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Potential Moderators of the Left Digit Effect in Numerical Estimation

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Supplementary Materials: Preregistration [see Index of Supplementary Materials]

Abstract

Recent work reveals a left digit effect in number line estimation such that adults' and children's estimates for three-digit numbers with different hundreds-place digits but nearly identical magnitudes are systematically different (e.g., 398 is placed too far to the left of 401 on a 0-1000 line, despite their almost indistinguishable magnitudes; Lai et al., 2018, https://doi.org/10.1111/desc.12657). In two preregistered studies (N = 218), we investigate the scope and malleability of the left digit effect. Experiment 1 used a typical forward-oriented 0-1000 number line estimation task and an atypical reverse-oriented 1000-0 number line estimation task. Experiment 2 used the same forward-oriented typical 0-1000 number line estimation task from Experiment 1, but with trial-by-trial corrective feedback. We observed a large left digit effect, regardless of the orientation of the line in Experiment 1 or the presence of corrective feedback in Experiment 2. Further, analyses using combined data showed that the pattern was present across most stimuli and participants. These findings demonstrate a left digit effect that is robust and widely observed, and that cannot be easily corrected with simple feedback. We discuss the implications of the findings for understanding sources of the effect and efforts to reduce it.

Keywords

number line estimation, left digit effect, atypical number line, corrective feedback

Number line estimation (NLE) tasks are widely acknowledged as effective instructional and assessment tools for numerical cognition and as reliable predictive measures for math outcomes (Barth & Paladino, 2011; Booth & Siegler, 2008; Brez et al., 2016; Ellis et al., 2021; Schneider et al., 2018; Siegler & Opfer, 2003; Siegler & Ramani, 2009; Slusser et al., 2013; Xing et al., 2021; Zhu et al., 2017). In typical NLE tasks, participants estimate the location of some numerical quantity (e.g., in the form of a spoken number word or Arabic numeral) on a horizontal line labeled only with endpoints (e.g., 0 and 1000). Accuracy on a 0-1000 NLE task in elementary school predicts later conceptual and procedural success with fractions (Hansen et al., 2015; Jordan et al., 2013), and using number lines as instructional tools supports fraction learning (Hamdan & Gunderson, 2017). Furthermore, number line estimation proficiency correlates substantially with counting, arithmetic, and standardized mathematical achievement tests (Ellis et al., 2021; Schneider et al., 2018).

A common measure of performance on these tasks, overall accuracy error, expresses the distance between placements and correct locations of target numerals relative to the numerical range of the number line (focusing on the degree of error and ignoring direction). This theoretically neutral measure of error is widely reported. Overall accuracy error in NLE tasks is known to improve with age (e.g., Berteletti et al., 2010; Booth & Siegler, 2006, 2008), use of reference points and benchmarks (e.g., Peeters et al., 2017; Slusser et al., 2013), familiarity with the numerical range

(Slusser et al., 2013), and trial-by-trial performance feedback (Eyler et al., 2018). Overall accuracy error as a measure encompasses error that might arise from a number of different sources. For example, error due to random noise would be expected. There is also considerable evidence that some error in number line performance reflects systematic bias in placements, with different theoretical approaches attributing patterns of bias to different sources. Proposed sources include psychological representations of magnitude (e.g., Dehaene et al., 2008; Siegler & Opfer, 2003), task-related skills such as proportion judgment (e.g., locating 35 as a proportion of the space between 0 and 100; Barth & Paladino, 2011; Cohen & Blanc-Goldhammer, 2011), and translation of numerals into line lengths (Cohen & Sarnecka, 2014). The present work addresses a source of error in NLE that has received less attention: an overweighting of target numerals' leftmost digits.

