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# Does the learning of two symbolic sets of numbers affect the automaticity of number processing in children?

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A B S T R A C T

We explored the effects of learning two different symbolic sets of numerals (Arabic and Indian) on the development of automatic number processing. Children in the school we examined learn Indian numerals between first and third grades. In third grade, they switch to a new set of numerals (i.e., Arabic numbers). Participants in this study performed a numerical Stroop-like task in which they assessed the numerical value or physical size of stimuli varying along these two dimensions. Each participant saw either Arabic or Indian numerals. The results of the size congruity effect in the physical task, for both Indian and Arabic numerals, suggest that studying two sets of numerals interferes with the acquisition of an automatic association of a numerical symbol and magnitude. This is true both for the first learned set of numerals (i.e., Indian numerals) and for the second one (i.e., Arabic numerals). Furthermore, we found an absence of the distance effect, which further supports this conclusion. This learning program gave us the unique opportunity to examine the connection between symbolic sets and the mental representation of numbers in a novel fashion.



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## Introduction

The number digits are an arbitrary set of symbols associated with specific numerosities (i.e., numerical meaning). Proficient access to the numerical value of digits (i.e., decoding) is a critical prerequisite for mathematical calculations (e.g., Butterworth, Zorzi, Girelli, & Jonckheere, 2001; Gallistel & Gelman, 1992; Holloway & Ansari, 2009). As an example from the field of reading, it has been shown that speeded and accurate decoding (i.e., associating phonemes with written letters) is crucial for reading, and a deficiency in this process may lead to dyslexia (reading disability) (Kitz & Tarver, 1989; Snowling, 1980). In the field of numerical cognition, decoding is still under investigation.

We had the unique opportunity of studying a population of Bedouin students who learned two sets of numerical symbolic sets (Arabic numerals, e.g., 2, 3, 4, vs. Indian numerals, e.g., ٢ ٣ ٤). In first grade these students learn Indian numbers, and in third grade they learn Arabic numbers. After learning the Arabic numbers, they do not further use the Indian numbers for mathematical calculations.[3] Hence, we were able to examine how the introduction of a new symbolic set influences the development of automaticity in the association of numerical symbols to quantities. In other words, how does a first learned set of numerical symbols (i.e., Indian numbers) influence the ability to learn and develop automaticity of decoding a new set of symbols (i.e., Arabic numbers)? Recent findings show that there is a significant correlation between automatic numerical processing and mathematical abilities in kindergarten children (Ben Shalom, Berger, Rubinsten, Tzelgov, & Henik, 2012). Furthermore, Holloway and Ansari (2009) suggested that, based on their results, basic numerical understanding is predictive of mathematical performance at the age when children are first introduced to formal mathematics (i.e., 6 years) and is diminished by the 8 years of age. Therefore, the purpose of the current study was to investigate the implications of learning two different symbolic numerical representations for automatic processing of numerical information. Prior to outlining our hypotheses and describing the study, we highlight pivotal advances in the development of numeracy and the influence of a symbolic set on it as well as important aspects of automaticity that guided our hypotheses and methodology.

### *Basic numerical knowledge*

There is increasing evidence supporting the nativistic idea that sensitivity to numbers is innate (e.g., Dehaene, Molko, Cohen, & Wilson, 2004; Nieder & Miller, 2004) and language independent (Dehaene, Dehaene-Lambertz, & Cohen, 1998; for a review, see Cantlon, Platt, & Brannon, 2009), although it is still somewhat controversial (see Verguts & Fias, 2004, for an alternative model). However, further acquisition of arithmetical knowledge requires learning the association between digit symbols (e.g., Arabic numbers, Indian numbers) and specific numerosities (Ansari, 2008; Von Aster & Shalev, 2007). This stage is critically dependent on language, and so is the next phase of numerical cognition development, which is the acquisition of number words, that is, the association between verbal labels to specific numerosities and the acquisition of verbal counting strategies (Ansari, 2008; Von Aster & Shalev, 2007). These two stages seem to occur within the preschool period (Kaufmann & Nuerk, 2005). The importance of language in numerical processing was shown in several recent studies, which found that different properties of a language system, such as language direction, influence transcoding of numbers (Duyck, Depestel, Fias, & Reynvoet, 2008; Helmreich et al., 2012; Pixner, Moeller, Hermanova, Nuerk, & Kaufmann, 2011; Pixner, Zuber, et al., 2011; Shaki, Fischer, & Göbel, 2012; Siegler & Mu, 2008; Zuber, Pixner, Moeller, & Nuerk, 2009). It has been further suggested that difficulty in automatically accessing such associations may be related to dyscalculia (a specific disorder in numerical processing; Rubinsten & Henik, 2006; Von Aster & Shalev, 2007).

### *Automaticity of numerical information*

One successful method for testing automatic access to the numerical value of digits is the numerical Stroop task (Paivio, 1975). In this task, participants are presented with pairs of Arabic numerals

[3] This system of teaching was removed from the educational programs of all the Bedouin schools approximately 3 years ago. The current study was conducted during the 2 years preceding that change.

and are asked to decide which of the numerals is larger. The numerals are presented in different physical sizes (e.g., 3 6), and the participants are asked to ignore the physical size of the numerals and to respond to the numerical values only. They can also be asked to respond to the physical size of the digits and to ignore their numerical values (e.g., Henik & Tzelgov, 1982). The two dimensions of the digits can be used to create congruent, incongruent, and neutral trials. In the congruent trials, the numerically larger digit is also physically larger (e.g., 3 7). In the incongruent trials the numerically larger digit is physically smaller (e.g., 3 7), and in the neutral trials the digits differ in only one dimension, either the physical dimension in the physical task (e.g., 3 3) or the numerical dimension in the numerical task (e.g., 3 7). Commonly, reaction times (RTs) are shorter for congruent trials than for incongruent trials—the *size congruity effect* (SiCE) (Henik & Tzelgov, 1982; Paivio, 1975; Schwarz & Heinze, 1998; Tzelgov, Meyer, & Henik, 1992).

