Digit identity influences numerical estimation in children and adults

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Research Highlights

- Number line estimation is widely used to draw conclusions about numerical cognition and development.
- Do the specific digits presented, rather than the numerical magnitudes of the target numerals, influence estimates?
- Children's (age 7-11) and adults' estimates were considerably different for numerals with different hundreds digits but nearly identical magnitudes in both speeded and non-speeded NLE tasks.
- Patterns of developmental change and individual difference are discussed.

Abstract

Learning the meanings of Arabic numerals involves mapping the number symbols to mental representations of their corresponding, approximate numerical quantities. It is often assumed that performance on numerical tasks, such as number line estimation (NLE), is primarily driven by translating from a presented numeral to a mental representation of its overall magnitude. Part of this assumption is that the overall numerical magnitude of the presented numeral, not the specific digits that comprise it, is what matters for task performance. Here we ask whether the magnitudes of the presented target numerals drive symbolic number line performance, or whether specific digits influence estimates. If the former is true, estimates of numerals with very similar magnitudes but different hundreds digits (such as 399 and 402) should be placed in similar locations. However, if the latter is true, these placements will differ significantly. In two studies ($N = 262$), children aged 7-11 and adults completed 0-1000 NLE tasks with target values drawn from a set of paired numerals that fell on either side of “Hundreds” boundaries (e.g. 698 and 701) and “Fifties” boundaries (e.g. 749 and 752). Study 1 used an atypical speeded NLE task, while Study 2 used a standard non-speeded NLE task. Under both speeded and non-speeded conditions, specific hundreds digits in the target numerals exerted a strong influence on estimates, with large effect sizes at all ages, showing that the magnitudes of target numerals are not the primary influence shaping children’s or adults’ placements. We discuss patterns of developmental change and individual difference revealed by planned and exploratory analyses.

Digit identity influences numerical estimation in children and adults

Learning the meanings of Arabic numerals (or number words) involves both acquiring knowledge about their positions in a sequential structure, and mapping number symbols to their corresponding approximate numerical quantities. A mainstream view in numerical cognition is that after acquiring such mappings, we don't typically process numerals digitally, like a computer. Rather, we access mental representations of their approximate analogical quantities and respond accordingly. This is demonstrated in part by *distance effects*, in which people take longer to compare numbers that are closer in magnitude (e.g. Dehaene, 1997; Dehaene, Dupoux, & Mehler, 1990; Hinrichs, Yurko, & Hu, 1981; Moyer & Landauer, 1967).

For many research paradigms used to investigate numerical thinking, it's assumed that performance is driven primarily, or even solely, by first translating numerical stimuli into mental representations of numerical magnitude, and then responding appropriately based on those representations. For example, a wealth of research exploring cognitive and developmental changes underlying number processing and representation supposes that such a process underlies performance on tasks like number line estimation. In number line estimation (NLE), participants must indicate where a given numeral (or some other external representation of number, such as a dot array or number word) belongs on a line between two labeled endpoints. Many researchers have claimed that these estimates provide direct readouts of the forms of our numerical magnitude representations (for example, it has been said that the task provides "particularly direct information about [children's] representations of numerical magnitude," Siegler & Booth, 2005, p. 207). The rough idea is that the target number is translated into an internal representation of its magnitude, which is then used to directly generate an estimate in the form of a location on the response line; in turn those estimates reveal the observer's reliance upon a particular kind of representation (e.g., logarithmically-spaced estimates reflect logarithmically-organized mental representations, linearly-spaced estimates reflect linear mental representations; e.g. Ashcraft & Moore, 2012; Berteletti et al, 2010; Booth & Siegler, 2006; Dehaene, Izard, Spelke, & Pica, 2008; Opfer & Siegler, 2007; Opfer, Thompson, & Kim, 2016; Siegler & Opfer, 2003; Siegler et al., 2009; Siegler, 2016; and many more).

Considerable evidence against this view has emerged in recent years. Researchers using a variety of methods have shown that performance in these estimation tasks is shaped by multiple cognitive processes, strategies, and/or computations that must prevent direct access to the forms of our numerical magnitude representations (e.g. Barth & Paladino, 2011; Barth et al., 2016; Chesney & Mathews, 2013; Cohen & Blanc-Goldhammer, 2011; Cohen & Quinlan, 2017; Cohen & Sarnecka, 2014; Friso-van den Bos et al., 2015; Hurst et al 2014; Link, Huber, Nuerk, & Moeller, 2014; Reinert, Huber, Nuerk, & Moeller, 2015; Rips, 2013; Rouder & Geary, 2014; Peeters, Degrande, Ebersbach, Verschaffel, & Luwel, 2016; Slusser, Santiago, & Barth, 2013; Slusser & Barth, in press; Sullivan & Barner, 2014; Sullivan, Juhasz, Slattery, & Barth, 2011; see also Cantlon, Cordes, Libertus, & Brannon, 2008). But despite disagreement about what cognitive and developmental theories should be built upon number line estimates, researchers in both groups described above have generally assumed that the overall numerical magnitudes of the presented targets do ultimately drive task performance (cf. Hurst, Monahan, Heller, & Cordes, 2014), whether or not they believe the nature of the underlying mental representations can be directly reconstructed from participants' placements.

Do target numerals' magnitudes truly drive number line placements? To our knowledge, the possible influence of the specific presented digits, rather than the holistic numerical

magnitudes of the target numerals, has not been investigated in the context of number line estimation. This is not surprising in one sense, given the common view that processing numbers (even multidigit numbers) leads us to access their corresponding magnitudes, which in turn shape our behavior. On the other hand, specific digits clearly matter in some situations. For example, the left digit effect (LDE) refers to the observation that the perceived difference between two compared prices (or other numbers) is often larger when leftmost digits differ (e.g. \$4.99 vs. \$5.00) than the same absolute differences that do not involve leftmost digits (e.g. \$4.39 vs. \$4.40) (Thomas & Morwitz, 2005; 2009). Also, reaction times when comparing two-digit numbers are typically slower when digits in the tens and units places are incompatible, which would not occur if numerical magnitude alone were the basis for comparison (Nuerk, Kaufman, Zoppoth, & Willmes, 2004; Nuerk, Moeller, & Willmes, 2015).

