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Time reading in middle and secondary school students: the influence of basic-numerical abilities

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Time reading in middle and secondary school students: The influence of basic-numerical abilities

Abstract

Time reading skills are central for the management of personal and professional life. However, little is known about the differential influence of basic numerical abilities on analog and digital time reading in general and in middle and secondary school students in particular. The present study investigated the influence of basic numerical skills separately for analog and digital time reading in $N = 709$ students from 5th to 8th grade. The present findings suggest that the development of time reading skills is not completed by the end of primary school. Results indicated that aspects of *magnitude manipulation* and *arithmetic fact knowledge* predicted analog time reading significantly over and above the influence of age. Furthermore, results showed that *spatial representations of number magnitude*, *magnitude manipulation*, *arithmetic fact knowledge*, and *conceptual knowledge* were significant predictors of digital time reading beyond general cognitive ability and sex. To the best of our knowledge, the present study is the first to show differential effects of basic numerical abilities on analog and digital time reading skills in middle and secondary school students. As time readings skills are crucial for everyday life, these results are highly relevant to better understand basic numerical processes underlying time reading.

198 words

Keywords: time reading, secondary school, mathematics, basic numerical abilities

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Introduction

The ability to tell the time constitutes a fundamental skill for everyday life. In a society that is determined by time, it is necessary to organize personal as well as professional activities (Bock, Irwin, Davidson, & Levelt, 2003; Friedman & Laycock, 1989). However, even though, time reading skills are taught during elementary school years, research on the development of time reading abilities and their association with basic numerical skills is still scarce. Yet, most studies did not define and/or differentiate time reading precisely with respect to analog or digital clock reading or mix it in a way that makes it difficult to differentiate analog and digital time reading [e.g., children first need to write down time shown on an analog clock face as spoken time (e.g., quarter to five) and then in a digital format (04:45)(Boulton-Lewis, Wills, & Mutch, 1997; Burny, 2012; Burny, Valcke, & Desoete, 2012; Burny, Valcke, Desoete, & Van Luit, 2013; Desoete, 2009). Thereby, the latter digital task highly depends on children's ability to read time from an analog clock and should, therefore, not be considered as a task only assessing digital time reading. Others focused on only one aspect of time reading (analog OR digital; e.g., Andersson, 2008; Labrell, Mikaeloff, Perdry, & Dellatolas, 2016). As a result of these inconsistencies with regard to the definition of time reading in previous research, studies on the differential effect of basic numerical skills on analog and digital time reading skills are missing. This is especially true for middle and secondary school students older than ten or eleven years, as it was assumed that the development of time reading skills is more or less completed by this age (e.g., Burny, Valcke, & Desoete, 2009; Levin & Gilat, 1983; Piaget, 1969; Siegler & Richards, 1979).

Early studies built on the assumption that learning to read the time is primarily a question of maturation (Levin & Gilat, 1983; Siegler & Richards, 1979). As a result,

researchers and educators suggested several age-related stages of time reading development. In particular, it was assumed that children can read analog and digital hour times at about the age of six, half hour times around the age of seven, five-minute times at the age of eight or nine and one-minute times at about the age of ten or eleven (e.g., Boulton-Lewis et al., 1997; Case, Sandieson, & Dennis, 1986; Friedman & Laycock, 1989; Siegler & McGilly, 1989). In western countries, this view found its way into the textbooks and, in consequence, into educational practice.

However, recent studies indicated that the development of time reading depends on the type of instruction (e.g., Burny et al., 2013; Monroe, Orme, & Erickson, 2002). For example, Burny et al. (2013) showed that Chinese children master analog time reading much earlier than Flemish children even though textbooks did not differ significantly. However, the Chinese curriculum introduces complex time reading such as telling five- or one-minute times much earlier. This indicates that children's time reading abilities are also influenced by the instruction they receive instead of mere maturation processes.

Nevertheless, learning to read time seems to be a difficult and tedious process (Foreman, Boyd-Davis, Moar, Korallo, & Chappell, 2008; Williams, 2004). Accordingly, teachers and students rate time reading as a difficult subject in primary education (e.g., Van Steenbrugge, Valcke, & Desoete, 2010). Moreover, analog clock reading was argued to be more difficult than digital time reading (e.g., Friedman & Laycock, 1989). Additionally, children with mathematical difficulties were found to experience specific problems in the acquisition of time reading skills (Andersson, 2008; Burny et al., 2012). And even some adults report struggling with simple time reading from analog clocks (e.g., transferring spoken times into written ones) and organizing everyday life with respect to time management (e.g., how long is a walk home and when do I have to leave; Desoete, 2009). This indicates that the development of time readings skills is not always completed by the age of eleven as suggested previously (e.g.,

Piaget, 1969).

Even though, research on factors influencing the development of time reading skills is still scarce, recent studies suggest that in primary school students time reading skills are strongly associated with mathematical abilities in general and basic numerical abilities in particular (e.g., Andersson, 2008; Burny, 2012; Burny et al., 2012; Cohen, Ricci, Kibby, & Edmonds, 2000; Friedman & Laycock, 1989; Williams, 2004). These basic numerical abilities are seen as the building blocks for later arithmetic and mathematical abilities and include, for instance, symbolic and non-symbolic numerical magnitude knowledge (e.g., Dehaene, Piazza, Pinel, & Cohen, 2003; Siegler, 2016; Siegler & Lortie-Forgues, 2014), spatial representations of numerical magnitude (e.g., Fischer & Shaki, 2014; Schneider, Grabner, & Paetsch, 2009), the acquisition of arithmetic fact knowledge (Dehaene et al., 2003) as well as procedural and conceptual numerical knowledge (e.g., Robinson, Dubé, & Beatch, 2017). These skills have been shown to be associated with current but also to predict future numerical and mathematical achievement in primary (e.g., Link, Nuerk, & Moeller, 2014; Moeller, Pixner, Zuber, Kaufmann, & Nuerk, 2011; Schneider et al., 2017; Schneider et al., 2009) as well as in secondary mathematics education (such as fraction or graph reading knowledge; e.g., Bailey, Siegler, & Geary, 2014; Hansen et al., 2015; Ludewig, Lambert, Dackermann, Scheiter, & Möller, 2019).