The SiCE indicates automaticity of the numerical information because it appears even though the numerical information is irrelevant to the task (e.g., Rubinsten, Henik, Berger, & Shahar-Shalev, 2002; Tzelgov et al., 1992). Two factors can influence the appearance of the SiCE: speed and accuracy of processing of the numerical and physical dimensions. The influence of the irrelevant dimension on performance is a function of its level of automaticity (MacLeod & Dunbar, 1988). The assumption is that physical size, which is a perceptual dimension, will be processed automatically from a very young age. However, the knowledge of the numerical value of a digit is developed slowly and is automatically processed only at a later stage (Girelli, Lucangeli, & Butterworth, 2000). Szucs and Soltész (2007) examined two components—facilitation and interference—of the SiCE in an event-related potentials (ERPs) study. Facilitation occurs when congruent trials are reacted to faster than neutral trials, and interference occurs when incongruent trials are reacted to slower than neutral trials. The authors found that these two components (i.e., facilitation and interference) appear during multiple stages of processing and are related to different cognitive processes. Moreover, Szucs, Soltész, Jármi, and Csépe (2007) found that partially different cognitive mechanisms underlie the performance of children and adults in the numerical Stroop task. They found that the differences in the facilitation and interference effects in children and in adults are not a result of numerical or physical magnitude processing alone but rather a result of a stronger response interference in children than in adults (see also Girelli et al., 2000; Rubinsten et al., 2002). These findings also suggest that caution is needed when reaching conclusions about numerical processing skills while interpreting behavioral data of the numerical Stroop task (Szucs et al., 2007; for additional studies of the neuronal components of the SiCE, see also Cohen Kadosh, Cohen Kadosh, Henik, & Linden, 2008; Cohen Kadosh, Cohen Kadosh, Linden, Berger, et al., 2007; Szucs & Soltész, 2008; for additional findings showing the differences in brain activations of children and adults with regard to interference and magnitude processing, see Wood, Ischebeck, Koppelstätter, Gotwald, & Kaufmann, 2009).

Another strong effect related to the associations between digits and their numerical value is the *distance effect*—the larger the numerical difference between two digits, the shorter the time to decide which digit is larger. For example, it takes a longer time to decide that 3 is larger than 2 than it takes to decide that 6 is larger than 2 (Moyer & Landauer, 1967). The distance effect has been found in a wide variety of studies with adults and with children (e.g., Ansari, 2008; Duncan & McFarland, 1980; Henik & Tzelgov, 1982; Price, Holloway, Räsänen, Vesterinen, & Ansari, 2007; Schwarz & Heinze, 1998; Tzelgov et al., 1992). Moyer and Landauer (1967) explained this effect by proposing that people convert written or auditory numbers into analog magnitudes. Different studies assume that this effect indicates an immediate access to the numbers' magnitudes, which in turn are placed on a mental number line (e.g., Duncan & McFarland, 1980; Henik & Tzelgov, 1982; Moyer & Landauer, 1967; Schwarz & Heinze, 1998; Tzelgov et al., 1992).

## *Development of automatic numerical processes*

Several studies have examined the development of the distance effect and the SiCE. Ansari, Garcia, Lucas, Hamon, and Dhital (2005) found evidence that the distance effect develops with age. Recent studies have shown that intentional processing of numerical magnitude (the type of processing examined by the distance effect) predicts variability in children's performance on standardized tests of mathematical achievement as early as first grade. These findings show that distinct connections between numbers and their meanings are particularly important for children's mathematical development (Bugden & Ansari, 2011; De Smedt, Verschaffel, & Ghesquière, 2009; Holloway & Ansari, 2009).

In addition, Rubinsten and colleagues (2002) found that although there was a numerical distance effect for all ages from first grade onward, there was no interference effect while performing a physical task at the beginning of first grade. The interference effect first appears at the end of first grade and develops gradually during the first years of school. In Girelli and colleagues' (2000) study, the authors found that the SiCE emerged in third grade only as an interference effect and was strengthened in fifth grade. They argued that their findings indicated that children under 8 years of age do not automatically access the quantitative values of Arabic numerals because numerical values do not interfere with physical judgments. The only evidence of an SiCE in kindergarten children was found by Ben Shalom and colleagues (2012). However, its components were different from those of older children and adults.

To summarize, these studies have collectively shown that even though the youngest children (preschoolers) show implicit knowledge of numerical value (as implied by the existence of a distance effect), they still do not seem to have automatic processing of numerical value for symbolic stimuli (i.e., Arabic numerals) when numerical value is irrelevant to the task requirements.

### *Learning two sets of numerical symbols*

Children in some Bedouin schools in Israel start studying arithmetic with Indian numerals. They use this symbolic system up to third grade and then switch to Arabic numerals, which are then mostly used in their studies. The Indian numerals continue to be used extensively in written Arabic material such as newspapers and books (Ibrahim, Eviatar, & Aharon-Peretz, 2002).

Ibrahim and colleagues (2002) found that students in the 10th grade process universal Arabic numerals faster than Indian numerals. They suggested that these results reflect differences in the frequency with which the students encountered the two types of digits and that this practice results in the formation of separate cognitive sets for the two types of numerals. For adult Arabic-speaking students, Ganor-Stern and Tzelgov (2008) found that there is automatic processing of numerical magnitude in both Arabic and Indian notations. They also found a slight difference in the processing between notations. Similar to Ibrahim and colleagues, they related the difference in processing between notations to the lower frequency of Indian symbols in the daily language.