Here, we ask whether the overall magnitudes of the presented target numerals drive bounded number line estimation (NLE) performance, or whether specific hundreds digits influence estimates. In two experiments, participants completed 0-1000 NLE tasks with target values that allowed us to disentangle these possibilities. Targets were drawn from a set of paired numerals, with each member of the pair falling on either side of a boundary value. There were two types of pairs: “Hundreds” pairs fell on either side of Hundreds boundaries (e.g. 298 and 302) and “Fifties” pairs fell on either side of Fifties boundaries (e.g. 848 and 853). Within each Hundreds pair, hundreds digits differed, but within each Fifties pair, hundreds digits were the same. Target numerals were paired in the study design only; pairs were not presented together during the task.

The two experiments used different procedures to maximize generalizability, but both addressed the same key question: Are number line estimates generated primarily from the magnitudes of presented target numerals? If so, the particular digits in the target numerals shouldn’t matter: estimates for numerals with different hundreds digits but nearly identical magnitudes should be indistinguishable, on average, such that placements for numbers like 398 and 401 should be the same (at least on a sufficiently large scale, such as a 0-1000 number range). If not, estimates for numerals with different hundreds digits but nearly identical magnitudes would differ, on average, such that 398 would be systematically placed farther to the left on the number line, and 401 farther to the right. We tested these possibilities for children aged 7-10 and adults in Experiment 1 using a nonstandard speeded 0-1000 NLE task, and for children aged 7-11 and adults in Experiment 2 using a standard, non-speeded NLE task ¹.

Experiment 1

In Experiment 1, we used a speeded number line estimation task to ask whether magnitudes of presented numerals drive estimation performance, or whether specific digits influence estimates. We were particularly interested in testing for the influence of specific hundreds digits. If the target numerals’ overall magnitudes determine placements, then estimates should be roughly the same for numerals that have different hundreds digits but map to very similar approximate magnitudes (such as 899 and 901). But if specific hundreds digits in the

¹ The analysis plans described in Experiment 1 were devised following casual observation of group data from the 9- and 10-year-old participants, combined. Thus for Experiment 1, analyses of the 9- and 10-year-old groups should be formally considered exploratory, while analyses of the adult and 7- and 8-year-old data are confirmatory. Experiment 2 is fully confirmatory.

target numerals influence placements, these estimates may differ significantly. Children and adults completed a 0-1000 NLE task with paired target values on either side of Hundreds boundaries (e.g. 899/901, such that hundreds digits differed; thus these pairs have similar approximate magnitudes and different hundreds digits and serve as critical test pairs) and Fifties boundaries (e.g. 848/853, such that hundreds digits were the same; thus these pairs have both similar approximate magnitudes and same hundreds digits and serve as control pairs that should be placed in similar positions).

Method

Participants. Participants included 83 schoolchildren, recruited from a local participant database, and 49 undergraduate students from Wesleyan University, who participated for pay or course credit. Eight children and six adults were excluded for developmental delay or concussion, non-completion, computer error, missed instructions, or producing estimates uncorrelated with the target numerals. Remaining participants were 17 7-year-olds ($M_{age} = 7;5$, range = 7;0 – 7;11, 10 female), 18 8-year-olds ($M_{age} = 8;4$, range = 8;0 – 8;9, 10 female), 20 9-year-olds ($M_{age} = 9;4$, range = 9;4 – 9;11, 11 female), 20 10-year-olds ($M_{age} = 10;5$, range = 10;0 – 10;11, 10 female), and 43 adults ($M_{age} = 20$ years, range = 18 – 22, 25 female). Children received stickers and small toys after participation. Testing took place in a quiet laboratory room.

Stimuli. Stimuli were created using MATLAB. Each trial commenced with a centered grey fixation rectangle (12.3 cm x 0.7 cm) preceding a stimulus screen (both 500 ms for adults and 750 ms for children), followed by a response screen (1500 ms for adults and 2250 ms for children). The stimulus screen displayed the target numeral centered on the screen in 24 pt. Century Gothic font. The response screen displayed a blank number line 12.3 cm long, endpoints marked “0” and “1000”, which appeared at different randomized positions on the screen for each trial. The paired target numerals consisted of ten Fifties pairs at boundaries 50 through 950, and nine Hundreds pairs at boundaries 100 through 900. This yielded 38 distinct target numerals: 47, 51, 98, 102, 147, 153, 199, 202, 249, 252, 298, 302, 349, 351, 398, 403, 449, 453, 499, 502, 547, 552, 597, 601, 647, 652, 699, 703, 747, 753, 798, 802, 848, 853, 899, 901, 949 and 953. Thus in this stimulus set the hundreds digits were also always the leftmost digits (except in the Hundreds pair 98/102 and the Fifties pair 47/51).

Target numeral choices were jittered slightly so that they fell just above and below Fifties and Hundreds boundary values, but were not exactly one unit away from the boundary (i.e., we did not limit the stimuli to numbers like 699 and 701, or 299 and 301, to avoid potentially conveying information about the study’s purpose).

Design. Adults and children each completed two blocks of the NLE task (“N”) and two blocks of a spatial task (“S”) (a separate study, partially reported in Barth, Lesser, Taggart, & Slusser, 2015); blocks were counterbalanced in NSSN or SNNS order for adults, and in NNSS or SSNN order for children to minimize task switching. Adults completed 38 trials per block, with each of the 38 target values appearing once per block; twice total. Children completed 19 trials per block, with each of the 38 target values appearing in only one of the two blocks; once total. Trials were presented in a new pseudorandom order for each participant. Paired target values were not presented together.

Procedure. Participants were seated at a table in front of a computer at a comfortable distance from the screen, close enough to use the mouse. Some participants completed the study on an HP ProBook 14” laptop with an external mouse, and some used an HP Compaq desktop with a Dell 15” monitor. To obscure potential landmarks, blank paper covered the upper portion

of the keyboard and the top of the screen. Adults and children received written and verbal instructions, and children also saw a picture of a blank 0-1000 number line on paper to demonstrate what the number line would look like (no response was made and no feedback was given). Adults completed two practice trials prior to the test trials; children completed four practice trials. Practice trials proceeded like experimental trials, using target values drawn randomly from the list of experimental targets (with different practice trial values for each participant), and with no feedback given. During each trial, participants were prompted to click the mouse at the location on the horizontal line that corresponded with the presented Arabic numeral. Mouseclick locations were recorded as numbers from 0-1000, corresponding to their locations on the response line. A 1000 ms pause separated trials for adults; a 1500 ms pause separated trials for children. For children, the task could be briefly paused in case of distraction.