Regarding the association of time reading and basic numerical abilities, there is only limited research on primary school students so far. As one would expect considering the above mentioned findings, there is first empirical evidence that time reading is associated with the mastery of basic numerical, arithmetical, and visuo-spatial abilities (e.g., Andersson, 2008; Burny, 2012; Eden, Wood, & Stein, 2003; Friedman & Laycock, 1989; Williams, 2004). For instance, Burny (2012) observed that Flemish First- to Six graders time reading skills (assessed using a mixed tasks on analog and digital time reading) were strongly correlated with their

mathematical achievement in general. In addition, visuo-spatial abilities were a significant predictor of time readings skills above mathematical achievement. Furthermore, Friedman and Laycock (1989) showed that first graders primarily relied on counting strategies or basic arithmetic operations such as addition (especially on complex digital time reading) while older children used calculation approaches more often to tell time from both analog clock faces but also more complex digital clocks. The authors also found that children applied multistep operations to manipulate times indicating the involvement of procedural processing strategies. In sum, this is in line with evidence indicating that children rely on multiple strategies which seem similar to those necessary to solve mental arithmetic tasks such as retrieval as well as mental computation strategies (e.g., Boulton-Lewis et al., 1997; Burny, 2012; Eden et al., 2003; Friedman & Laycock, 1989).

However, there are still several open questions regarding the association between time reading and basic numerical abilities. First, all above mentioned studies focused on primary school students. To the best of our knowledge, there is currently no study on time reading skills in middle and secondary school students. Even though it is assumed that children should have mastered time reading by the age of ten or eleven, Desoete (2009) showed that even some adults still experience difficulties in time reading. Therefore, time reading skills might still be subject to development in middle and secondary school years. Second, all studies on the relation of basic numerical abilities or mathematical achievement and time reading considered rather global numerical and mathematical achievement measures which do not allow to differentiate the influence of specific basic numerical abilities such as magnitude manipulations, spatial representation of number magnitude, arithmetic fact knowledge or approximate calculation on time reading.

Therefore, the present study set off to investigate the differential effects of a more comprehensive battery of basic numerical abilities on time reading in middle and secondary school students to better understand the contributions of basic numerical abilities to the

acquisition of time reading skills. This is especially relevant for middle and secondary school students because due to the assumption that time reading skills are mastered by the end of primary school, studies on this age group are missing. Moreover, the present study is among the first to examine this influence using a comprehensive range of different basic numerical abilities instead of a global score of mathematical skills. We administered a broad battery of different basic numerical abilities which have been shown to be relevant for mathematical achievement and are commonly used to assess basic numerical abilities (e.g., Bailey et al., 2014; Dehaene et al., 2003; Fischer & Shaki, 2014; Hansen et al., 2015; Link et al., 2014; Moeller, Pixner, et al., 2011; Robinson et al., 2017; Schneider et al., 2009; Siegler & Lortie-Forgues, 2014). Furthermore, we considered both analog and digital time reading tasks to differentially determine the influence of basic numerical abilities on both aspects of time reading. Accordingly, we defined analog time reading as the skill to tell the time from an analog clock face and digital time reading as the skill to write down time given verbally (e.g., quarter after six) in digital notation (e.g., 6:15).

In line with previous research as described above, we expected basic numerical abilities to predict time reading in general significantly. In particular, addition (reflecting magnitude manipulation) and arithmetic fact knowledge (e.g., multiplication) were shown to be significant predictors of mathematical achievement in general (e.g., Geary, Nicholas, Li, & Sun, 2017; Jordan, Hanich, & Kaplan, 2003; Krajewski & Schneider, 2009; Träff, Skagerlund, Olsson, & Östergren, 2017) and digital time reading but also to a lesser extent analog time reading in particular (e.g., Friedman & Laycock, 1989). Even though studies are missing, it seems reasonable that subtraction skills also reflecting magnitude manipulation (e.g., Dehaene & Cohen, 1997) should also be a relevant predictor of time reading in general. To tell the time, children need to apply flexible strategies to manipulate numerical information. For instance, when telling one-minute times (e.g., 17:43), children may start at 17.50 and “subtract” the surplus minutes or start at 17:30 and then “add” the missing minutes. As this is relevant for

both analog and digital time reading, we expect to find associations with magnitude manipulation and arithmetic fact knowledge for both types of time readings tasks.

Moreover, above described studies indicate that time reading involves the representation of visuo-spatial aspects. This seems to be especially relevant for reading analog clocks as it has been assumed that time is spatially represented on a mental time line (e.g., Bachtold, Baumüller, & Brugger, 1998; Burny et al., 2009; Eden et al., 2003; Labrell et al., 2016).

Additionally, in a more explorative approach, we aimed at evaluating influences of other important basic numerical abilities such as non-symbolic magnitude representations, approximate calculation, basic geometry, and conceptual knowledge about arithmetic on time reading. As studies on the association of these abilities and time reading skills are missing, no explicit hypotheses can be drawn. However, both analog and digital time reading skills were repeatedly observed to be associated with mathematical achievement in general (e.g., Boulton-Lewis et al., 1997; Burny, 2012; Burny et al., 2012; Friedman & Laycock, 1989) and in turn, mathematical achievement is predicted significantly by non-symbolic magnitude representation, approximate calculation, conceptual knowledge and basic geometry (e.g., Bizzaro, Giofrè, Girelli, & Cornoldi, 2018; Bull, Marschark, Nordmann, Sapere, & Skene, 2018; Cowan et al., 2011; Halberda, Mazocco, & Feigenson, 2008; Hart et al., 2016; Lowrie, Logan, & Ramful, 2017), we expect that these basic numerical abilities may also be relevant for time reading. Non-symbolic magnitude understanding and approximate calculation are thought to represent a basic numerical intuition for quantification (Feigenson, Dehaene, & Spelke, 2004) associated with mathematical achievement (e.g., Halberda et al., 2008). When it comes to time reading, children also need to develop an intuitive understanding of numerical information conveyed by (non-symbolic) clock faces or numbers on a digital clock with respect to what time of day it is (e.g., morning or afternoon) or how long it is to the next full hour (e.g., quarter after or quarter to) to quickly apply strategies to identify the precise time. As this is

relevant for both analog and digital time reading skills, we expect non-symbolic magnitude understanding and approximate calculation to be relevant for both types of readings skills.

Furthermore, conceptual skills were found to help children to flexibly operate with principles, concepts and relationships of numbers and were thus observed to be relevant for mathematical achievement (e.g., Bailey, Hoard, Nugent, & Geary, 2012; Cowan et al., 2011; Kaufmann, Handl, & Thöny, 2003). As it was shown that time reading is a highly complex process of combining different strategies (e.g., Burny, 2012; Burny et al., 2009; Eden et al., 2003; Friedman & Laycock, 1989) especially in analog time reading but to a lesser extent also in digital time reading, we assume that proficient mastery of arithmetic concepts should also allow children to better apply these to other mathematical domains such as time reading.

Finally, we added a measure on basic geometry as a second index of visuospatial skills different and more complex than those represented by number line estimation. It has been shown beforehand that the spatial abilities involved in geometrical tasks influence mathematical achievement in general (e.g., Bizzaro et al., 2018; Lowrie et al., 2017). As analog time reading is particularly influenced by similar visuo-spatial abilities (e.g., Cohen et al., 2000), we expect basic geometry to be relevant for these tasks.

