Contemporary Educational Psychology 44-45 (2016) 83–94

Contents lists available at ScienceDirect

Contemporary Educational Psychology

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

Empirical study

Counting and rapid naming predict the fluency of arithmetic and reading skills

Tuire Koponen [a,b,*], Paula Salmi [a], Minna Torppa [b], Kenneth Eklund [b], Tuija Aro [a,b], Mikko Aro [b], Anna-Maija Poikkeus [b], Marja-Kristiina Lerkkanen [b], Jari-Erik Nurmi [b]

[a] Niilo Mäki Institute, Finland
[b] University of Jyväskylä, Finland

ARTICLE INFO

Article history:
Available online 2 March 2016

Keywords:
Counting
RAN
Arithmetic calculation fluency
Reading fluency
Longitudinal study

ABSTRACT

Understanding of the factors that underlie the development of fluency in reading and arithmetic is limited. This longitudinal study examined whether verbal counting and rapid automatized naming (RAN) were predictors of arithmetic and reading fluency in a population-based sample and to what extent related early emerging cognitive abilities and socioeconomic background accounted for the predictive power of counting and RAN. In addition, in order to examine the uniqueness of counting as a numerical predictor of reading fluency, the influence of another early number skill—number concept—was controlled. Three hundred and seventy-eight Finnish children were followed from kindergarten to Grade 3 (from 6 to 10 years). The results demonstrated that counting and RAN were powerful predictors of arithmetic and reading fluency. Controlling for phonological awareness, vocabulary, memory, and mother's education had little impact on the predictive relation of counting and RAN to fluency in arithmetic and reading. The number concept skill did not remove the predictive relation of counting with reading or arithmetic and had only a predictive relation to arithmetic fluency after controlling for cognitive skills. Findings suggest that the strong predictive relation counting had with reading and arithmetic fluency does not exist with all number skills. This finding supports the view that there is something specific in the verbal counting skill related to the development of fluency, which should be studied in the future.

1. Counting and rapid naming: general or skill-specific predictors of arithmetic and reading fluency

Fluency in reading and arithmetic calculation is crucial for later development of academic skills. Fluent reading skill serves as a tool for learning other school subjects, such as biology or history. Development of reading fluency at the beginning of one's school career has also been shown to be a strong predictor of later reading comprehension (Kim, Petscher, Schatschneider, & Foorman, 2010). Similarly, basic arithmetic calculation skill serves as a tool needed in mathematical problem solving as well as in other subjects, such as science. Fluent calculation skill supports learning, because it frees up the individual's resources from use of low-level computation to use in more complex problem solving and reasoning (Meyer, Salimpoor, Wu, Geary, & Menon, 2010). Dysfluency in these two basic skills hampers the later academic learning and it's important to support the adequate development of these skills.

Despite the importance of fluent mastery of these basic skills, explicit attention to joint fluency in reading and arithmetical calculation has been rare. Thus, an understanding of the factors underlying the development of fluency in reading and arithmetic is as of yet limited. Knowledge of the cognitive factors underlying the development of fluency is theoretically important and necessary for the development of more efficient instructional practices. Knowledge of early predictors could also help teachers to identify and provide support for children at risk of later dysfluency in reading and arithmetic.

There is strong evidence for a close connection between arithmetic and reading skills in both population-based samples (e.g., Koponen, Aunola, Ahonen, & Nurmi, 2007) and samples including children with difficulties in reading and arithmetic (Räsänen & Ahonen, 1995; von Aster & Shalev, 2007). Furthermore, a meta-analysis by Duncan et al. (2007) showed that early math skills were as predictive of later reading achievement as early reading skills, suggesting a close relationship between math and reading. However, there are few studies examining joint predictors of fluency in reading and arithmetic. Consequently, the aim of the present study was to add to the knowledge base on the predictors of fluency both in reading and in arithmetic skills. We focused on two cognitive skills due to their demonstrated links to fluency: rapid automatized

* Corresponding author. Niilo Mäki Institute, University of Jyväskylä, PL 35 40014, Finland.
E-mail address: tuire.koponen@nmi.fi (T. Koponen).

http://dx.doi.org/10.1016/j.cedpsych.2016.02.004
0361-476X/

naming (RAN) and verbal counting. RAN has been shown to be the strongest predictors of reading fluency (e.g., Landerl & Wimmer, 2008). Moreover, there is also evidence that RAN is related to arithmetic fluency (e.g., Georgiou, Tziraki, Manolitsis, & Fella, 2013; Koponen et al., 2007). Similarly, verbal counting, the ability to recite number words forward and backward, was found to be a strong predictor of arithmetic fluency (Koponen, Salmi, Eklund, & Aro, 2013; Zhang et al., 2014), and there are also a few empirical findings suggesting that counting is a predictor of reading fluency (Koponen et al., 2013; Leppänen, 2006). However, in previous studies investigating joint predictors of reading and arithmetic fluency, there are limitations that should be taken into account. The studies have typically been cross-sectional, have not modeled predictors of reading and arithmetic fluency within the same sample, and have not examined the relation between counting and reading in population-based samples (see an exception in Leppänen, 2006). Moreover, the studies have not taken into account other cognitive predictors, such as working memory.