Analyses. An individual's estimate for a target value was removed as an outlier if it differed from the group mean for that target value by more than 2 SDs. We did not find order effects and report subsequent data collapsing across different block orders.

If paired target values are placed in essentially the same location, then the larger member of the pair should sometimes be placed to the left of the smaller, and should sometimes be placed to the right, with no systematic pattern. But if specific digits matter and paired target values are not placed in the same location, then the larger member of the pair should systematically be placed to the right. Difference scores were calculated to determine formally whether placements differed for numbers with different digits but nearly identical magnitudes. For each pair of target values from each participant's data, we calculated *placement for larger numeral* – *placement for smaller numeral* for nineteen total pairs (e.g. the estimate for 652 minus the estimate for 649, or the estimate for 701 minus the estimate for 698).

For each individual participant, we calculated a mean difference score for the Fifties pairs and a mean difference score for the Hundreds pairs, such that each participant yielded two scores. Individuals' data were excluded at this point if more than 5 pairs were missing (one 7-year-old, one 8-year-old, one 9-year-old, one 10-year-old, no adults). The following participants were included in the final dataset: 16 7-year-olds ($M_{age} = 7;5$), 17 8-year-olds ($M_{age} = 8;4$), 19 9-year-olds ($M_{age} = 9;5$), 19 10-year-olds ($M_{age} = 10;5$), and 43 adults ($M_{age} = 20$ years).

Percent absolute error (PAE) was calculated by dividing the absolute difference between the participant's estimate and the number corresponding to the presented position by the numerical range, then multiplying the quotient by 100 to express a percentage (see also Booth & Siegler, 2006; Slusser et al., 2013). The average PAE, reported for each age group, aligns with previous reports of increasing accuracy with age and experience: 7-year-olds (PAE = 15.9%), 8-year-olds (PAE = 9.60%), 9-year-olds (PAE = 7.18%), 10-year-olds (PAE = 6.64%), and adults (PAE = 3.00%).

Results

Figure 1A depicts bias in group median placements for target values comprising Fifties pairs (open circles) and Hundreds pairs (filled circles) for each age group in Experiment 1. To graphically depict whether group medians systematically exhibited larger estimates for larger members of pairs, we drew a connecting line between each pair in which the larger target numeral fell to the right of the smaller numeral in the group median estimates (e.g. when 601 was placed to the right of 598). Most of the Hundreds pairs, but not the Fifties pairs, show such connecting lines (see Figure 1A).

Note different y-axis for 7-year-old data in Column A

Figure 1. Results of Experiment 1 (0-1000 speeded number line task). A) Bias in group median estimates for each age group for paired target numerals at Fifties boundaries (e.g. 349, 351) and Hundreds boundaries (e.g. 398, 401). Accurate estimates fall on $y = 0$, positive y values indicate placement too far to the right, and negative y values indicate placement too far to the left. Vertical lines connect paired targets to indicate all pairs for which the larger member of the pair was located to the right of the smaller member at the group median level. B) Difference scores for the Fifties and Hundreds pairs for each age group. Difference scores reflect the difference in placements for the higher vs. lower member of a pair (e.g. placement of 401 minus placement of 398; see Exp. 1, Analyses section for details). Error bars represent 95 percent confidence intervals.

Difference scores (generated from individual participants' data, not from group medians; see Analyses section above) for Fifties and Hundreds pairs for each age group are shown in Figure 1B. If specific hundreds digits presented do not matter, such that estimates are the same on average for target numerals below and above Hundreds boundary values, then the Hundreds difference scores should not differ from zero. If the specific hundreds digits do matter, such that

target numerals above Hundreds boundaries are systematically placed to the right, then this should be reflected in Hundreds difference scores that are greater than zero. Fifties pairs do not differ in hundreds digits or in approximate magnitudes, so they should produce difference scores equivalent to zero. We did not have a strong prediction about age effects, but included age groups in our analysis. An ANOVA using difference scores as the dependent variable revealed a main effect of boundary type (Fifties vs. Hundreds, $F(1,109) = 131.3$, $p < .001$, $\eta_p^2 = 0.546$), an effect of age ($F(4,109) = 6.32$, $p < .001$, $\eta_p^2 = 0.188$), and an interaction ($F(4,109) = 10.2$, $p < .001$, $\eta_p^2 = 0.271$). The main effect of Boundary Type comes from the distinction between the Hundreds difference scores, which were greater than zero, and the Fifties difference scores, which were not distinguishable from zero; the interaction with age appears to reflect the overall reduction in Hundreds difference scores with age. Difference scores for Hundreds pairs were significantly greater than 0, corrected for multiple comparisons ($\alpha = 0.01$), for all age groups (all $t > 6.20$, all $p < .001$, all $d > 1.01$) except 7-year-olds ($t(15) = 1.56$, $p = .139$). Difference scores for Fifties pairs were not significantly different from zero for any age group (all t between -1.23 and 0.342 , all $p > .233$). Difference scores for Hundreds pairs were significantly different from those for Fifties pairs, corrected for multiple comparisons, for all age groups (all $t > 4.58$, all $p < .001$, $d > 0.699$) except 7-year-olds ($t(15) = 1.46$, $p = .166$).

Discussion

In the speeded 0-1000 number line estimation task of Experiment 1, hundreds digit identity influenced the estimates of children aged 8-10 and adults (but not 7-year-olds). That is, numerals like 502 were placed systematically to the right of numbers like 499, even though their approximate numerical magnitudes are generally indistinguishable on a 0-1000 scale. In the context of the 0-1000 number line task, no such effect was found for the Fifties pairs: numerals like 452 and 449 were placed in the same locations overall. Because the hundreds digits were also always the leftmost digits in our stimuli (except for the Hundreds pair 98/102 and the Fifties pair 47/51), we cannot determine whether this finding is best understood as a broad “leftmost” digit effect or whether it might be more limited. We return to this question in the General Discussion, but throughout the paper we refer to effects of “hundreds digits” for simplicity.

If estimates in the symbolic number line task are generated solely or primarily from the magnitudes of presented target numerals, then numbers like 499 and 502 should be placed in the same location. The present data aren’t consistent with this idea: target numerals with the same approximate magnitude that shared a hundreds digit (e.g. 449, 452) were placed in the same location, while target numerals with the same approximate magnitude that did not share a hundreds digit (e.g. 499, 502) were placed in considerably different locations for all participants over age 7 (see Figure 1).