Taken together, the current study set off to evaluate the contributions of basic numerical abilities to time reading differentially for analog and digital clock faces. Therefore, we assessed participants on a broad battery of basic numerical abilities as well as analog and digital time reading. In line with previous results, we hypothesized that both analog as well as digital time reading should be predicted by basic numerical abilities reflecting magnitude manipulations (e.g., addition and subtraction) and spatial aspects of numerical representations (indexed by number line estimation). Beyond that, our approach was more explorative and we included measures of other basic numerical abilities that were observed to predict mathematics achievement more generally, which in turn is also associated with time reading (e.g., non-symbolic numerosity processing, conceptual knowledge, basic geometry, etc.) for the latter we

only had weaker assumptions on potentially positive associations with analog and digital time reading.

Methods

Participants

The current work presents a subset of a larger sample ($N = 1565$) which was assessed on a battery of basic numerical and curricular mathematical abilities with the aim of developing a differentiated math test for middle and secondary schools in Germany. Please note that in Germany, primary school ends with grade 4 and secondary school thus starts with grade 5, which may be considered middle school or junior high school in other school systems. In German secondary education, no systematic teaching on time reading is provided. The sample represented the regional distribution of types of schools in the state Baden-Württemberg.

To investigate time reading performance a total of 753 participants was considered for analysis. These participants included all students from grade 5 to grade 8, as performance in time reading remained constant after 8th grade. We excluded students with missing values on at least one of the considered variables (i.e., the tests on basic numerical abilities, age, sex, or general cognitive ability), resulting in a final sample of 709 students (5th grade $N = 144$, 6th grade $N = 150$, 7th grade $N = 200$, and 8th grade $N = 215$) for the analyses (age $M = 12.98$ years; $SD = 1.31$; 51.62 % females). To pursue our research question we used a statistical approach similar to Ludewig, Lambert, Dackermann, Scheiter, & Moeller (2019).

Measures

Time reading

To measure time reading abilities, we developed a test consisting of 10 items measuring the ability to read and write analog (i.e., 6 items) as well as digital time (i.e., 4 items). Analog and digital time reading were assessed on the five- and one-minute level. Additionally, children

had to report hours and minutes separately on a 24h hour scale as it is common in Germany. For this, tasks included information on the respective time of the day (e.g., morning, afternoon, night). The time limit for this task was 2 minutes. Correct responses were scored with one point each for hours and minutes so that the maximum achievable score was 12 points for analog and 8 points for digital time reading.

Basic Numerical Abilities

A comprehensive battery of basic numerical abilities was administered including eight subtests: i) addition, ii) subtraction, iii) multiplication, iv) number line estimation, v) arithmetic estimation, vi) conceptual knowledge about arithmetic, vii) non-symbolic magnitude comparison, and viii) basic geometry. All subtests were speeded to assess the level of automatization. Furthermore, all subtests only addressed numerical/mathematical abilities of primary school curriculum and examples to ensure task understanding. Unless indicated differently, correctly solved items were considered as sum scores for analyses.

i and ii) Magnitude manipulations: In two subscales, participants had to solve 36 addition and subtraction problems each, ordered in increasing difficulty. Addition and subtraction problems covered numbers ranging up to 10,000. For each operation, students had to solve as many problems as possible within 2 minutes. Basic arithmetic operations like addition and subtraction are considered to reflect magnitude manipulation (e.g., Ashcraft, 1982).

iii) Arithmetic fact knowledge: To assess arithmetic fact knowledge participants had to solve as many multiplication problems as possible within a time limit of again 2 minutes. The 36 multiplication problems covered problems with single-digit (19 problems), two-digit (15 problems) and three-digit operands (2 problems) presented in ascending order according to difficulty. Arithmetic fact knowledge was repeatedly found an essential predictor of mathematical achievement (e.g., Butterworth, 2005; Jordan & Hanich, 2003).

iv) *Spatial representation of number magnitude*: In a number line estimation task, students had to estimate the correct location of a given target number on a number line. Only the endpoints of the number line were defined (e.g., estimate the location of 64 on a number line ranging from 0 to 100). In total, the task included 24 items on number lines with changing endpoints (i.e., 6 items on a number line from 0 to 10 and 0 to 100, respectively, and 4 items on a number line from 0 to 1.000, 0 to 10.000 and 0 to 100.000, respectively). Time limit for this task was 1.5 minutes. The mean absolute estimation accuracy in percent served as predictor variable. This task is widely used to assess spatial aspects of number magnitude (e.g., Siegler & Opfer, 2003).

v) *Approximate calculation*: In this task, students were presented a problem with two different incorrect solution probes and had to estimate and choose the probe being closer to the correct result (e.g., “Which result is closer to $347 - 120$? solution probes: 215 or 260”). 16 addition and 16 subtraction problems were presented. Difficulty level increased with item number due to increasing problem sizes. Students had 2 minutes to solve as many problems as possible. Approximate calculation is a well-known predictor of exact arithmetic (Barth et al., 2006).

vi) *Conceptual knowledge*: In this task, students were shown two problems of which the first problem was presented with a solution. They had to decide whether knowing the solution of the first problem helps them to solve the second problem without having to calculate (e.g., “Does $4 + 8 = 12$ help you to solve $12 - 4 = \underline{\quad}$?”). 40 pairs of arithmetic problems including addition, subtraction, multiplication and division were presented. These included simple adaptations within the same arithmetic task (e.g., $628 + 253 = 881 \rightarrow 628 + 254 = \underline{\quad}$?) as well as inversions representing the relationships of the four basic arithmetic operations (e.g., $27 * 5 = 135 \rightarrow 135 : 27 = \underline{\quad}$?). Students were instructed to solve as many problems as possible within 2 minutes. The conceptual knowledge test thus reflects the understanding of principles,

concepts and relationships of numbers which is important for mathematics achievement (e.g., Barr, Doyle, Clifford, De Leo, & Dubeau, 2003; Rittle-Johnson & Alibali, 1999).

vii) *Non-symbolic magnitude understanding*: 24 pairs of dot clouds (ranging from 30 to 69 elements) were shown and students had to decide which of the two dot clouds was numerically larger. Dot clouds were matched for overall surface to prevent children from using strategies based on perceptual features: for half of the items the surface with the lower quantity of dots was larger and for the other half the surface with the higher quantity of dots was larger. In order to avoid counting-based strategies, the time limit for this task was 1 minute. We used this task to assess the approximate number system (ANS) which is argued to be crucial for the development of more sophisticated numerical skills like basic arithmetic (e.g., Feigenson et al., 2004).

viii) *Basic geometry*: Students had to solve 12 mirror image problems. For this, a flipped geometrical form had to be drawn by mirroring it on a presented axis. For each correct line in the drawing, students were given one point. The percentage of correctly solved items served as predictor variable. Basic geometry is one 10 basic abilities specified by the National Council of Supervisors in Mathematics (NCSM) in 1976 (e.g., Denmark & Kepner, 1980) as it has crucial applications for everyday life problems (e.g., Sherard, 1981). However, geometry is assessed only seldom when evaluating basic numerical abilities.