This longitudinal study examined whether verbal counting and RAN are predictors of arithmetic and reading fluency. We also controlled for the predictive relations of phonological awareness, verbal short-term memory, working memory, and vocabulary measured at kindergarten, as well as mother's education in order to determine whether these related, early emerging cognitive abilities and/or socio-economic background explained the predictive power of counting and RAN. Previous studies on the topic have not explicitly examined the role of working memory and vocabulary as potential underlying factors that could explain the possible predictive relations between counting and reading fluency or RAN and arithmetic fluency. In this study, the aim was to try to confirm the previous findings of counting as a predictor of reading fluency (Koponen et al., 2013; Leppänen, 2006), as well as to examine whether the domain-general relation of counting and fluency (both with reading and arithmetic) is specific or whether counting skill is a proxy for a more general relation between early number processing skills and fluency. For that purpose, we also included the measure of number concept skill in the study.

1.1. Development of fluency in reading and arithmetic and their relation to counting and RAN

In the current study, fluency in reading was operationalized as the rate and accuracy of word reading, and fluency in calculation is operationalized as the rate and accuracy of solving basic arithmetical problems with single and multi-digit numbers. Reading and calculation skills share similar developmental steps. In the early stage of acquisition, both skills are based on one-by-one coding. Calculation is based on serially reciting number words (Ostad, 1999; Siegler & Shrager, 1984), and reading is based on the serial phonemic assembly of letter sounds (Share, 1995). At later stages of skill development, there is a shift toward processing and retrieving larger units, such as arithmetic facts in calculation (Ostad, 1999; Siegler & Shrager, 1984) or larger orthographic units in reading. In the present study, calculation and reading fluency were assessed at the age of 9 and 10 years, meaning that children had at least two years of instruction in basic reading and arithmetic. At that age, fluent reading reflects direct recognition of words or word parts and retrieval of corresponding phonological output from long-term memory. Dysfluent reading still requires the serial decoding of single graphemes. Similarly, in arithmetic, fluent calculation reflects the fast retrieval of arithmetical facts or the ability to derive calculations on the basis of some known arithmetical facts. Dysfluent calculation is manifested as counting-based strategies (e.g., 6 + 5 counted as "*six*, then *seven, eight, nine, ten, eleven*"). To summarize, the development and fluent mastery of both reading and arithmetic skills are preceded by the serial processing of information, and there is a developmental shift toward retrieval of information directly from long-term memory as a main processing strategy. Thus, the ability to effortlessly process serial information and to retrieve verbal information rapidly from long-term memory are skills required for learning to read and calculate fluently. We suggest that verbal counting ability can be seen as an indicator of the ability to process sequential information (in this case, number words and their correct order). RAN, on the other hand, has been defined as the ability to access phonological information related to visual stimuli from long-term memory. Thus, it could be related to the retrieval of the phonological code for both words and arithmetical facts from memory.

1.2. RAN and counting as a predictors of reading and arithmetic

The relation between RAN and reading fluency has been well established (e.g., Landerl & Wimmer, 2008; Norton & Wolf, 2012). For example, Wolf, Bowers, and Biddle (2000) suggested that reading and rapid serial naming share many cognitive and linguistic subprocesses, such as attentional, visual, perceptual, lexical, and rapid serial processing, which could explain the identified predictive relations. Similarly, it has been reported that verbal counting is a strong predictor of later arithmetic fluency (e.g., Koponen et al., 2007; Zhang et al., 2014). The ability to recite number words (i.e., counting forward and backward from a given number) is an essential skill for the development of later arithmetic skills, because the use of memory-based retrieval strategies is based on a preceding developmental stage where counting-based strategies are used (Barrouillet & Fayol, 1998).

Recent findings have suggested that RAN and counting are not skill-specific predictors for either reading or arithmetic but that RAN can predict arithmetic fluency and that counting can predict reading fluency. A recent study on RAN demonstrated that the RAN–math relationship was similar to RAN's relationship to reading, where pause time rather than articulation speed was the critical component (Georgiou et al., 2013). Thus, the retrieval process itself seems to be critical in relation to both reading and mathematics.

In contrast to the relation between RAN and reading fluency, the relation between counting and reading has been much less studied. Both counting and reading are serial processes requiring monitoring and holding information in one's memory while processing. One-by-one processing is a central feature in counting (1, 2, 3, 4…) as well as in the early developmental phase of reading (e.g., A-U-T-O). However, these skills become more automatized following practice with, for example, skip counting (2, 4, 6 or 5, 10, 15), and direct retrieval of verbal output corresponding to a letter sequence (recognizing syllables AU-TO or whole word AUTO) becomes possible. Leppänen's (2006) study was the first to report the predictive relation between counting and reading fluency. Leppänen suggested that working memory could be the common factor underlying the relation but did not examine the issue. Koponen et al. (2013) recently examined the relation between counting and reading fluency by controlling for phonological awareness and verbal short-term memory, but not working memory. They found that counting and RAN were strong predictors of both reading and arithmetic fluency even after controlling for phonological awareness and verbal short-term memory. However, their findings were based on a sample containing a substantial proportion (23.5%) of children with dyslexia, which could have influenced the identified predictive relations. Moreover, they did not examine whether the predictive role of counting was unique and how the controlling for other early number skills could have an effect on the results. Recent findings of the relation between linguistic and numerical skills with reading and arithmetic skills have revealed that quantity skills (magnitude comparisons) are significantly related to arithmetic skills but not to reading after linguistic skills are taken into account (Sowinski et al., 2015). This