### *The current study*

The purpose of this study was to examine two major questions. First, does the existence of an earlier learned set of digit symbols interfere with the automatic decoding of a new set? Second, what happens to the old set of symbols after a second set is learned? Is its automaticity interfered with by a new set of decoded symbols?

To examine these questions, we designed a cross-sectional study similar to that of Rubinsten and colleagues (2002). We used the SiCE to study the automaticity of number processing in two sets of numbers. The study was conducted in a Bedouin elementary school on children in second, third, and fifth grades. In this school, children studied the Indian set of numbers in the early grades and in third grade they stopped using this set of numbers and started learning the Arabic set. We were interested in examining how this switch in a numerical set of numbers affects the processing of the new set of numbers and whether it changes the processing of the old one. We examined the facilitation and interference effects of the SiCE, which were found to be suggestive of the level of the automatic decoding process of numerical symbols into magnitudes. The second-grade students were tested only with Indian numbers, whereas the third- and fifth-grade students were tested with both the Arabic and Indian sets.

In the numerical task, for both symbolic sets, we assumed that the children in all grades would show an SiCE composed of both an interference effect (i.e., RT of incongruent trials minus RT of neutral trials) and a facilitation effect (RT of neutral trials minus RT of congruent trials). This would be in accord with previous studies.

In the physical comparison task, using Indian numerals, we assumed that second-grade students would show an SiCE that would be composed of an interference effect and no facilitation effect. This hypothesis was based on previous results in Rubinsten and colleagues' (2002) study on children at the end of first grade. Regarding third and fifth grades, if the learning of a new set did not interfere with the old set, we expected to see a progressive maturation of the SiCE effect, showing both facilitation and interference patterns. In contrast, if the learning of a new set of symbols in third grade interfered with this development, we expected that SiCE development would be degraded.

As for the Arabic numbers, in third grade two predictions were possible. One was that children would show a congruity effect similar to the one found for Indian digits in second-grade students (composed of an interference effect with no facilitation). This would indicate that learning the first set of symbols did not affect the processing of a new set of symbols and that each time children learn a new set they begin the process from scratch. Another possibility was that third-grade students would show a full congruity effect, similar to the one expected for Indian numbers. Such a finding would indicate that the skills learned during the first two years of schooling were transferred and also used for the new set of symbols (the Arabic numbers). In fifth grade, we expected to see a further development of the SiCE composed of both interference and facilitation components.

We also tested Arabic-speaking adult students at Ben-Gurion University of the Negev with the same procedure. We predicted that they would show a full SiCE for both Arabic and Indian numerals. However, if one of these sets of numerals was not fully and automatically developed, we should be able to see this influence on the facilitation and interference components of the SiCE in the university students.

In addition to examining facilitation and interference, we also examined the numerical distance effect, expecting, based on the literature, that it would be present from second grade onward (e.g., Girelli et al., 2000; Rubinsten et al., 2002).

## Method

### *Participants*

Five groups of children were examined: (a) second-grade students who were tested only on Indian numbers (mean age = 6.5 years, *SD* = 3.67 months, 19 participants), (b) third-grade students who were tested only on Indian numbers (mean age = 8.2 years, *SD* = 3.74 months, 26 participants), (c) third-grade students who were tested only on Arabic numbers (mean age = 8.2 years, *SD* = 3.89 months, 26 participants), (d) fifth-grade students who were tested only on Indian numbers (mean age = 10.71 - years, *SD* = 3.0 months, 23 participants), and (e) fifth-grade students who were tested only on Arabic numbers (mean age = 10.7 years, *SD* = 3.8 months, 23 participants). In addition, the experiment was administered to a control group of 26 Bedouin university students (13 were tested on Indian numerals and 13 on Arabic numerals). All participants had intact or corrected vision. The children were all from the same elementary school in a Bedouin community. The study was carried out with the authorization of the Ministry of Education and the school principal. Children with no attention or developmental problems were selected by the teachers. Children with more than 20% errors were removed from the analysis, resulting in 17 children in second grade, 45 children in third grade (24 with Indian numbers and 21 with Arabic numbers), and 41 children in fifth grade (20 with Indian numbers and 21 with Arabic numbers) who participated in the study. No adult students were removed from the analysis (all had an error rate of <10%).

### *Stimuli*

The stimuli consisted of two digits that appeared on both sides of where a black square fixation point appeared previously on a computer monitor. Each participant performed two kinds of comparisons. In one the relevant dimension was physical size, and in the other it was numerical value. To examine the numerical distance effect, three distances were used (1, 2, and 5).

There were three conditions of congruity. A congruent stimulus was defined as a pair of digits in which a given digit was larger on both the relevant and irrelevant dimensions (e.g., 6 4 for Arabic numerals and ٦ ٤ for Indian numerals). A neutral stimulus was defined as a pair of digits that differed only on the relevant dimension (e.g., 6 4 in Arabic and ٦ ٤ in Indian for the numerical comparisons or 4 4 in Arabic and ٤ ٤ in Indian for the physical comparisons). An incongruent stimulus was defined as a pair of digits in which a given digit was simultaneously larger on one dimension and smaller on the other (e.g., 6 4 for Arabic numerals and ٦ ٤ for Indian numerals).