The youngest children are likely to have had the least knowledge of and experience with numbers in this range. Both the rapid reading of these numerals and the processing of their numerical meanings might have been extremely difficult for 7-year-olds. It is possible that 7-year-olds could exhibit similar effects for 3-digit numerals presented differently. It is also possible that 7-year-olds generally do not have the number knowledge or multidigit processing ability that is necessary to produce these effects (that is, a child who doesn’t know how to process “799” and “801” in the first place wouldn’t be expected to differentiate them based on their hundreds digits).

While the findings of Experiment 1 suggest that the usual interpretation of the sources of estimates in this task is inaccurate, there are limitations to this study that do not allow for broad

generalization. In particular, the number line task used here was nonstandard in multiple respects. First, the task was rapid, allowing a short time period in which to respond. It is more common for NLE tasks for school-age children to be non-speeded. Second, the response line appeared in a different position for every trial, which should increase difficulty and perhaps alter strategies. Three other qualities of the procedure might have made the task difficult for participants, especially children: the numerical estimation task was presented in the same testing session with other tasks; children saw the target numeral but did not hear it spoken; and the task required participants to use a mouse for their responses. Taken together, these qualities could mean that the findings of Experiment 1 reflect specialized strategies that participants developed specifically for this instantiation of the number line task, and that the same effects would not appear in a standard task. To test this possibility, in Experiment 2 we employed the same overall experimental design with a standard number line estimation task.

Experiment 2

In Experiment 2, we asked whether the finding that specific hundreds digits influence number line placements was the result of a specialized strategy used for the atypical number line task of Experiment 1, or whether it is a broader characteristic of symbolic NLE tasks. If the latter, it should also appear in the typical NLE task of Experiment 2. The overall logic remained the same in Experiment 2: if specific digits don't matter, estimates should be roughly the same for different numerals that map to similar approximate magnitudes (such as 399 and 402), but if they do, estimates should differ. As in Experiment 1, children and adults completed a 0-1000 NLE task with paired target values on either side of Hundreds boundaries (e.g. 698/701) and Fifties boundaries (e.g. 649/652). Target numerals were the same as in Experiment 1, but methods differed considerably in Experiment 2. The task was presented on a touchscreen tablet; it was not speeded; and the response line was stationary. Thus the task of Experiment 2 was a standard number line estimation task, representative of the way the NLE task is most commonly presented. Experiment 2 tested a similar but slightly broader age range (7- through 11-year-olds and adults).

Method

Participants. Participants included 106 schoolchildren recruited from a local participant database and 24 undergraduate students from Wesleyan University who participated for course credit. Ten children (no adults) were excluded for non-completion or producing estimates uncorrelated with the target numerals. The remaining sample included 16 7-year-olds ($M_{age} = 7;4$; range = 7;1 – 7;9, 13 female), 21 8-year-olds ($M_{age} = 8;5$, range = 8;1 – 8;11, 14 female), 19 9-year-olds ($M_{age} = 9;4$; range = 9;0 – 9;11, 12 female), 20 10-year-olds ($M_{age} = 10;4$; range = 10;0 – 10;11, 11 female), 20 11-year-olds ($M_{age} = 11;4$, range = 11;0 – 11;11, 12 female), and 24 undergraduates ($M_{age} = 20$ years, range = 18 – 22, 15 female). Children received stickers and small toys following participation. Testing took place in a quiet laboratory room.

Stimuli. Customized stimuli were created with a commercial iPad application (EstimationLine, <https://hume.ca/ix/estimationline.html>) and presented on an Apple iPad Air oriented horizontally. EstimationLine displayed a black 16.65 cm horizontal line (situated approximately 5.8 cm above the bottom of the screen) with small vertical lines at each end (extended approximately 1.4 cm above and below the horizontal line), and endpoints labeled 0

and 1000. A green rectangular icon (labeled “Go”) and a red rectangular icon (labeled “Done”) were located at the lower left hand and lower right corners, respectively (approximately 0.4 mm from the left/right of the screen and 1.1 cm above the bottom of the screen). Target numerals were identical to those used in Experiment 1 and were again presented in pseudorandom order.

Design. All participants first completed one practice trial. Participants then completed two blocks of 38 trials each (each target value presented once per block).

Procedure. Participants were provided with written and spoken instructions, similar to methodology used by Siegler & Opfer (2003). The 0-1000 number line and rectangular icons were visible on the screen throughout the experiment. The experimenter began by saying, “In this game, you will see a number line with endpoints from 0 to 1000. A number will appear on the screen and your job is to touch on the line where you think that number should go. A red mark will show where you have touched the screen.” The experimenter then touched the Go icon, and text reading “Where is [N]” appeared approximately 5.8 cm from the left of the screen and 12 cm above the bottom of the screen. The experimenter asked, “If 0 goes here (points at the left endpoint) and 1000 goes here (points at the right endpoint), where would you put [N]?” After the participant touched the line, they (if an adult participant) or the researcher (if a child participant) would press the Done icon to advance to the next trial. Small gray text that read “Retry” appeared just below the Done icon after the participant touched the line. However, participants were instructed to use the Retry option only if they made an accidental estimate. For all participants, the first trial was a practice trial with target numeral 270, and experimental trials followed. For children, the experimenter repeated the full spoken question (“If 0 goes here ..”) during the first few experimental trials. For children (but not adults), the target numeral was always read out loud, throughout the session. The first and second trial blocks were separated by a screen asking “Continue to the next set?” Participants had the option to press a red “No” icon to quit or a blue “Yes” icon to continue. No feedback was provided for practice or test trials.

Analyses

As in Experiment 1, an individual’s estimate for a target value was removed as an outlier if it differed from the group mean for that target value by more than 2 SDs. PAEs and difference scores were also calculated for each participant. Individuals’ data were excluded at this point if more than 5 pairs were missing due to outlier removal (one 7-year-old, one 8-year-old, two 9-year-olds, two 10-year-olds, one 11-year-old, no adults). The following participants were included in the final dataset: 15 7-year-olds ($M_{age} = 7;4$), 20 8-year-olds ($M_{age} = 8;5$), 17 9-year-olds ($M_{age} = 9;4$), 18 10-year-olds ($M_{age} = 10;4$), 19 11-year-olds ($M_{age} = 11;4$), and 24 adults ($M_{age} = 20$ years).

Results

Percent absolute error (PAE) calculations were as follows: 7-year-olds, PAE = 13.9%; 8-year-olds, PAE = 8.58%; 9-year-olds, PAE = 6.03%; 10-year-olds, PAE = 6.19%; 11-year-olds, PAE = 4.30%; and adults, PAE = 2.79%.