In much of the work to date, the overall magnitude of a target numeral is thought to guide participants' placements of numbers on a number line (e.g., 398 and 401 are predicted to be placed in similar locations on a 0-1000 line given their similar overall magnitudes). However, there is strong evidence that the individual digits comprising target numerals also influence bounded number line estimates (Kayton et al., 2022; Lai et al., 2018; Patalano et al., 2023; Savelkouls et al., 2020; Williams et al., 2022). For example, Lai et al. (2018) observed a strong influence of leftmost digits on estimates of three-digit numbers with similar magnitudes but different leftmost hundreds-place digits, and there were large effect sizes at all ages tested. Children and adults placed numerals like 798 and 802 (numbers with indistinguishable magnitudes but different leftmost hundreds place digits) in very different locations on a 0-1000 number line. There was noticeable individual variation in that some participants produced estimates more heavily influenced by leftmost digits than others. This effect did not arise for pairs of numerals with indistinguishable magnitudes and the same leftmost hundreds place digit: Children and adults placed numbers like 747 and 753 in approximately the same location.

The left digit effect in NLE is consistently present and robust across tasks varying in presentation modality, numerical range, and required response speed. For instance, the effect arises regardless of whether number words are read aloud by the experimenter or presented visually as Arabic numerals (Lai et al., 2018; Williams et al., 2022). The effect also extends to estimates of two-digit numbers falling around decade boundaries on a 0-100 number line task (e.g., 59 and 61 are placed in very different locations; Patalano et al., 2023; Savelkouls et al., 2020; Williams et al., 2022). The effect arises on speeded computer-based tasks (Lai et al., 2018) and persists when numbers around boundary values (the numbers commonly used to assess left digit effects, e.g., 798 and 802) are embedded in a more extensive stimulus set (Williams et al., 2020). Additionally, the effect remains even with instructional interventions designed to increase task effort through competitive summary feedback (presented using a game format; Kayton et al., 2022), suggesting that the effect is unlikely due to a lack of motivation or insufficient task effort alone, although further work is needed.

A number of important questions grow out of past work that speak to the generalizability of the left digit effect. We introduce three of these questions here and expand on each in turn. First, does the left digit effect extend to "atypical" NLE tasks (i.e., those beyond the typical, left-to-right oriented 0-100 and 0-1000 lines)? Second, is a left digit effect present on NLE tasks in which trial-by-trial corrective feedback (rather than summary feedback across trials) is provided? Third, is the left digit effect widely observed not just when assessed using aggregate data, but also at the level of individual target boundaries (e.g., 100s, 200s) and individual people? These three questions are the focus of the present work. While the organizing theme of this work is the generalizability of the left digit effect (across contexts, stimuli, and individuals), the work also has important implications for understanding the source of the left digit effect and may suggest approaches to reducing the effect in adults. In the remainder of the introduction, we further motivate each research question and describe how we will address each here.

The present work had three goals. Our first goal was to test whether the left digit effect extends to an atypical reverse-oriented 1000-0 number line (on which numbers increase from right to left). Atypical number lines, including noncanonical numerical ranges (e.g., 1,639-2,897; Booth & Newton, 2012; Di Lonardo et al., 2020; Hurst et al., 2014; Luwel et al., 2018) and spatial orientations (e.g., Di Lonardo et al., 2020; Ebersbach, 2015; Klein et al., 2014; Mihulowicz et al., 2015; Simms et al., 2013), are used to better understand performance and the strategies that underlie performance. For example, children have lower accuracy error on the typical forward-oriented number line than on the reverse-oriented number line (Ebersbach, 2015). For adults, an initial study from Di Lonardo et al. (2020) found that, on the forward-oriented number line, adults showed a bias towards scanning from left to right (consistent with a left-to-right orientation in Western cultures; see also Göbel et al., 2011) and placed targets too far to the left. In contrast, on the reverse-oriented number line, the left-to-right scanning bias was reduced, and targets were no longer placed too far to the left (i.e., errors were equally likely to be in either direction). Overall accuracy error was also reduced on the reverse-oriented number line (Di Lonardo et al., 2020). These findings suggest that the spatial orientation of the number line affects several aspects of adults' performance and further motivates the question of whether the left digit bias extends to the reverse-oriented number line.