As mentioned above, there were three numerical distances: 1 (the digits 1–2, 3–4, 6–7, and 8–9), 2 (the digits 1–3, 2–4, 6–8, and 7–9), and 5 (the digits 1–6, 2–7, 3–8, and 4–9). There were different physical distances that were not analyzed. We used these physical distances to eliminate an asymmetry between the two dimensions, although we were not interested in the physical distance effect per se.

*Neutral stimuli in the physical comparison*

This condition was composed of the same digit in two different physical sizes. To keep the factorial design, we created the neutral stimuli from the digits that were used for the other two conditions (congruent and incongruent). For example, because the pair 3–4 was used to produce congruent and incongruent stimuli for numerical distance 1, neutral pairs included in the analysis as numerical distance 1 were created using the same two digits (i.e., 3 3 and 4 4). Similarly, because the pair 3–5 was used to produce the congruent and incongruent conditions for a numerical distance of 2 units, neutral pairs using these two digits (i.e., 3 3 and 5 5) were included in the analysis as numerical distance 2. In this way the comparison among the congruent, incongruent, and neutral conditions was made using the same digits.

*Neutral stimuli in the numerical comparison*

This condition was composed of two digits that were different in numerical value but of the same physical size. To keep the factorial design, we created the neutral stimuli from the digits and physical sizes that were used for the other two conditions (congruent and incongruent). For example, for the pair of sizes 11–12 mm, which was used to produce congruent and incongruent stimuli, neutral pairs included in the analysis were created using pairs with the same two digits but with the different sizes (e.g., 3 4 in size 11 mm and 3 4 in size 12 mm). Similarly, we created different neutral pairs for different physical distances. In this way, the comparison among the congruent, incongruent, and neutral conditions was made using the same physical sizes.

Before every experimental block, participants were presented with 9 practice trials. The practice block was similar to the experimental block. Each experimental block had 27 different possible conditions (3 physical distances, 3 numerical distances, and 3 congruency conditions). Each condition had 16 trials for a total of 432 trials per block. To shorten the duration of the experiment and to adjust it to children, each experimental block consisted of 108 trials only. To create the two experimental blocks, only one example of physical distance was selected randomly for each example of numerical distance. These stimuli pairs appeared in three conditions (i.e., congruent, incongruent, and neutral). Therefore, each task consisted of 108 different stimuli (see below) composed of 36 congruent, 36 incongruent, and 36 neutral pairs of digits. The numbers of congruent, neutral, and incongruent trials and the number of trials representing the numerical and physical distances were the same for all children. The specific examples used differed among children.

It is important to note that some of the numerical symbols in the Arabic and Indian sets of numbers are very similar and might raise interference between the sets (see Fig. 1). For example, the Arabic number 3 is similar to the Indian number 4 (٤), and the Arabic number 7 is similar to the Indian number 6 (٦). To examine this potential interference, we ran an experiment on Bedouin university students. In this experiment, all of the possible pairs created from the numbers 1 to 9 (36 pairs) were presented to the participants either in Arabic numbers or in Indian numbers, and the participants were instructed to decide which number was larger. We collected RTs for each pair of numbers and compared those for pairs of numbers that were potentially problematic due to physical similarity (e.g., 3–4 for Arabic numerals in which we suspected the 3 elicited Indian ٤) with RTs for pairs that were not (e.g., 1–2). The comparison was always within the same original numerical distance of the exam-

| Arabic | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Indian | ١ | ٢ | ٣ | ٤ | ٥ | ٦ | ٧ | ٨ | ٩ |

**Fig. 1.** The Indian and Arabic numerical symbols. Notice that the Arabic number 3 is similar to the mirror image of the Indian number 4 and that the Arabic number 7 is similar to the Indian number 6.

ined problematic pair. If an Arabic digit elicited an Indian digit and created a different distance (e.g., 3–4 is originally a pair with distance 1; if the digit 3 elicits the Indian digit ٤, then the pair would now have a distance of 0), we expected slower RTs for this problematic pair. Accordingly, we compared the problematic pairs with non-problematic pairs with the same distance. We wanted to see which pairs would show significantly slower RTs.

We found that the Arabic digit 3 did not consistently seem to elicit the Indian digit ٤ and vice versa. However, the Arabic digit 7 and the Indian digit ٦ did seem to elicit each other. Therefore, we excluded the latter numerals from the current study. This is explained in more detail in Appendixes A and B.

### *Design*

The variables manipulated were group (second-grade, third-grade, fifth-grade, or university students), relevant dimension (physical or numerical), physical distance (distance of 1, 2, or 4 mm), numerical distance (1, 2, or 5), congruity (incongruent, neutral, or congruent), and type of numerical symbols (Indian or Arabic). Thus, we had a $3 \times 2 \times 3 \times 3 \times 3 \times 2$ factorial design for third-grade, fifth-grade, and university students. For second-grade students who saw only Indian numerals, the design was $2 \times 3 \times 3 \times 3$. Group and type of symbol were the between-participants variables.

### *Procedure*

The participant's task was to decide which of two digits in a given display was larger. Participants were presented with either Indian or Arabic numerals. Each participant took part in one session composed of two different blocks. In one block "larger" was defined by physical size, and in the other block it was defined by numerical value. The stimuli in each block were presented in a random order. Half of the participants performed physical comparisons first, and the other half performed numerical comparisons first. Before each block began, participants were given a practice block. The participants were asked to respond as quickly as possible but to avoid errors. They indicated their choices by pressing one of two keys corresponding to the side of the display with the chosen digit (i.e., the "L" and "A" keys with the right and left index fingers, respectively). Each trial began with a fixation point presented for 1000 ms. Then, 500 ms after the fixation point was eliminated, a pair of digits appeared and remained in view until the participant pressed a key (but not for more than 5000 ms). A new trial began 1500 ms after the participant's response (see Fig. 2).