Figure 2A depicts bias in the group median placements of members of Fifties pairs (open circles) and Hundreds pairs (filled circles) for each age group in Experiment 2. As in Experiment 1, we drew a connecting line between every pair in which the larger target numeral was placed to the right of the smaller numeral. As in Experiment 1, most Hundreds pairs show such connecting lines, but this is not so for Fifties pairs.

Note different y-axis for 7-year-old data in Column A

Figure 2. Results of Experiment 2 (0-1000 non-speeded number line task). A) Bias in group median estimates for each age group for paired target numerals at Fifties boundaries (e.g. 349, 351) and Hundreds boundaries (e.g. 398, 401). Accurate estimates fall on $y = 0$, positive y values indicate placement too far to the right, and negative y values indicate placement too far to the left. Vertical lines connect paired targets to indicate all pairs for which the larger member of the pair was located to the right of the smaller member at the group median level. B) Difference scores for the Fifties and Hundreds pairs for each age group. Difference scores reflect the difference in placements for the higher vs. lower member of a pair (e.g. placement of 401 minus placement of 398; see Exp. 1, Analyses section for details). Error bars represent 95 percent confidence intervals.

We again used difference scores to determine whether placements for numbers with different digits but nearly identical magnitudes were the same or different. Difference scores for Fifties and Hundreds pairs for each age group are shown in Figure 2B. An ANOVA revealed a main effect of boundary type (Fifties vs. Hundreds, $F(1, 107) = 207.7$, $p < .001$, $\eta_p^2 = 0.660$), a main effect of age ($F(5, 107) = 5.88$, $p < .001$, $\eta_p^2 = 0.125$), and an interaction ($F(5, 107) = 3.30$, $p = .008$, $\eta_p^2 = 0.134$). As in Experiment 1, the main effect of Boundary Type comes from the distinction between the Hundreds difference scores, which were greater than zero, and the Fifties difference scores, which were not distinguishable from zero; thus the interaction with age reflects the overall reduction in Hundreds difference scores with age. Difference scores for Hundreds pairs were significantly greater than zero, corrected for multiple comparisons ($\alpha = 0.008$), for all ages (all $t > 4.80$, all $p < .001$, all $d > 1.13$), while Fifties difference scores were not significantly different from zero for any age group (all t between -0.913 and 1.27 , all $p > .221$). Difference scores for paired target numbers at Hundreds boundaries were significantly different from those at Fifties boundaries for all age groups, corrected for multiple comparisons (all $t > 3.53$, all $p < .004$, $d > 0.910$). Overall, for the target numerals in Hundreds pairs, larger numerals were systematically placed to the right of smaller numerals, but this was not true for the target numerals in Fifties pairs.

Discussion

In the standard 0-1000 number line estimation task of Experiment 2, specific hundreds digits influenced the estimates of children (at all ages tested, 7-11 years) and adults, though the magnitude of the effect was smaller in adults. As in the speeded and atypical task of Experiment 1, numbers like 502 were systematically placed to the right of numbers like 499, even though their approximate numerical magnitudes are essentially identical. In Experiment 2, 7-year-olds showed this effect like the other age groups, while in Experiment 1 they did not. We attribute this to the high speed of the Experiment 1 task: 7-year-olds produced highly variable and inaccurate estimates in Experiment 1, but they appeared better able to perform the non-speeded task of Experiment 2. We again found no effect of for the Fifties pairs in this 0-1000 task: numerals like 452 and 449 were placed in the same locations overall.

Figure 3 summarizes the key findings of Experiments 1 and 2, showing simultaneous confidence intervals for the difference scores for Hundreds and Fifties pairs for all age groups, in both experiments. Just as in Experiment 1, target numerals with the same approximate magnitude that did not share a hundreds digit (e.g. 499, 502) were placed in considerably different locations for participants in Experiment 2. This shows that the findings of Experiment 1 did not result from strategies that participants applied specifically in response to the atypical speeded task used in that experiment: the same results arose for the standard number line estimation task of Experiment 2.

Exploratory analyses: Experiments 1 and 2

Our basic results clearly show that hundreds digits in the presented target numerals exert a strong influence on estimates. But could it be that some participant groups *only* use hundreds digits, such that their estimates show no influence from the other digits in the target numerals? We conducted exploratory analyses to answer this question by identifying a new set of target numerals: pairs with the same hundreds digits but very different magnitudes, such as 899/801 or 398/303. We call these “High-Low” pairs. For each participant, we calculated a mean difference

Figure 3. Key findings from Experiments 1 (Column A) and 2 (Column B). Graphs show simultaneous 95% confidence intervals (familywise confidence level 95%) of Fifties and Hundreds difference scores. Difference scores reflect the different in placements for the higher vs. lower member of a pair (e.g. placement of 401 minus placement of 398). Bars represent the range of difference scores for each age group, boxes represent 25th percentile (bottom of box) and 75th percentile (top of box), and bolded line through the center of each stem and leaf represents the median or 50th percentile. In both experiments, CIs for Fifties difference scores contain 0 and CIs for Hundreds scores do not, except for the 7-year-olds of Experiment 1.

score for the High-Low pairs. These High-Low difference scores should differ from zero if numbers like 801 and 899 are placed differently (if hundreds digits aren't solely responsible for placements). But if hundreds digits *alone* contribute to estimates, placements would not differ for numbers like 801 and 899, and the High-Low scores would not differ from zero, on average ².

² Individuals' data were excluded at this point if more than 2 pairs were missing. For Experiment 1, this resulted in one child being excluded such that the following participants remained in the exploratory analyses: 17 7-year-olds ($M_{age} = 7;5$), 18 8-year-olds ($M_{age} = 8;4$), 19 9-year-olds ($M_{age} = 9;5$), 20 10-year-olds ($M_{age} = 10;5$), and 43 adults ($M_{age} = 19.7$). For Experiment 2, six children were excluded and the following participants remained: 15 7-year-olds ($M_{age} = 7;4$), 20 8-year-olds ($M_{age} = 8;5$), 17 9-year-olds ($M_{age} = 9;4$), 18 10-year-olds ($M_{age} = 10;4$), 20 11-year-olds ($M_{age} = 11;4$), and 24 adults ($M_{age} = 19.5$).

