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When the mental number line involves a delay: The writing of numbers by children of different arithmetical abilities

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ABSTRACT

Our study focused on number transcoding in children. It investigated how 9-year-olds with and without arithmetical disabilities wrote Arabic digits after they had heard them as number words. Planning time before writing each digit was registered. Analyses revealed that the two groups differed not only in arithmetical abilities but also in verbal and reading abilities. Children with arithmetical disabilities were overall slower in planning Arabic digits than were control children with normal arithmetical abilities. In addition, they showed a number size effect for numbers smaller than 10, suggesting a semantically mediated route in number processing. Control children did not need more planning time for large numbers (e.g., 8) than for small numbers (e.g., 3), suggesting a direct nonsemantic route. For both two- and three-digit numbers, both groups of children showed a number size effect, although the effect was smaller each time for control children. The presence of the stronger number size effect for children with arithmetical disabilities was seen as a delay in the development of quick and direct transcoding. The relation between transcoding problems and arithmetical disabilities is discussed. A defect in the linking of numerical symbols to analog numerical representations is proposed as an explanation for the transcoding problems found in some children.

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Introduction

Children with arithmetical disabilities are known predominantly for problems in solving mental addition and subtraction tasks. They use less efficient strategies (e.g., counting procedures rather than retrieval) that take more time and demand more attentional control, and thus allow for more errors, than do children who have relatively normal abilities (Geary, 2003). Although problems in arithmetic are typical for these learning disabilities, there is more and more evidence (Rousselle & Noel, 2007) that the problems are widespread and may concern any task that involves numerical symbols. Translation between verbal numbers and Arabic digits, also called transcoding, seems to be one of these problems (Geary, Hamson, & Hoard, 2000). In the current study, we investigated why transcoding is a problem for children with arithmetical disabilities.

With the onset of language development, verbal numbers become the main source of quantity information (e.g., in Dutch: *vierentwintig* [twenty four]). Later on, with increasing complexity in arithmetical operations, Arabic numerals (e.g., 24) become the more efficient, and thus the dominant, source of quantity information (Fayol & Seron, 2005). From then onward, children must learn two types of symbolic codes for quantities that often need to be converted. Not being able to do the transcoding quickly and correctly is often considered to be an indication of arithmetical disabilities. Children with these problems make many errors in multidigit numbers, as is visible from both the writing of Arabic numerals from numbers presented orally and the reading of numbers from Arabic numerals (Gross-Tsur, Manor, & Shalev, 1996; Hanich, Jordan, Kaplan, & Dick, 2001), whereas they sometimes appear to be relatively error free in transcoding small numbers (Geary et al., 2000; Geary, Hoard, & Hamson, 1999). The contrast between transcoding small and large numbers was studied here for children differing in arithmetical abilities. Rather than focusing on errors, we used production times (Lochy, Pillon, Zesiger, & Seron, 2002) from hearing the verbal number to writing the Arabic digit so as to clarify the underlying mechanisms.

Small and multidigit numbers may be associated with lexical and syntactic mechanisms, respectively (McCloskey, Caramazza, & Basili, 1985; McCloskey, Macaruso, & Whetstone, 1992; Power & Dal Martello, 1990). Lexical mechanisms probably operate exclusively on basic or lexical units such as digits or words that represent small numbers under *ten,* teens such as *fourteen* and *eighteen,* tens such as *thirty,* and larger numbers that, at least in Dutch (but not in English), function as multipliers and can be used as separate numbers such as *(one) hundred* [*honderd*] and *(one) thousand* [*duizend*]. Syntactic mechanisms are concerned with the rules that children need to master so as to be able to comprehend and produce the composition of more complex numbers (e.g., *seven thousand three hundred and three* and 7303) from the lexical primitives in both verbal and Arabic codes. These rules are largely code specific. Compare again *seven thousand three hundred and three* and 7303 in which the Arabic 0 solves the problem of the absence of tens. Syntactic mechanisms, therefore, are probably tied to comprehension and production of these codes. Transcoding, then, involves knowledge of rules regarding how the two number codes are related. For example, if Dutch-speaking children hear *drieëntwintig* [twenty three] and need to write 23, they must change sequences and translate units that are specified before the decades in the verbal code (e.g., *drie* = three) to units specified after the decades in the Arabic numeral code (e.g., 3). Translation rules become more complex when they apply to larger numbers, thereby also including the rules for component numbers. Children must learn rules about the application of zeros in multiplicative Arabic number structures, such as 700 and 3000, as well as in additive structures, such as 703 and 3024, in which zeros of round numbers are partly overwritten by combinations of ones, tens, hundreds, and the like. Although errors in transcoding (Geary et al., 2000) suggest that children with low arithmetical abilities fail more in the translation of complex numbers requiring the execution of syntactic mechanisms than in the translation of lexicalized units such as single-digit numbers, children's processing times provide more direct evidence for this hypothesis and may help to clarify the mechanisms involved.

Some theoretical models, such as the developmental model by Barouillet and colleagues (Barouillet, Camos, Perruchet, & Seron, 2004), imply differences in processing time. Adapted from a model on