## Results

Error rates were generally low, and because their distributions were extremely uneven with zero error rates in most of the conditions, we did not conduct statistical analysis on this measure. For every participant in each condition, the mean RT was calculated (for correct trials only). We excluded RTs shorter than 200 ms. We performed a $z$-transformation on individual item RT using the mean and standard deviation per participant for standardization, thereby creating approximately standard normal distribution of RTs for all children and adults (for a full explanation of this technique, see Nuerk, Kaufmann, Zoppoth, & Williams, 2004). The results presented below are all according to this analysis.

Due to the complex designs used in this study, and in order to simplify presentation of the results, we present only the hypothesis-based planned comparisons of the interference and facilitation

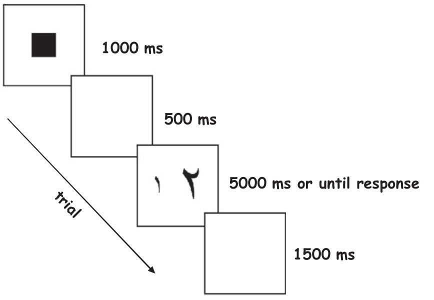


**Fig. 2.** A trial in the experiment.

components, for each relevant dimension (numerical vs. physical) and for each symbolic set (Indian vs. Arabic), followed by the analysis of the distance effect results in the numerical task for the different grades and symbolic sets.

*Numerical comparison tasks (physical dimension irrelevant)*

*Indian numerals*

Facilitation was significant for all but fifth grade (for which it was marginally significant), $F(1, 16) = 8.91$, $p < .01$, $\eta^2 = .36$; $F(1, 23) = 4.77$, $p < .05$, $\eta^2 = .17$; $F(1, 20) = 4.23$, $p = .06$, $\eta^2 = .17$; and $F(1, 12) = 45.07$, $p < .01$, $\eta^2 = .79$, for second-grade, third-grade, fifth-grade, and university students, respectively. Interference was significant for all groups, $F(1, 16) = 8.80$, $p < .01$, $\eta^2 = .35$; $F(1, 23) = 8.92$, $p < .01$, $\eta^2 = .28$; $F(1, 20) = 38.64$, $p < .01$, $\eta^2 = .66$; and $F(1, 12) = 23.11$, $p < .01$, $\eta^2 = .66$, for second-grade, third-grade, fifth-grade, and university students, respectively (see Fig. 3, top panel).

*Arabic numerals*

Both facilitation and interference effects were found for all tested groups: third-grade students—facilitation effect, $F(1, 20) = 6.45$, $p < .05$, $\eta^2 = .24$; interference effect, $F(1, 20) = 14.84$, $p < .01$, $\eta^2 = .43$; fifth-grade students—facilitation effect, $F(1, 19) = 15.81$, $p < .01$, $\eta^2 = .46$; interference effect, $F(1, 19) = 18.24$, $p < .01$, $\eta^2 = .49$; university students—facilitation effect, $F(1, 12) = 25.22$, $p < .01$, $\eta^2 = .68$; interference effect, $F(1, 12) = 29.69$, $p < .01$, $\eta^2 = .71$ (see Fig. 3, bottom panel).

*Physical comparisons (numerical dimension irrelevant)*

*Indian numerals*

Second-grade and third-grade students showed no facilitation or interference effects. Fifth-grade students showed a significant facilitation effect, $F(1, 20) = 7.94$, $p < .05$, $\eta^2 = .28$, but no interference effect. University students showed no facilitation effect, but the interference effect was significant, $F(1, 12) = 18.81$, $p < .01$, $\eta^2 = .61$ (see Fig. 3, top panel).

*Arabic numerals*

For all groups, no facilitation was found, but the interference effects were significant, $F(1, 20) = 44.33$, $p < .01$, $\eta^2 = .69$; $F(1, 19) = 23.30$, $p < .01$, $\eta^2 = .55$; and $F(1, 12) = 56.15$, $p < .01$, $\eta^2 = .82$, for third-grade, fifth-grade, and university students, respectively (see Fig. 3, bottom panel).

We examined linear and quadratic trends between grades for the interference and facilitation effects in the numerical task separately for Indian and Arabic numerals. We found that there were no significant changes in the quadratic or linear trends between the different school grades. The changes of effect sizes were only in the comparison of each grade with the university students.

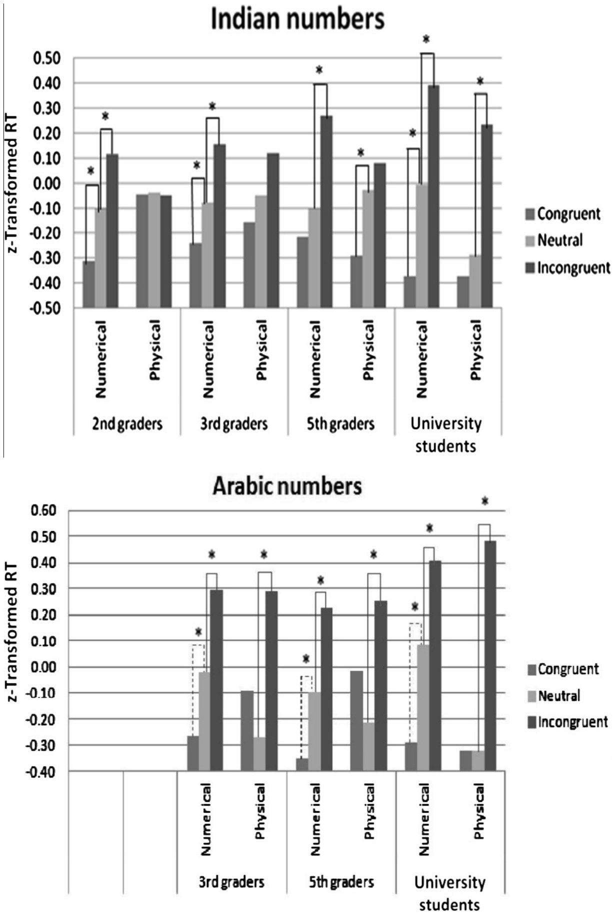


**Fig. 3.** Facilitation (i.e., comparison of neutral vs. congruent trial RT) and interference (i.e., comparison of neutral vs. incongruent trial RT) effects by language, grade and relevant dimension. Facilitation is marked by a dashed line, and interference is marked by a solid line. $^{*}p < .05$.