For Exp. 1, High-Low difference scores were greater than zero (corrected for multiple comparisons) for children aged 9 and 10 and adults (all $t > 3.55$, all $p < .003$, all $d > 0.793$), but not for children ages 7 and 8 (all t between 0.619 and 1.52, all $p > .147$). A one-way ANOVA using High-Low difference scores as the dependent variable revealed a main effect of age, $F(4,112) = 15.4$, $p < .001$, $\eta^2 = 0.354$. Bonferroni post-hoc comparisons suggested that adults drove this effect of age (adults compared to all other ages, all $p < .002$). For Exp. 2, High vs. Low difference scores were significantly greater than zero (corrected for multiple comparisons) for all age groups (all $t > 3.84$, all $p < .002$, all $d > 0.507$) except 7-year-olds, $t(14) = 1.46$, $p = .166$. A one-way ANOVA using High vs. Low difference scores as the dependent variable revealed a main effect of age, $F(5,108) = 13.9$, $p < .001$, $\eta^2 = 0.394$. Bonferroni post-hoc comparisons highlighted that adults drove this effect of age (adults compared to all ages, all $p < 0.004$), and revealed a significant difference between 11-year-olds and 7-year-olds, $p = .034$.

These analyses revealed that 7-year-olds (in both experiments) and 8-year-olds (in the speeded task of Experiment 1, but not the standard task of Experiment 2) produced indistinguishable placements for numbers like 801 and 899. All other age groups produced different placements for these types of target numerals, showing that hundreds digits *and* other digits contributed to estimates for older children and adults, but not for the youngest participants. Because the 7-year-olds of Experiment 1 produced highly variable estimates and showed no hundreds-digit effects (i.e., their placements of numbers like 799 and 801 did not differ, so there are no significant findings at all in this group), it seems likely that the speeded 0-1000 task was difficult for children of this age and their results should not be overinterpreted. This leaves the 8-year-olds of Experiment 1 and the 7-year-olds of Experiment 2: both of these groups produced different estimates for numbers like 801 and 798 (different in hundreds digits but not magnitudes), but *not* for numbers like 798 and 701 (different in magnitudes but not hundreds digits). These findings point to a developmental progression in which children first make symbolic 0-1000 number line placements based only on hundreds digits, and then later begin to incorporate information about the target numerals' magnitudes beyond their hundreds digits.

We next compared the differences scores for Hundreds pairs from our main findings (e.g. placements for numbers like 801 vs. 798), to the High-Low difference scores from the exploratory analyses (e.g. placements for numbers like 798 vs. 702). Were the former or the latter placed more differently on the number line? In other words, did the target numerals' hundreds digits alone or their overall magnitudes matter more in determining estimates? For Experiment 1, an ANOVA revealed a main effect of difference score type (Hundreds Difference Scores vs. High-Low Difference Scores), $F(1, 109) = 4.74$, $p = .032$, $\eta_p^2 = 0.042$, a main effect of age, $F(4,109) = 30.3$, $p < .001$, $\eta_p^2 = 0.527$, and an interaction, $F(4,109) = 16.9$, $p < .001$, $\eta_p^2 = 0.384$. For Experiment 2, an ANOVA revealed a main effect of difference score type (Hundreds Difference Scores vs. High-Low Difference Scores), $F(1, 107) = 5.17$, $p = .025$, $\eta_p^2 = 0.046$, a main effect of age, $F(5,107) = 16.5$, $p < .001$, $\eta_p^2 = 0.435$, and an interaction, $F(5,107) = 9.78$, $p < .001$, $\eta_p^2 = 0.314$. Thus for both experiments, difference scores were larger for Hundreds pairs than for High-Low pairs: participants differentiated numbers like 801 and 798 more than they differentiated numbers like 792 and 702.

Data from all individual child participants are shown in Figure 4 arranged by age in months. This figure depicts individual differences and allows for visual comparisons across the types of difference scores. Hundreds pairs difference scores (top) and High-Low difference scores (bottom) are shown for Experiment 1 (left column) and Experiment 2 (right column). Note that mean difference scores (solid horizontal lines) fall between 50 and 60 for Hundreds

Figure 4. Individual child data. A) Experiment 1, Hundreds difference scores vs. age in months, and mean Hundreds difference score for all children. Nearly all individual children had positive Hundreds difference scores; a positive Hundreds difference score means that larger members of Hundreds pairs were placed to the right of smaller members (e.g. 701 placed to the right of 698; see Exp. 1, Analyses section for details). Hundreds difference scores and age in months were positively correlated in Exp. 1, Pearson's $r = 0.257$, $n = 71$, $p = 0.031$. B) Experiment 2, Hundreds difference scores vs. age in months, and mean Hundreds difference score for all children. Nearly all individual children again had positive Hundreds difference scores. Hundreds difference scores and age were not correlated in Exp. 2, Pearson's $r = 0.070$, $n = 89$, $p = 0.514$. C) Experiment 1, High-Low difference scores vs. age in months, and mean High-Low difference score for all children. A positive High-Low difference score means that larger members of High-Low pairs were placed to the right of smaller members (e.g. 798 placed to the right of 701). High-Low difference scores were not correlated with age in months in Exp. 1, Pearson's $r = -0.025$, $n = 74$, $p = 0.829$. D) Experiment 2, High-Low difference scores vs. age in months, and mean High-Low difference score for all children. High-Low difference scores and age in months were correlated in Exp. 2, Pearson's $r = 0.266$, $n = 90$, $p = 0.011$.

pairs (801 vs. 798) and between 20 and 30 for High-Low pairs (798 vs. 702). Nearly all individuals' Hundreds difference scores fall above zero (dashed horizontal line), showing that the group-level effects we found were not simply driven by a subset of individuals.

At the group level, the previous exploratory analyses showed that people's estimates are generally influenced strongly by hundreds digits though they also took into account other information about the target numerals beyond the hundreds digits (except for the youngest children, who differentiated numerals *only* by hundreds digits). This leaves open the question of individual differences. Is there a relationship between individuals' differentiation of numbers like 801 vs. 798 and their differentiation of numbers like 798 vs. 702? These are not independent, because a person using *only* hundreds digits would place 801 and 798 far apart, but 798 and 702 close together. Yet there might be no correlation between these two kinds of difference scores: it is possible that most or all individuals' estimates would show *some* influence of hundreds digits along with the ability to use information beyond the hundreds digits, with no systematic relationship between the two. Another possibility is that some individuals are strongly influenced by hundreds digits only, with others relying much less on hundreds digits, such that a negative correlation between these two types of scores would be observed.

