, 1992). Many other issues remain unresolved. Only a few studies have explored when children map between arrays and digits or between number words and digits. These studies have shown that children acquire the mapping between number words and digits during the preschool years: 4- and 5-year-old children, who can order digits in a number-to-position task, can also name those digits (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010). The studies have also shown that children appear to know that the mapping between number words and digits is stable over time, during this age period: 3- to 5-year-old children, who see a digit with both an array and the number word with which they correspond, can remember the number word and repeat it, even when the digit reappears with another array that contains a different number of objects (Bialystok, 2000). None of the prior studies on digits have explored whether children acquire the digit mappings for small numbers or quantities before acquiring those for larger numbers or quantities or whether children learn the mappings in both directions simultaneously (e.g., digits-to-arrays and arrays-to-digits).

The present study addresses three unresolved questions. The first is whether children acquire the mappings for digits in a symmetric fashion, performing equally well in either direction. For example, do young children map from arrays to digits at the same time as they map from digits to arrays? Similarly, do they map from number words to digits at the same time they map from digits to number words? There are two reasons for assuming that children acquire these mappings in both directions at the same time. First, it is likely that children encounter both directions with equal frequency and in many of the same contexts. Second, children could have a knowledge of numbers that is relatively abstract (e.g., cardinality, stable order) because they have already acquired the mapping between arrays and number words. By linking digits to this abstract knowledge, they might gain the ability to map across representations in either direction.

Our second question (the more important one) is which of the other codes do children map digits to initially? Do they map between arrays and digits before they map between number words and digits, or vice versa? There are two reasons to expect that children map between number words and digits before they map between arrays and digits. The first reason is that children may get more practice mapping between number words and digits. For example, they may recite the number-word list as they follow the digit list at school. In contrast, it is difficult to think of contexts in which children repeatedly map between arrays and digits. The second reason has to do with the correspondence between representations. Children may easily map between number words and digits because they use one/one correspondence (one number word/one digit). But they may not easily map between arrays and digits because they use one/many correspondence (one digit and many elements in an array). Indeed, they may approximate arrays with more than three elements.

However, there are also two good reasons why children might map between arrays and digits before they map between number words and digits. The first has to do with the codes. The non-symbolic system of arrays is the foundation of the symbolic system of number words (Berteletti et al., 2010). If symbolic digits are learned in the same fashion as number words, then arrays may also serve as their foundation. Children may find it easier to map a symbolic code to a non-symbolic code, and may have difficulty establishing direct mappings between two symbolic codes. The second reason relates to the properties of the representations. Perhaps the mapping process is easier when both representations are perceptually available for the duration of the task (as arrays and digits typically are), and this process may be more difficult when one of the representations is only fleetingly present (as number words typically are).

Our third research question is whether children acquire the digit mappings according to the size of the numbers they represent. Do they acquire digit mappings for numbers in the subitizing range (1–3) before digit mappings for slightly larger numbers (4–6), or do they acquire all of these mappings at the same time? There are two reasons to expect children to acquire digit mappings for small numbers prior to digit mappings for large numbers. The first reason has to do with the familiarization with the representation pairs. Children typically have more experience with the representation pairs involving small digits than with the representation pairs involving large digits. The second reason has to do with the codes. Perhaps children find it easier to map a symbolic code to the non-symbolic system for representing the individuals in small arrays than to map a symbolic code to the non-symbolic system for representing the magnitude of large arrays (Benoit et al., 2004; Huang, Spelke, & Snedeker, 2010; Le Corre & Carey, 2007, 2008; Le Corre et al., 2006). Children may be able to use subitizing to reliably represent the number of individuals in a small array and map it to a digit, before they can use estimation to approximately represent the magnitude of a large array and map it to a digit.

In the present experiment, we tested three groups of children aged 3 to 5 years on three kinds of representations: arrays of dots, number words, and digits, in the usual mode of presentation (i.e., arrays and digits remained visible and number words were fleeting). The children had to choose the correct representation of a number when encountering another representation of the same number. We compared the directions of the representation pairs,