*Distance effect (simple effects): Numerical comparisons*

The distance effect was not significant in second-grade and fifth-grade students. In third-grade students, it was significant only for Arabic numerals, $F(1, 20) = 13.99$, $p < .01$, $\eta^2 = .41$, but not for Indian numerals. University students showed a significant distance effect both for Indian numerals, $F(1, 12) = 31.78$, $p < .01$, $\eta^2 = .73$, and for Arabic numerals, $F(1, 12) = 30.87$, $p < .01$, $\eta^2 = .72$.

## Discussion

We examined the implications of learning two sets of numerals on the strength of association between the digits and their numerical values. We studied performance of Arabic-speaking children who learned Indian numerals during the first 2 years of school and switched to Arabic numerals in third grade. The results can be summarized as follows. First, children and university students showed an SiCE composed of both facilitation and interference effects in the numerical task, that is, when the numerical dimension was relevant to the task and the physical dimension was irrelevant for both

Indian and Arabic numerals (fifth-grade students using Indian numbers showed a marginally significant facilitation effect in this condition). Second, in the physical task (i.e., when the numerical dimension was irrelevant to the task), the facilitation and interference effect patterns were different for the different numeral sets. For Indian numerals, the first numerical symbolic set that the children learned, second- and third-grade students showed no SiCE. The effect first began to appear only in fifth grade and was composed of the facilitation component only (the expected interference was not significant). Interestingly, although university students did show an interference component, they did not show a full SiCE because the facilitation component was missing. For Arabic numerals, the second numerical symbolic set that was learned by the children, no facilitation component was found in any tested group. The interference effect began to appear already in third grade. It is important to notice that the university students showed the same pattern of results for both Indian and Arabic numerals (i.e., an interference-based effect). Third, the numerical distance effect was absent in second grade. In third grade it appeared in Indian and Arabic numerals, and in fifth grade it was absent again. University students showed an intact distance effect.

Our overall expectations were based on the patterns found by Rubinsten and colleagues (2002) in children who learned one single numerical symbolic set. First, it was hypothesized that in second grade the SiCE should be composed only of the interference component. This was not found in the current study. In third grade and onward, we expected that when using Indian symbols, there would be a progression of the SiCE effect or a degradation, depending on whether the learning of a new set of symbols in third grade would affect the learning of the old one or not. We found no SiCE component in third grade, a facilitation component in fifth grade, and an interference component for university students. Notice that the university students showed the same pattern of SiCE in this symbolic set as first-grade students did in Rubinsten and colleagues (2002) study. Taken together, our results are consistent with the idea that learning a new numerical symbolic set at the same time as the Indian set of symbols markedly affects and delays the process of acquiring automaticity in the associations between the Indian set of symbols and their respective numerical quantities.

As for the Arabic set of symbols, we hypothesized that the effects either would be similar to those for Indian numerals in earlier grades or would be composed of both facilitation and interference components, showing a transfer of numerical information between sets of symbols. The results are not quite consistent with either hypothesis. From third grade onward and into adulthood, it seems that the facilitation component is absent for Arabic numerals. These results show that when the Arabic numerals were learned in third grade as a second symbolic set, the patterns of results were different from both those displayed by children who just began studying arithmetic (i.e., first grade in Rubinsten et al.'s (2002) study) and those for the second-grade children in the current study.

Focusing on the time of transfer (third grade), we found that children showed interference of numerical values on physical comparisons in the new symbolic system (i.e., Arabic numerals) and no SiCE for the originally learned symbolic set (i.e., Indian numerals). This suggests that some transfer between the two symbolic systems did occur. The non-significant SiCE with the Indian symbols might be due to an attempt to suppress this system while studying the new Arabic symbolic system. Censabella and Noël (2005) found a similar effect in fourth-grade students who did not master the skills of addition before studying multiplication. These children showed an interference effect in solving addition problems after solving multiplication problems. This results in a degradation of the SiCE effect for Indian numerals that can be found all the way up to university students.