General cognitive ability

Students' general cognitive ability was assessed using two subtests of the German version of the Culture Fair Intelligence Scale 20-revision (i.e., continuation of sequences and completion of matrices; CFT 20-R (Weiß, 2006)). Both subtests assess pattern recognition abilities. Subtests were administered as stated in the manual.

Procedure

All tests were administered as paper-pencil measures during regular school hours in the students' classrooms. Testing took a maximum of 90 minutes with students being tested in groups reflecting the respective classroom constellations. First, students had to complete the test battery on basic numerical abilities in the following order: addition, subtraction, multiplication, number line estimation, approximate calculation, conceptual knowledge, non-symbolic magnitude comparison, and basic geometry. After a short break, time reading skills and, finally, general cognitive ability was assessed. All students were below the age of 18 and therefore parents received information about the study and provided written informed consent prior to testing. The study was approved by regional school authorities.

Statistical Analyses

Preliminary Analysis

To investigate whether time reading differed for reading analog or digital clocks we ran a linear mixed effects model evaluating the potentially differential relationship of time reading (analog vs. digital) with basic numerical abilities, age and sex. Therefore, we defined all interactions of basic numerical abilities, age and sex with time reading as fixed effects and included a random intercept for subjects to account for individual variability.

The linear mixed effect model was fitted using 'lmer' from the "lme4" R package (Bates, Mächler, Bolker, & Walker, 2014). To provide *p*-values we used the 'summary' function of the "lmerTest" R package (Kuznetsova, Brockhoff, & Christensen, 2015). Additionally, summary statistics were also extracted via the 'analyze' function of "psycho" R package (Makowski, 2018).

The overall model predicting differences in performance on the two time reading scales (analog vs. digital) explained a significant proportion of variance ($R^2 = 47.89\%$, in which the fixed effects explained $R^2 = 33.96\%$ of the variance). As indicated by significant interactions specific basic numerical abilities, general cognitive abilities, and age were associated

differentially with performance on the two time reading scales. In particular, the interaction between time reading and spatial representation of number magnitude was significant [$\beta = 0.04$, $SE = 0.01$, $t(709) = 5.67$, $p < 0.001$, $VIF = 2.42$; see Appendix Fig. A1A] indicating that the influence of spatial representation of number magnitude was more pronounced for digital time reading as compared to analog time reading. Furthermore, the interaction between time reading and conceptual knowledge also was significant [$\beta = 0.06$, $SE = 0.02$, $t(709) = 3.24$, $p < 0.01$, $VIF = 2.53$; see Appendix Fig. A1B]. This reflected that the influence of conceptual knowledge was more pronounced for digital time reading as compared to analog time reading. Beyond differential effects for basic numerical abilities, the interaction between time reading and general cognitive ability also was significant [$\beta = 0.06$, $SE = 0.03$, $t(709) = 2.26$, $p < 0.05$, $VIF = 2.37$; see Appendix Fig. A2A] revealing that the influence of general cognitive abilities was more pronounced for digital time reading compared to analog time reading. Finally, the interaction between time reading and age also was significant [$\beta = -2.69$, $SE = 1.03$, $t(709) = -2.61$, $p < 0.01$, $VIF = 1.77$; see Appendix Fig. A2B] revealing that the influence of age was more pronounced for analog time reading compared to digital time reading.

These results clearly indicate that specific basic numerical abilities (as well as age and general cognitive abilities) seemed to have differential associations with the two time reading scales. Therefore, we conducted separate multiple regression and relative weight analyses for analog and digital time reading scales to evaluate relevant basic numerical predictors of analog and digital time reading, respectively.

Multiple regression

Accordingly, we conducted two separate multiple regression analyses to determine the influence of the measured basic numerical predictors on analog time reading as well as on digital time reading, respectively. We considered 11 predictor variables in the multiple regression and relative weight analyses. These included the eight basic numerical abilities assessed (i.e., non-symbolic magnitude understanding, spatial representation of number

magnitude, approximate calculation, magnitude manipulations (i.e., addition and subtraction), arithmetic fact knowledge, conceptual knowledge, and basic geometry) as well as general cognitive ability, age and sex. All continuous variables were centered, age was log transformed as it was not normally distributed and sex was effect coded (i.e., female = -1, male = 1) prior to analyses.

In preliminary analyses, we also incorporated interaction terms of age and sex with general cognitive ability and the eight basic numerical abilities as predictor variables (i.e., 29 predictor variables). However, as none of these interaction predictors turned out to be significant (all $b < 0.09$, all $p > .12$), we did not consider them for our final regression models.

We used False Discovery Rate (FDR) controlling the p -value for multiple testing (Benjamini & Hochberg, 1995).

Relative weight analysis

Determining the relative contribution of each predictor to the explained variance is usually difficult because predictor variables are typically correlated with one another. Therefore, in a final step, we used relative weight analysis as suggested by Johnson (2000) to quantify the relative importance of the correlated predictor variables from the multiple regression analyses. Relative weight analysis determines which variables contribute the most regarding explained variance in terms of R^2 . For this, the 11 predictor variables were transformed into a set of orthogonal variables in a way that they are maximally related to the original predictors. The resulting relative weights represent the predictors' additive decomposition of the total model R^2 . There are two measures of relative weight: raw relative weight and rescaled relative weight. Raw relative weights add up to the R^2 of the model while rescaled relative weights add up to 100% representing the relative importance of a particular variable in the final regression model. Relative weights can be understood as the share of explained variance to which each predictor variable can be appropriately assigned (Tonidandel & LeBreton, 2015). We performed separate

relative weight analyses to identify significance of relative weights for analog time reading and digital time reading using the procedure described by (Tonidandel, Lebreton, & Johnson, 2009).

Statistical software

Statistical analyses were performed with R (R Core Team, 2017). For the multiple regression analyses, we used the ‘lm’ function for fitting linear models of the standard R package “state” (R Core Team, 2017). Additionally, we used the ‘p.adjust’ function with the ‘fdr’ method to adjust p -values. For the relative weights analysis, we applied the syntax provided by (Tonidandel & LeBreton, 2015).

Results

Descriptive Statistics

The mean *analog* time reading score was $M = 5.43$ ($SD = 2.34$, obtained range = 0-11) of 12 possible points. The mean *digital* time reading score was $M = 4.59$ ($SD = 2.90$, obtained range = 0-8) of 8 possible points. Descriptive statistics for all predictor variables are shown in Table 1. For a detailed table of descriptive statistics separated by grades (i.e., 5th grade to 8th grade, including mean ages for each grade level) see Appendix A.