Figure 5. Scatter plots of difference scores for Hundred Pairs (representing differences in placements for numbers like 802 vs. 798) compared to difference scores for High vs. Low pairs (representing differences in placements for numbers like 798 vs. 703), within individuals. Across both experiments, there was a strong negative correlation between Hundreds Pairs difference scores and Low vs. High difference scores: Experiment 1 ($n = 114$, Pearson's $r = -0.871$, $p < .001$) and Experiment 2 ($n = 113$, Pearson's $r = -0.877$, $p < .001$). Correlations are also significant within adult participants alone (Experiment 1, Pearson's $r = -0.854$, $p < .001$, $n = 43$; Experiment 2, Pearson's $r = -0.954$, $p < .001$, $n = 24$).

The data support the latter possibility. Figure 5 shows individuals' Hundreds difference scores (which reflect their different placements of numbers like 801 and 798: same magnitudes, different hundreds digits) plotted against their High-Low difference scores (which reflect their

different placements of numbers like 798 and 702: same hundreds digits, different magnitudes). There is a strong negative correlation. Thus it is not the case that individual participants' estimates are all roughly equally affected by hundreds-digit information. Rather, there are individuals who rely heavily on hundreds digits, and others who do not. The distribution is not bimodal: there are also people who appear somewhat, but not extremely, influenced by hundreds digits. Apparently considerable individual differences exist in the influence of hundreds (or leftmost) digit information on symbolic number line placements: a source of individual difference other than those that have already been explored (to our knowledge). Also of interest is that this correlation exists within adults in both experiments (Figure 5). Our data don't allow us to specify the locus of these individual differences, but this would be a fruitful area for future research.

General Discussion

We asked whether numerical estimates in symbolic number line tasks are generated primarily from the magnitudes of the target numerals, or whether specific digits influence estimates. The logic of the design was as follows: If placements in NLE tasks are based solely or primarily on target numerals' magnitudes, then the particular digits presented in the target numerals shouldn't matter. Estimates for numerals with different digits but nearly identical magnitudes should be indistinguishable, such that placements for numbers like 398 and 401 should be the same. Otherwise, if specific digits in the target numerals do play a role (such that estimation performance is not driven primarily by overall target magnitude), then estimates for numerals with different digits but nearly identical magnitudes would differ: numbers like 398 would be placed farther to the left on the number line, and numbers like 401 farther to the right.

We tested these possibilities in two experiments using 0-1000 number line estimation tasks whose target numerals were paired³, with each member of a pair falling on either side of a critical boundary. "Hundreds" pairs consisted of numerals like 398 and 401; "Fifties" pairs consisted of numerals like 348 and 351. Experiment 1 tested children aged 7-10 and adults in an atypical computerized NLE task: responses were speeded, and the response line could appear in different locations on a screen. Experiment 2 used the same design in a standard non-speeded NLE task with children aged 7-11 and adults.

Both experiments yielded the same unambiguous results: Estimates were systematically different for numerals with different digits but nearly identical magnitudes when the numerals differed in the hundreds digit. That is, estimates for Hundreds pairs differed, with large effect sizes at all ages: numbers like 401 were systematically placed to the right of numbers like 398 (for all participant groups, except for 7-year-olds performing the speeded task of Experiment 1). In contrast, placements for paired target numerals that fell on either side of a Fifties boundary, so that both numerals shared a hundreds digit, did not differ: numbers like 348 and 351 were placed in the same location for all participant groups.

Overall, the findings are not consistent with the most common interpretation of the cognitive processes underlying numerical estimation in symbolic number line tasks. The data show that estimates in these tasks – at least for the 0-1000 range tested here – cannot be generated solely or primarily from the magnitudes of the presented target numerals, because placements differ dramatically when hundreds digits differ but magnitudes remain the same. This

³ Target numerals were "paired" in the study design only; pairs were not presented together during the task.

finding holds both for children, whose experience with numbers in the 0-1000 range is limited, and for adults, whose experience is extensive. Thus participants, regardless of age, cannot be arriving at their estimates simply by translating from the presented Arabic numeral to a mental representation of that Arabic numeral's approximate magnitude, and then marking a corresponding position on the line⁴. Although symbolic NLE tasks are commonly interpreted as though this kind of process underlies participants' placements (Ashcraft & Moore, 2012; Berteletti et al, 2010; Booth & Siegler, 2006; Dehaene, Izard, Spelke, & Pica, 2008; Opfer & Siegler, 2007; Opfer, Thompson, & Kim, 2016; Siegler & Opfer, 2003; Siegler et al., 2009; Siegler, 2016), it is not compatible with the present findings.

These results show that representations of the overall magnitudes of the presented target numerals are not the sole or primary influence shaping children's and adults' placements on symbolic number line estimation tasks, at least for numbers in the 0-1000 range. Placements differ considerably when hundreds digits differ, in children and adults. These findings do not allow us to specify exactly how the particular digits in target numerals influence participants' placements, but they do allow some possibilities to be ruled out. First, the finding is general in the sense that it appears both in the atypical speeded NLE task of Experiment 1 and the standard NLE task of Experiment 2. This shows that specific presented digits influence estimates in typical NLE tasks, not just in the atypical speeded case: the effect cannot be the result of specialized strategies developed in response to the fast pace of the speeded task. Second, the fact that the effect arose even during the fast-paced speeded task suggests that the underlying process is unlikely to require deliberation, or even multiple steps. For example, the results could potentially come from participants attempting to place (say) "398" by first identifying the correct location of 400, and then adjusting their final placement leftward, but overestimating the appropriate adjustment amount. This possibility seems unlikely because of the rapid pace of the Experiment 1 task. We also know that the effect doesn't arise only from hearing the target numerals spoken (as in Experiment 2, where children both saw each target numeral and heard it read to them, e.g. "four hundred and ninety-eight"). This is because adults and children exhibited the same effect in Experiment 1 (where no target numerals were spoken) and adults also showed the effect in Experiment 2 (where only children heard the target numerals spoken).

In follow-up analyses, we asked whether some groups' estimates were *only* shaped by hundreds digit identity, with no identifiable influence from the other digits in the target numerals. The youngest children in both experiments produced different estimates for numbers like 801 and 798 (different in hundreds digits but not magnitudes), but *not* for numbers like 798 and 701 (different in magnitudes but not hundreds digits). This reveals a clear developmental progression: children first make symbolic 0-1000 number line placements based only on hundreds digits, and then only later do their placements show evidence of being shaped by information available in the target numerals beyond their hundreds digits. Even after children cease making estimates that are shaped only by the value of the hundreds digit, however, hundreds digit identity still exerts a strong influence: across both experiments, participants differentiated numbers like 801 and 798 more than they differentiated numbers like 792 and 702.