It seems that the participants in the current research experienced more difficulty in acquiring the association between symbols and magnitudes than do children who study one symbolic system only. Such difficulty could result from a lack of training or a shortened period of training, or it might be due to the competition between two sets of symbols. Studies with Russian–English bilinguals support the hypothesis of training. It has been found that these bilinguals solved exact arithmetic problems faster in the language and symbolic set used during training independent of whether that language was English or Russian (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Spelke & Tsivkin, 2001). This finding suggests that facts acquired during training were stored in a language-specific format and that the arithmetical skill did not transfer readily to a different language (additional support can be found in Venkatraman, Siong, Chee, & Ansari, 2006). Additional studies have shown evidence that linguistic attributes influence magnitude processing even when they are allegedly not needed. These studies also used bilinguals and examined languages in which reading of numbers was from left to right or from right to left (e.g., Duyck et al., 2008; Helmreich et al., 2012; Pixner, Moeller et al., 2011; Pixner, Zuber et al., 2011; Shaki et al., 2012; Siegler & Mu, 2008). Interestingly, in the current study, we found some indications for transfer in third grade, but it seems that participants did not fully transfer the information studied in one language (i.e., verbal symbols) for use in the other language. Furthermore, it is important to mention that the results of this study indicate that these children did acquire basic numerical processing skills. We deduced this from the high accuracy rates, which showed that the children in our study managed to decide which a digit was numerically larger. Furthermore, university students developed a numerical distance effect, which further strengthens this assumption and suggests that they created a mental number line that could be used for both Arabic and Indian numerals (this is in accord with Ganor-Stern & Tzelgov, 2008, and Ibrahim et al., 2002). However, as mentioned, the construction of this mental number line might be delayed in children learning two sets of numerical symbols, as suggested by the lack of a distance effect for Arabic numerals in the school-aged child groups of this study. Still, additional research is needed to support this claim because we did not include a control group.

As noted earlier, physical comparisons in the current study were characterized by lack of facilitation. Only fifth-grade students using Indian symbols showed significant facilitation. The lack of facilitation was noted in earlier studies in first-grade students (Rubinsten et al., 2002), in university students suffering from developmental dyscalculia (Rubinsten & Henik, 2005; Rubinsten & Henik, 2006), in transcranial magnetic stimulation-induced dyscalculia (Cohen Kadosh et al., 2007), and in acquired acalculia (Ashkenazi, Henik, Ifergane, & Shelef, 2008). The current study did not include a group of participants who studied arithmetic with one symbolic system (i.e., Arabic numerals) only. Such a control group would have allowed for testing similar effects with the same stimuli; hence, conclusions should be made cautiously. Nevertheless, the comparison with previous studies supports the suggestion regarding difficulty in activation of symbolic–magnitude associations. Note that the lack of facilitation might be indicative that a symbolic–magnitude association has not developed to be fully automatic or that the use of two symbolic systems somehow suppresses certain automatic processing. Further studies are required in order to examine this issue.

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## Appendix A.

Comparisons for Arabic numeral 3 (similar to Indian digit ٤) and Arabic numeral 7 (similar to Indian digit ٦).

| Numerical pair (mean RT) | Real distance | Distance if Indian numeral is elicited | Compared with pairs (mean RT) | Significance |
|---|---|---|---|---|
| 2–3 (642 ms) | 1 | 2 | 9–6,8–5,5–2,4–1 (645 ms) | $F(1, 14) = 0.16$, $MSE = 250$, *ns* |
| 3–4 (601 ms) | 1 | 0 | 9–6,8–5,5–2,4–1 (645 ms) | $F(1, 14) = 49.66$, $MSE = 290$, $p < .01$, $\eta^2 = .78$ |
| 6–7 (707 ms) | 1 | 0 | 9–6,8–5,5–2,4–1 (645 ms) | $F(1, 14) = 58.29$, $MSE = 496$, $p < .01$, $\eta^2 = .81$ |

**Appendix A.** (*continued*)

| Numerical pair (mean RT) | Real distance | Distance if Indian numeral is elicited | Compared with pairs (mean RT) | Significance |
|---|---|---|---|---|
| 8–7 (686 ms) | 1 | 2 | 9–6,8–5,5–2,4–1 (645 ms) | $F(1, 14) = 24.25$, $MSE = 536$, $p < .01$, $\eta^2 = .63$ |
| 1–3 (529 ms) | 2 | 3 | 8–6,6–4,4–2 (593 ms) | $F(1, 14) = 89.73$, $MSE = 343$, $p < .01$, $\eta^2 = .87$ |
| 3–5 (594 ms) | 2 | 1 | 8–6,6–4,4–2 (593 ms) | $F(1, 14) = 0.04$, $MSE = 163$, *ns* |
| 7–5 (621 ms) | 2 | 1 | 8–6,6–4,4–2 (593 ms) | $F(1, 14) = 16.65$, $MSE = 345$, $p < .01$, $\eta^2 = .54$ |
| 9–7 (658 ms) | 2 | 3 | 8–6,6–4,4–2 (593 ms) | $F(1, 14) = 74.44$, $MSE = 423$, $p < .01$, $\eta^2 = .84$ |
| 6–3 (574 ms) | 3 | 2 | 9–8,6–5,5–4,2–1 (553 ms) | $F(1, 14) = 33.16$, $MSE = 95$, $p < .01$, $\eta^2 = .70$ |
| 7–4 (526 ms) | 3 | 2 | 9–8,6–5,5–4,2–1 (553 ms) | $F(1, 14) = 7.88$, $MSE = 699$, $p < .05$, $\eta^2 = .36$ |
| 7–3 (551 ms) | 4 | 3 | 9–8,6–5,5–4,2–1 (553 ms) | $F(1, 14) = 0.84$, $MSE = 95$, *ns* |
| 8–3 (509 ms) | 5 | 4 | 9–6,4–1 (519 ms) | $F(1, 14) = 1.40$, $MSE = 466$, *ns* |
| 2–7 (554 ms) | 5 | 4 | 9–6,4–1 (519 ms) | $F(1, 14) = 12.25$, $MSE = 754$, $p < .01$, $\eta^2 = .47$ |
| 9–3 (514 ms) | 6 | 5 | 8–2 (510 ms) | $F(1, 14) = 2.50$, MSE = 31, *ns* |
| 7–1 (566 ms) | 6 | 5 | 8–2 (510 ms) | $F(1, 14) = 37.85$, $MSE = 602$, $p < .01$, $\eta^2 = .73$ |