Insert Table 1 about here.

The correlation matrix depicted in Table 2 indicates that all variables apart from sex were significantly correlated with performance in the analog as well as the digital time reading task. Sex was not correlated significantly with performance on addition, arithmetic fact knowledge, basic geometry, non-symbolic magnitude comparison, and general cognitive

ability. Additionally, age was not significantly correlated with arithmetic fact knowledge, general cognitive ability and sex. About 59% of correlations were below $r = .30$.

Insert Table 2 about here.

Multiple regression analyses

The regression model for *analog time reading* explained 22% of the variance [$R^2 = .22$, $adj. R^2 = .20$, $F(11, 697) = 17.40$, $p < .001$]. Three variables significantly predicted performance in the analog time reading test: magnitude manipulation as reflected by addition, age, and arithmetic fact knowledge (see Table 3). Closer inspection of the beta weights indicated that higher age and for both basic numerical predictors better performance was associated with better performance on the analog time reading test.

The regression model for *digital time reading* explained 39% of the variance [$R^2 = .39$, $adj. R^2 = .38$, $F(11, 697) = 40.79$, $p < .001$] with six variables significantly predicting performance: i) spatial representation of number magnitude, ii) conceptual knowledge, iii) arithmetic fact knowledge, iv) magnitude manipulation as reflected by subtraction, v) general cognitive ability, and vi) sex (see Table 4). Closer inspection of the respective beta weights indicated that better performance on the basic numerical predictors was associated with better performance on the digital time reading test. Additionally, girls were found to perform better than boys.

Relative weight analyses

In line with the results of the multiple regression analysis, those of the relative weight analysis for analog time reading (see Table 3) point to magnitude manipulation as reflected by addition with a rescaled relative weight of about 19% to be the best predictor of analog time reading performance. This was followed by contributions of age (17%), magnitude manipulation as reflected by subtraction (about 17%), arithmetic fact knowledge (16%), basic

geometry (8%), approximate calculation (7%), conceptual knowledge, and general cognitive ability (both about 6%, respectively).

Although subtraction, basic geometry, approximate calculation, conceptual knowledge and general cognitive ability were not found to be significant predictors in the multiple regression analysis, relative weight analysis revealed significant rescaled relative weights for these predictors. This indicates that these basic numerical abilities may also be relevant for analog time reading.

The predictors spatial representation of numerical magnitude, sex and non-symbolic magnitude understanding had only small rescaled relative weights indicating that their contribution to performance in analog time reading may not be as relevant.

Again, in line with the results of the multiple regression analysis, the relative weight analysis for digital time reading (see Table 4) indicated spatial representation of numerical magnitude to be the best predictor of digital time reading with a rescaled relative weight of 19%. This was followed by contributions of conceptual knowledge (about 16%), arithmetic fact knowledge (14%), magnitude manipulations as reflected by subtraction (13%) and addition (11%), general cognitive ability (10%), approximate calculation (about 7%), and basic geometry (5%). Interestingly, sex was a significant predictor in the multiple regression analysis but not in the relative weight analysis. This indicates that for this particular model the contribution of sex does not explain variance better than a random variable.

Although addition, approximate calculation, and basic geometry were not found to be significant predictors in the multiple regression analysis, relative weight analysis indicated significant rescaled relative weights for these predictors. This implies that these basic numerical abilities may also be relevant for digital time reading.

The predictors sex and non-symbolic magnitude understanding had only small rescaled relative weights. Therefore, their importance for performance in digital time reading may not be as relevant.

Insert Table 3 about here.

Insert Table 4 about here.

Discussion

The purpose of the current study was to investigate the influence of basic numerical abilities on analog and digital time readings skills in middle and secondary school students. Previous studies mainly focused on children in primary education as it was assumed that children master time reading by the age of ten or eleven. However, research on children and adults with mathematical learning difficulties suggested that these skills undergo further development (Burny et al., 2012; Desoete, 2009). Therefore, research on the influence of basic numerical skills on time reading in general and time reading on analog and digital clocks in particular in middle and secondary school is still rather scarce. There is first evidence that in primary school age, mastery of basic numerical, arithmetical, and visuo-spatial abilities are associated with time reading (e.g., Andersson, 2008; Burny, 2012; Friedman & Laycock, 1989; Williams, 2004). However, research on the differential influences i) of a more comprehensive set of basic numerical abilities (i.e., also including basic geometry or arithmetic fact knowledge) ii) on analog and digital time reading in middle and secondary school children is missing. In the following, we first present the overall findings on the influence of basic numerical skills on analog and digital time reading before we discuss findings specifically.

The results of the present study substantiated that time reading skills for analog as well as digital clocks develop further after the age of ten or eleven as children's time reading performance for both clock types increased with age in our middle and secondary school sample (i.e., from grade five to grade eight). On the one hand, this might indicate that time reading is not yet fully mastered by age ten or eleven. Second, these findings may also point to an increase

in familiarity and automation in time reading as has been found in other mathematical domains (e.g., Moeller, Klein, & Nuerk, 2011). Further studies on time reading skills in secondary education are needed for deepening our understanding of the nature of the development of time reading skills after primary school.

In line with previous studies, results also indicated that basic numerical abilities were associated significantly with analog as well as digital time reading skills (e.g., Andersson, 2008; Burny, 2012; Burny et al., 2012; Friedman & Laycock, 1989; Williams, 2004). However, we evaluated the differential influence of a more comprehensive set of basic numerical abilities on time reading in a three-step approach: First, in a preliminary analysis we evaluated whether basic numerical abilities were associated differentially with analog and digital time reading. This analysis indicated that the effects of spatial representation of magnitude and conceptual knowledge were more pronounced for digital as compared to analog time reading (as was the effect of general cognitive ability). In contrast, the effect of age was more pronounced for analog than digital time reading. These results clearly indicate differential influences of some basic numerical abilities on the two time reading scales. Therefore, in a second step, we performed separate multiple regression analyses for analog and digital time reading skills to evaluate respective relevant basic numerical predictors. In a final step we investigated the relative importance of these predictors on both time reading scales by conducting separate relative weight analyses for analog and digital time reading.

For analog time reading multiple regression and relative weight analysis consistently revealed that magnitude manipulations (as indicated by *addition*), *age* and arithmetic fact knowledge (operationalized by a *multiplication* task) were relevant predictors. Moreover, magnitude manipulations (as reflected by *subtraction*), *basic geometry*, *approximate calculation*, *conceptual knowledge*, and *general cognitive ability* also contributed to explained variance and were observed to be relevant predictors in the relative weight but not in the multiple regression analysis. *Spatial representations of numerical magnitude*, *sex* and *non-*

symbolic magnitude understanding were not observed to be relevant predictors of analog time reading.