We also found that individual participants' estimates are not equally affected by hundreds-digit information. Rather, there are individuals who rely heavily on hundreds digits, and others who do not (even among adults). The distribution is not bimodal: there are also people who appear somewhat, but not extremely, influenced by hundreds digits. This shows that

⁴ The data don't show that approximate magnitude representations are uninvolved, but they do show that the mental representations shaping estimates cannot be representations *of the overall magnitudes of the target numerals*.

considerable individual differences exist in the influence of hundreds (or leftmost) digit information on symbolic number line placements: a novel source of individual difference, to our knowledge. These individual differences indicate areas for future work. Are people who show more digit-dependence likely to score lower on assessments of numeracy? Might these tendencies be predictive of economic decision-making: are people who place 798 and 801 far apart on the number line more likely to be swayed by left digit effects in marketplace transactions? Do children who rely more on leftmost digits understand place value less well, and have less knowledge of multi-digit numbers in general, as might be expected? Do they also produce lower scores on formal tests of math achievement?

Additional open questions involve the degree to which these findings will generalize. A strength of this work is that the two NLE task versions differed considerably, but results were remarkably similar across the two experiments. However, only the 0-1000 range was tested here. While this numerical range is commonly used in NLE tasks, and so these results are highly relevant to prior work in this area, we don't know based on the current data whether similar effects will arise in different numerical contexts: will two-digit numbers lead to similar findings, or will larger ranges? Will even younger children show the same patterns of performance when tested with a smaller numerical range?

How should we understand these results to relate to the left digit effect? Is the effect we observe specifically a hundreds-digit effect, or is it indeed a more general LDE? We cannot differentiate these based on the current data, because in our stimulus set the hundreds digits were also always the leftmost digits (except for the Hundreds pair 98/102 and the Fifties pair 47/51). One proposed explanation for that effect is that under certain conditions, the holistic analog magnitude that is encoded when we convert from number symbols becomes anchored on the leftmost digit (Thomas & Morwitz, 2005; 2009). Alternatively, models of number representation that assume decomposed rather than holistic processing can also explain the LDE (Huber, Nuerk, Willmes, & Moeller, 2016). Support for decomposed processing of multidigit numbers, rather than analog magnitude representations that encompass the holistic magnitudes of single-digit and multi-digit numbers, comes from tasks like two-digit number comparisons using pairs of numbers that are either unit-decade compatible (e.g. 42 and 57) or unit-decade incompatible (e.g. 47 and 62), while overall absolute distance for each pair is held constant. Comparisons are typically slower when digits in the tens and units places are incompatible, which should not occur if numerical magnitudes alone are the bases for comparison. Accordingly, it has been argued that place-value models (e.g. Nuerk, Kaufman, Zoppoth, & Willmes, 2004; Nuerk, Moeller, & Willmes, 2015; Moeller, Fischer, Nuerk, & Willmes, 2009; Moeller, Nuerk, & Willmes, 2009; Verguts & De Moor, 2005), rather than the classic analog model, are necessary to characterize our representations of multi-digit numbers: the processing of such numbers, from this perspective, cannot be well described as a simple mapping of multi-digit numbers to their analog magnitudes. While the present results (like the LDE in general), in our view, are consistent with multiple models of numerical representation, they add to the collection of findings showing that the specific digits involved in a numerical task may shape behavior in many number-processing situations.

Do results similar to those found here arise in other tasks that are generally assumed to probe numerical magnitude (rather than being heavily influenced by digit identity)? To give one example, many researchers have recently adopted unbounded NLE tasks as an alternative to the more traditional bounded task, in order to avoid some of the disadvantages of the bounded task (Cohen & Blanc-Goldhammer, 2011; Cohen & Quinlan, 2017; Cohen & Sarnecka, 2014; Link et

al., 2014; Reinert et al., 2015, 2017). Do participants in unbounded tasks also rely unexpectedly on the specific digits presented, and if so, how might this effect influence the interpretation of the results?

These findings of strong digit effects in bounded NLE tasks have implications for the design and interpretation of other symbolic NLE studies. The usual assumption when designing these studies is that only the target magnitudes matter. Therefore, experimenters typically sample their target numerals without regard for the specific digits they contain: 798 is assumed to be equivalent to 802, for the purpose of 0-1000 number line estimation. Because sampling is often rather sparse, the digits that happen to be present in the final set of target numerals could have a large influence on overall response patterns and, potentially, on the eventual interpretation of the data. For example, 0-1000 number line estimation accuracy predicts later conceptual and procedural success with fractions (Hansen et al., 2015; Jordan, Hansen, Fuchs, Siegler, Gersten, & Micklos, 2013); it is possible that the digit-dependence effects identified in the present paper contribute to these types of links in ways that might be illuminating to our understanding of children's underlying numerical competence.

The present results clearly call for careful attention to the digits in target numerals when researchers design or interpret NLE studies that use three-digit numbers; future work will determine whether this effect extends to other ranges. It is also common to equate number-line estimation tasks using symbolic target numerals and those using dot sets to convey target numerosities; the present findings of strong digit effects show that these tasks differ more than has generally been acknowledged.

Conclusions

In two symbolic 0-1000 number line estimation experiments, we found that school-age children's and adults' estimates were systematically different for numerals with different digits but nearly identical magnitudes when those numerals differed in their hundreds digit (e.g. 801 and 798). Effect sizes were large at all ages. These findings are not consistent with the most common interpretation of the cognitive processes underlying numerical estimation in symbolic number line tasks: that estimates are generated by accessing numerical magnitude representations that map accurately (if noisily) onto the magnitudes of the presented target numerals. Exploratory analyses taken together with the key findings from our main analyses reveal a clear developmental progression: at least for the numerical range tested here, children first make symbolic number line placements based only on hundreds digits, and then later begin to incorporate information about the target numerals' magnitudes beyond their hundreds digits. Future studies might explore whether this developmental progression also exists for younger children working with smaller numerical ranges. The findings also reveal considerable differences in the degree to which individuals are influenced by digit identity (even in adults), which may prove fruitful as a predictor of other numerical, mathematical, and economic behaviors.

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