*Note.* The comparisons conducted in the control study were between pairs of digits that included Arabic numerals that elicited similar Indian numerals (problematic pairs) and pairs with the same real distance, which we assumed did not elicit any Indian numeral (non-problematic pairs). Underlined entries are comparisons of pairs that included the Arabic digit 7 (which elicits the Indian digit ٦) that were found to be significant and showed a general direction of disturbance (six of the seven comparisons were found to be significantly different for this digit). As can be seen, these comparisons, which include the problematic digit 7, were generally slower than comparisons of pairs with the same original real distance. These results led us to assume that the digit 7 elicits the digit ٦, and this in turn creates confusion for the participants, which results in generally slower RTs. For the Arabic digit 3, this was not consistent. Only three comparisons showed a significant difference between the problematic pair and control pairs. Two of the three showed faster RTs for the problematic pair. Therefore, we did not remove this digit from our study. The entry colored in gray marks the pair in which we saw a general direction of disturbance.

## Appendix B.

Comparisons for Indian numeral ٤ (similar to Arabic digit 3) and Indian numeral ٦ (similar to Arabic digit 7).

| Numerical pair (mean RT) | Real distance | Distance if Indian numeral is elicited | Compared with pairs (mean RT) | Significance |
|---|---|---|---|---|
| 3–4 (694 ms) | 1 | 0 | 1–2,2–3,7–8,8–9 (642 ms) | $F(1, 14) = 4.51$, $MSE = 4345$, $p = .051$, $\eta^2 = .24$ |
| 4–5 (749 ms) | 1 | 2 | 1–2,2–3,7–8,8–9 (642 ms) | $F(1, 14) = 22.34$, $MSE = 3797$, $p < .01$, $\eta^2 = .61$ |
| 5–6 (627 ms) | 1 | 2 | 1–2,2–3,7–8,8–9 (642 ms) | $F(1, 14) = 0.74$, $MSE = 2338$, *ns* |
| 6–7 (708 ms) | 1 | 0 | 1–2,2–3,7–8,8–9 (642 ms) | $F(1, 14) = 10.15$, $MSE = 3171$, $p < .01$, $\eta^2 = .42$ |
| 2–4 (601 ms) | 2 | 1 | 9–7,7–5,5–3,3–1 (622 ms) | $F(1, 14) = 2.18$, $MSE = 1569$, *ns* |
| 4–6 (620 ms) | 2 | 3 | 9–7,7–5,5–3,3–1 (622 ms) | $F(1, 14) = 0.03$, $MSE = 987$, *ns* |
| 6–8 (647 ms) | 2 | 1 | 9–7,7–5,5–3,3–1 (622 ms) | $F(1, 14) = 1.56$, $MSE = 2930$, *ns* |
| 1–4 (546 ms) | 3 | 2 | 8–5,5–2 (623 ms) | $F(1, 14) = 51.43$, $MSE = 863$, $p < .01$, $\eta^2 = .79$ |
| 4–7 (603 ms) | 3 | 4 | 8–5,5–2 (623 ms) | $F(1, 14) = 4.21$, $MSE = 680$, $p = .06$, $\eta^2 = .23$ |
| 3–6 (601 ms) | 3 | 4 | 8–5,5–2 (623 ms) | $F(1, 14) = 5.28$, $MSE = 653$, $p < .05$, $\eta^2 = .27$ |
| 6–9 (592 ms) | 3 | 2 | 8–5,5–2 (623 ms) | $F(1, 14) = 6.03$, $MSE = 1159$, $p < .05$, $\eta^2 = .30$ |
| 2–6 (575 ms) | 4 | 5 | 9–7,5–5,3–1 (564 ms) | $F(1, 14) = 0.85$, $MSE = 1149$, *ns* |
| 4–8 (582 ms) | 4 | 5 | 9–7,5–5,3–1 (564 ms) | $F(1, 14) = 2.58$, $MSE = 976$, *ns* |
| 4–9 (552 ms) | 5 | 6 | 2–7,3–8 (583 ms) | $F(1, 14) = 2.57$, $MSE = 2817$, *ns* |
| 1–6 (520 ms) | 5 | 6 | 2–7,3–8 (583 ms) | $F(1, 14) = 10.75$, $MSE = 2799$, $p < .01$, $\eta^2 = .43$ |

*Note*. The comparisons conducted in the control study were between pairs of digits that included Indian numerals that elicited similar Arabic numerals (problematic pairs) and pairs with the same real distance, which we assumed did not elicit any Arabic numerals (non-problematic pairs). Underlined entries are the significant comparisons for the Indian digit ٦ in which the direction of the results suggests that the Arabic digit's value (i.e., 7) was elicited, causing a relevant disturbance or, rather, accelerating the RTs (three of four significant comparisons). The entry colored in gray marks the pairs in which we saw a general direction of disturbance for the Indian digit ٤ (which elicits the Arabic digit 3). Standing on its own, this table might suggest random results. However, taking into consideration both tables, we can see that there is an indication for a general tendency of the Arabic digit 7 to elicit the Indian digit ٦. Due to these results, we decided to remove these digits from our study in a controlled fashion. As for the Indian digit ٤, it did not seem to consistently elicit the Arabic digit 3 (two of three significant comparisons for this numeral showed a general disturbance). Apart from the results in the Arabic numerals table, in general we found the results to be random and, thus, left this pair of digits in the study. The difference in results between the pair 7 and ٦ and the pair 3 and ٤ might be due to physical differences between them. The Arabic digit 7 and the Indian digit ٦ are almost identical. However, the Arabic digit 3 and the Indian digit ٤ are reversed in a mirror fashion. This might be the reason for the different results between the two pairs of digits.

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