For digital time reading multiple regression and relative weight analysis consistently indicated that spatial representations of number magnitude (as reflected in *number line estimation*), *conceptual knowledge*, arithmetic fact knowledge (operationalized by a *multiplication* task), magnitude manipulations (as indicated by *subtraction*), *general cognitive ability* and *sex* were relevant predictors. Magnitude manipulations (as assessed by *addition*), *approximate calculation* and *basic geometry* also contributed to explained variance and turned out as predictors in the relative weight analysis but not in the multiple regression analysis. *Age* and *non-symbolic magnitude understanding* were not observed to be relevant predictors of digital time reading. Interestingly, *sex* was a significant predictor in the multiple regression analysis for digital time reading but not in the relative weight analysis. This indicates that the contribution of *sex* did not explain more variance than a random variable in the relative weight analysis and therefore should not be considered as relevant predictor for digital time reading.

These findings are in line with previous studies on the role of basic numerical abilities on more sophisticated mathematical skills (e.g., Geary, 2011; Sasanguie, De Smedt, Defever, & Reynvoet, 2012). However, to the best of our knowledge this study is the first to provide a differential picture of the influences of basic numerical abilities on analog and digital time reading skills in middle and secondary school students up to grade 8. As argued in the introduction we expected that more different basic numerical predictors should be observed relevant for digital time reading as compared to analog time reading, as digital time is presented using numbers only and may thus be associated more closely with other basic numerical abilities.

In the following, we will discuss these results elaborating on the relevant basic numerical abilities in turn as this allows for direct evaluation of similarities and differences in

the relevance of basic numerical abilities as predictors for analog and digital time reading (for an overview on significant predictors see Table 5).

Insert Table 5 about here.

Analog time reading skills

The most relevant predictor of analog time reading was *magnitude manipulation* (as reflected by addition). This is in line with previous studies which reported that children commonly use addition-based strategies to move around analog clock faces in steps of five- and/or one- minute increments to determine minute values (e.g., Case et al., 1986; Friedman & Laycock, 1989). Similar to this, Siegler and McGilly (1989) described strategies like moving backwards by steps of five and one minute(s) reflecting subtraction as found as a relevant predictor in the relative weight analysis. Taken together, this indicates that middle and secondary school children also seemed to rely on strategies based on magnitude manipulation such as addition and subtraction to navigate on the analog clock face. Additionally, in accordance with previous studies on time reading skills, *arithmetic fact knowledge* (multiplication; e.g., Case et al., 1986; Friedman & Laycock, 1989; Siegler & McGilly, 1989) was also a relevant predictor of analog time reading. This seems plausible as time reading requires specific fact knowledge such as knowledge about the 12-hour clock and the 24-hour clock counterparts or the distribution of the numbers of the 60 minutes scale of the minute hand including the division in four quarters (cf. Burny, 2012).

Finally, age was identified an important predictor of analog time reading (but not digital time reading), reflecting that higher age was associated with better performance. This finding is partly in line with previous studies showing that performance in analog time reading and understanding increases with experience and thus by grade level and age (e.g., Friedman & Laycock, 1989). However, one might also argue that this finding is somewhat contradictory as

time reading skills have been suggested to be mastered by the age of around 11 what would correspond to the age of German grade 5 students (e.g., Burny, 2012; Friedman & Laycock, 1989; Williams, 2004). As such, age should no longer be a relevant predictor of analog time reading in the age group investigated in the current study. In this context, the present findings might indicate that analog time reading may be more complex than assumed so far and that the ability to read analog clock faces further develops even after formal instruction on it ends by the end of primary school. Similar to other domains of mathematical learning (e.g., addition of two-digit numbers; Moeller, Klein, et al., 2011)), it seems reasonable that analog time reading skills are subject to a process of maturation and automation in secondary education while the development of simple digital time reading may be completed much earlier.

Furthermore, it is important to note that beyond above described influences of the significant predictors of analog time reading in the regression analysis, *magnitude manipulations* (as assessed by subtraction), *basic geometry*, *approximate calculation*, *conceptual knowledge* and *general cognitive ability* were identified as further relevant predictors in the relative weight analysis. The lack of significance in the multiple regression analysis may be explained by their high correlation with other significant predictors and therefore their shared variance with these predictors. For instance, subtraction was highly correlated with addition, basic geometry was correlated with both approximate calculation and subtraction. Approximate calculation was highly correlated with subtraction and number line estimation and so on (see table 2 for details). Nevertheless, based on the results of the relative weight analysis, these predictors should also be considered in future studies on analog time reading.

Digital time reading

The most relevant predictor for digital time reading was spatial representation of number magnitude (as reflected by number line estimation). This was unexpected as we assumed this

predictor to be of particular importance for analog time reading. However, number line estimation is also argued to provide a spatialized measure of children's number magnitude understanding (e.g., Siegler & Opfer, 2003) and through this an important predictor of mathematical achievement more generally (e.g., Ashcraft & Moore, 2012; Booth & Siegler, 2006; Burny, 2012; Fazio, Bailey, Thompson, & Siegler, 2014; Geary, 2011; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Schneider et al., 2009).

At the same time, digital time reading was found to be predicted by number magnitude processing in the current and previous studies (e.g., Burny, 2012; Burny et al., 2012; Friedman & Laycock, 1989). Moreover, the relevance of a spatial representation of number magnitude seems reasonable according to the idea of a mental time line (e.g., Bonato, Zorzi, & Umiltà, 2012) representing time spatially similarly as the mental number line does for number magnitude (e.g., Arzy, Adi-Japha, & Blanke, 2009; Dehaene et al., 2003; e.g., Restle, 1970). The fact that spatial representation of number magnitude was not observed to be a relevant predictor for analog time reading may be driven by the actual spatial layout of the number line task, in which numbers have to be positioned with magnitudes increasing from left to right. In contrast, on an analog clock face, larger numbers are found on the left side and smaller numbers on the right, which was previously observed to override typical left-to-right oriented spatial-numerical associations (Bächtold, Baumüller, & Brugger, 1998).

Furthermore, this might particularly apply to the specific age group of the present study. As outlined above, analog and digital time reading skills are assumed to be mastered by the age of around 11 (Friedman & Laycock, 1989). As such, it might be possible that the ability to spatially represent numbers on a number line is more relevant to analog time reading in children who are currently learning to master the analog clock face. This would be the case during elementary school years up to grade four or five. While still learning analog time reading, children might rely on their mental number line more often to orientate on the analog clock face. With maturation and automation of reading analog time, magnitude manipulation

strategies might become more efficient for analog time reading which in turn may reduce influences of spatial representations of numbers as assessed by number line estimation.

Moreover, number line estimation is a good predictor of number magnitude understanding (e.g., Siegler & Opfer, 2003) and manipulation more generally (see Schneider, Thompson, & Rittle-Johnson, 2018 for a review), and as a consequence, of digital time readings skills. In the present study, the digital time reading task required the students to “produce” a digital time based on verbal expressions of time (e.g., quarter after six), which also required operating on the magnitude of the respective numbers. As a result, the number line estimation task might have represented this aspect more strongly in this age group.

Moreover, students’ *conceptual knowledge* of numerical concepts and procedures was a significant predictor of digital time reading. Conceptual knowledge reflects the understanding of principles, concepts and relationships of numbers (Barr et al., 2003; Rittle-Johnson & Alibali, 1999). With respect to digital time reading, this finding might indicate that students with a better ability to apply numerical concepts and procedures are also better in integrating hours and minutes on the production of digital times based on spoken times more easily.

Furthermore, arithmetic fact knowledge was also a significant predictor for digital time reading. As mentioned above digital time reading is highly associated with reading and therefore retrieving number names. Arithmetic fact knowledge (e.g., De Visscher & Noël, 2014; De Visscher, Noel, & De Smedt, 2016) is a relevant predictor for mathematics achievement in general. As such, children who store and retrieve arithmetic facts more proficiently also seemed to master time reading on digital as well as analog (see above) clocks better.

Additionally, *magnitude manipulation* (as assessed by subtraction and addition in the relative weight analysis) was also found to be a significant predictor of digital time reading. As already discussed above this indicates that processes of magnitude manipulation play also an important role in digital time reading as especially subtraction is assumed to be the arithmetic

operation relying most on this process (e.g., Berteletti, Man, & Booth, 2015; Linsen, Verschaffel, Reynvoet, & De Smedt, 2014; Linsen, Verschaffel, Reynvoet, & De Smedt, 2015). Moreover, Friedmann & Laycock (1989) concluded that digital clocks lead children to use numerical calculation strategies like adding or incrementing decades. Even though the time reading tasks of the present study did not involve direct calculations, it can be assumed that children relied on strategies involving magnitude manipulations such as moving forth and back in time.

Importantly, above described influences of basic numerical abilities on digital time reading were significant over and above the also significant influence of *general cognitive ability*. In particular, reasoning processes, which were assessed by the task applied to assess general cognitive ability, are considered crucial for developing a profound understanding of time (e.g., Long & Kamii, 2001). Therefore, the observed influence of general cognitive ability on time reading seems reasonable.

Finally, *sex* was a significant predictor in the multiple regression analysis with girls performing better in the digital time reading than boys. Previous studies showed that females are more successful in applying learned arithmetic procedures than males (e.g., Gallagher, 1998; Gallagher et al., 2000; Kessel & Linn, 1996). As digital time reading requires successful application of arithmetic procedures and strategies it seems plausible that females may perform better than males on this task. However, *sex* was not a significant predictor in the relative weight analysis and thus, the relevance of *sex* for digital time reading should be regarded carefully.

Furthermore, it is important to note that beyond above described influences of the significant predictors of digital time reading in the regression analysis, *approximate calculation*, *magnitude manipulations* (as assessed by addition) and *basic geometry* were identified as additional relevant predictors in the relative weight analysis. Again, the lack of significance in the multiple regression analysis may be explained by their high correlation with other significant predictors and therefore their shared variance with these predictors as already

described above. Nevertheless, based on the results of the relative weight analysis, these three predictors should be considered in future studies especially on younger age groups as the present findings suggest that they may be relevant for digital time reading. Because these basic numerical abilities as well as time reading skills develop considerably during elementary school years, it might be that the influence of approximate calculation, magnitude manipulation and basic geometry on time reading skills is more pronounced in this particular age group.

Limitations and Perspectives

In summary, we observed that middle and secondary school students' analog as well as digital time reading was predicted significantly by several basic numerical abilities which have previously been shown to be associated with other more sophisticated mathematical domains such as word-problem solving (e.g., Fuchs et al., 2006; Fuchs et al., 2009; Swanson, Lussier, & Orosco, 2015), graph reading (e.g., Ludewig et al., 2019), or fraction knowledge (e.g., Bailey et al., 2014; Hansen et al., 2015) in general, and time reading in particular (e.g., Burny, 2012).

However, when interpreting the present findings some limitations of the study need to be considered. First, the data underlying the present study are cross-sectional. Therefore, the present findings are correlational and do not allow firm conclusions about the nature of the observed associations. Nevertheless, based on previous findings on the longitudinal impact of basic numerical abilities on mathematical achievement (e.g., Hirsch, Lambert, Coppens, & Moeller, 2018), the present data suggest that analog and digital time reading draw significantly on basic numerical abilities. Yet, longitudinal studies on the role of basic numerical skills on the development of time reading skills are needed and should also include primary school years to evaluate the development of analog and digital time reading comprehensively.

In this context, it is important to note that formal instruction on time reading usually ends with primary school when students are assumed to have mastered the concept of time and time measurement. Thus, the significant influence of age observed in the current study does

not reflect an effect of schooling. Including younger students, especially in longitudinally studies, would provide us with additional information about the development of time reading and the role of basic numerical abilities in this development.

Moreover, it should be considered that the tasks used to assess time reading did not include any calculations with time. The results are therefore limited to analog and digital time reading in terms of telling the time and can thus not be generalized to dealing and calculating with as well as measuring time intervals. The latter is thought to be much more complex and even difficult for adults (Burny, 2012; Desoete, 2009). Therefore, one might speculate that the differential influences of basic numerical abilities might be different when students are expected to actually manipulate, this means calculate with time intervals. In consequence, future studies should also consider calculation with times and time intervals.

Despite these limitations, the present study is among the first to show that time reading skills still develop in middle and secondary school when formal instruction on the topic already ended. Additionally, our results indicated that a differential evaluation of influences of basic numerical skills can provide us with more detailed information about numerical processes underlying analog time reading (e.g., magnitude manipulation and arithmetic fact knowledge) as well as digital time reading (e.g., spatial representation of number magnitude, conceptual knowledge, arithmetic fact knowledge, and magnitude manipulation). This is especially relevant when supporting students and adults who still struggle with either analog or digital time reading. As the lack of this ability poses a severe obstacle for several everyday situations such as planning appointments, meetings, and thus time management in personal and professional life more broadly, better understanding of the mechanisms and processes underlying (the development of) analog and digital time reading should receive much more attention in future research on children's numerical development.

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Tables**TABLE 1:** Descriptive Statistics and obtained range of all measures (N = 709).

	<i>M</i>	<i>SD</i>	<i>Range</i>
Magnitude manipulation: addition	18.70	4.17	4 - 31
Magnitude manipulation: subtraction	15.02	4.61	1 - 29
Arithmetic fact knowledge	20.34	4.68	5 - 29
Spatial representation (% correct)	74.88	18.44	9.72 - 97.14
Approximate calculation	17.83	5.24	0 - 32
Conceptual knowledge	16.15	6.33	1 - 32
Basic geometry (% correct)	52.83	20.21	0.00 - 96.53
Non-symbolic magnitude understanding	18.35	3.27	0 - 24
General cognitive ability	17.46	4.45	3 - 28

TABLE 2: Correlations between analog time reading, digital time reading, basic numerical abilities, general cognitive ability, as well as sex and age.

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Time reading: analog	1											
2. Time reading: digital	.40**	1										
3. Magnitude Manipulation: addition	.37**	.45**	1									
4. Magnitude Manipulation: subtraction	.37**	.47**	.74**	1								
5. Arithmetic fact knowledge	.34**	.45**	.62**	.62**	1							
6. Spatial representation of numerical magnitude (%)	.18**	.44**	.34**	.37**	.31**	1						
7. Approximate calculation	.26**	.37**	.48**	.51**	.35**	.50**	1					
8. Conceptual knowledge	.25**	.44**	.42**	.38**	.34**	.41**	.48**	1				
9. Basic geometry	.24**	.29**	.27**	.35**	.30**	.22**	.16**	.24**	1			
10. Non-symbolic magnitude understanding	.08*	.14**	.13**	.19**	.16**	.20**	.18**	.15**	.19**	1		
11. General cognitive ability	.22**	.36**	.35**	.41**	.33**	.23**	.20**	.27**	.45**	.22**	1	
12. SexEff ^a	-.02	-.07	.02	.11**	-.02	.09*	.11**	-.11**	-.05	-.03	-.06	1
13. Log(age)	.23**	.15**	.11**	.09*	.07	.15**	.21**	.19**	.09*	.08*	.06	-.02

Note: ** $p < .01$, * $p < .05$. $N = 709$. ^aCode female = -1, male = 1

TABLE 3: Results of multiple regression [Criteria = Time reading: analog, $R^2 = .22$, $adj. R^2 = .20$, $F(11,697) = 17.40$, $p < .001$] and relative weights analyses.

	<i>B</i>	β	[<i>L-CI</i> , <i>U-CI</i>]	<i>RW</i>	<i>t</i>	<i>p</i>	<i>RS-RW</i> (%)
Intercept	5.43	.00	[-.07, .07]	.00	69.22	.000	0
Magnitude Manipulation: addition	0.08	.14	[.03, .24]	.04	2.50	.038	18.82*
Log(age)	4.13	.18	[.11, .25]	.04	5.23	.000	17.46*
Magnitude Manipulation: subtraction	0.06	.12	[.00, .23]	.04	2.04	.084	16.89*
Arithmetic fact knowledge	0.06	.13	[.03, .21]	.04	2.54	.038	16.33*
Basic geometry (%)	0.01	.08	[.01, .16]	.02	2.17	.074	8.40*
Approximate calculation	0.02	.04	[-.05, .13]	.02	0.95	.541	7.29*
Conceptual knowledge	0.01	.03	[-.05, .12]	.01	0.83	.541	6.22*
General cognitive ability	0.02	.04	[-.04, .11]	.01	0.88	.541	5.64*
Spatial representation of numerical magnitude (%)	0.00	-.02	[-.1, .06]	.00	-0.58	.727	2.26
Sex ^a	-0.05	-.02	[-.09, .05]	.00	-0.66	.557	0.38
Non-symbolic magnitude understanding.	-0.02	-.03	[-.1, .04]	.00	-0.74	.555	0.33

Note: *B*: unstandardized regression weight; β : standardized regression weight; *L-CI*: lower boundary (2.5%); *U-CI*: upper boundary (97.5%); *RW*: raw relative weight (within rounding error raw weights will sum to R^2); *t*: t-value measures the size of the effect relative to the variation in sample data; *p*: p-value; *RS-RW*: relative weight rescaled as a percentage of predicted variance in the criterion variable attributed to each predictor (within rounding error rescaled weights sum to 100 %). ^a code female = -1, male = 1. * significantly different from a random variable.

TABLE 4: Results of multiple regression [Criteria = Time reading: digital, $R^2 = .39$, $adj. R^2 = .38$, $F(11,697) = 40.79$, $p < .001$] and relative weights analyses.

	<i>B</i>	β	[<i>L-CI</i> , <i>U-CI</i>]	<i>RW</i>	<i>t</i>	<i>p</i>	<i>RS-RW</i> (%)
Intercept	4.55	.00	[-.06, .06]	.00	53.10	.000	0
Spatial representation of numerical magnitude (%)	0.04	.22	[.15, .29]	.07	6.24	.000	19.01*
Conceptual knowledge	0.08	.17	[.10, .24]	.06	4.63	.000	15.93*
Arithmetic fact knowledge	0.09	.15	[.07, .23]	.06	3.71	.001	14.36*
Magnitude Manipulation: subtraction	0.08	.13	[.04, .23]	.05	2.68	.015	13.17*
Magnitude Manipulation: addition	0.04	.05	[-.04, .15]	.04	1.14	.335	11.06*
General cognitive ability	0.08	.12	[.05, .19]	.04	3.51	.001	10.24*
Approximate calculation	0.00	.00	[-.08, .08]	.03	0.07	.942	6.93*
Basic geometry (%)	0.01	.04	[-.03, .11]	.02	1.08	.335	5.18*
Log(age)	1.44	.05	[-.01, .11]	.01	1.67	.144	2.02
Sex ^a	-0.21	-.07	[-.013, -.01]	.01	-2.31	.036	1.47
Non-symbolic magnitude understanding.	-0.03	-.03	[-.09, .03]	.00	-0.96	.368	0.63

Note: *B*: unstandardized regression weight; β : standardized regression weight; *L-CI*: lower boundary (2.5%); *U-CI*: upper boundary (97.5%); *RW*: raw relative weight (within rounding error raw weights will sum to R^2); *t*: t-value measures the size of the effect relative to the variation in sample data; *p*: p-value; *RS-RW*: relative weight rescaled as a percentage of predicted variance in the criterion variable attributed to each predictor (within rounding error rescaled weights sum to 100 %). ^a code female = -1, male = 1. * significantly different from a random variable.

TABLE 5: Overview of significant predictors (*) of analog and digital time reading in the multiple regression and relative weights analysis.

	Analog time reading		Digital time reading	
	Multiple Regression	Relative Weights	Multiple Regression	Relative Weights
Magnitude Manipulation: Addition	*	*		*
Magnitude Manipulation: Subtraction		*	*	*
Arithmetic fact knowledge	*	*	*	*
Spatial representation of numerical magnitude			*	*
Approximate calculation		*		*
Conceptual understanding		*	*	*
Non-symbolic magnitude understanding				
Basic geometry		*		*
General cognitive ability		*	*	*
Sex			*	
Age(log)	*	*		

Data availability statement:

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to restrictions set up by the local school boards on data security.