In Experiment 1, participants completed a typical forward-oriented 0-1000 NLE task and an atypical reverse-oriented 1000-0 NLE task. We considered several possible outcomes. The first is that, on the reverse-oriented line, the left digit effect will be reduced or eliminated (similar to the findings for overall accuracy error in Di Lonardo et al., 2020). This finding would suggest that the left digit effect is at least partially moderated by the spatial orientation of the line. We considered an alternative possibility in light of the evidence of greater overall accuracy error when numerical ranges are novel or unfamiliar (Chesney & Matthews, 2013; Luwel et al., 2018). That is, the reverse-oriented number line may result in a larger left digit effect because the task is less familiar and more effortful. Finally, we considered the possibility that a sizeable left digit effect of similar magnitude to the original finding would persist regardless of the orientation of the number line. This outcome would provide evidence of the robustness of the left digit effect in NLE across typical and atypical contexts. It would also be consistent with one cognitive account of the left digit effect suggesting that the overweighting of leftmost digits occurs in the conversion of symbols to magnitudes rather than being dependent on response format (see Thomas & Morwitz, 2005; see also Kayton et al., 2022, for a discussion).

Our second goal was to test whether the left digit effect persists in the context of a trial-by-trial corrective feedback intervention. This question speaks to the malleability of the left digit effect and whether it is relatively immutable or the result of a bias that is easily corrected. Kayton et al. (2022) showed that summary feedback used to enhance motivation did not reduce the left digit effect. But, because that feedback was a summary score across trials, it could not easily be used to assess *how* to change one's placements for individual target numerals. It thus remains possible that the effect is easily corrected once placement errors are transparent. In past work with children, receiving corrective feedback for a small selection of target numerals led to reductions in overall accuracy error (Barth et al., 2016; Opfer & Siegler, 2007). In past work with adults, corrective feedback (on a set of five trials) reduced overall accuracy error, especially among adults without a college education (Eyler et al., 2018). No work has used trial-by-trial corrective feedback to study the left digit effect, and even the study of overall accuracy error in adults by Eyler et al. (2018) used only a small number of trials. Thus, there is a need for further study of the use of trial-by-trial corrective feedback for improving adult NLE performance.

In Experiment 2, participants completed three blocks of the typical forward-oriented 0-1000 NLE task (the same one used in Experiment 1), during which they received either trial-by-trial corrective feedback in the middle block or no feedback. We again considered several possibilities. The first is that, following corrective feedback, the left digit effect will be reduced or eliminated, similar to the reduction in overall accuracy error in past work with adults (Eyler et al., 2018). If feedback helps reduce the left digit effect, this study will be the first to show that the left digit effect is malleable, setting the stage for developing educational interventions to reduce it. We also considered the alternative possibility that, following corrective feedback, the left digit effect remains unchanged. Such a finding would be consistent with Kayton et al. (2022), in which summary accuracy feedback did not reduce the effect. The finding would provide evidence of the robustness of the left digit effect in NLE across feedback contexts and would support the possibility that the effect is not easily corrected through brief interventions.

Our third and final goal was to investigate if the left digit effect is widely observed across pairs of target numerals and across individuals, or if only a subset of target pairs or individual participants show the effect. In other words, in addition to assessing the generalizability of the left digit effect across task variations, we also consider generalizability across target boundaries and individuals. It may be that the effect extends across a range of task variations but that only a subset of target boundaries or individuals drive the effect. If so, the findings would inform when and how often to expect a digit dependent placement pattern to arise and may suggest new avenues for understanding why it arises (e.g., by looking at the common characteristics of boundaries or individuals showing the pattern). To explore this question, using the data from Experiments 1 and 2 combined, we tested for significant left digit effects at the level of individual pairs of target numerals and individual participants. We specifically tested for left digit effects using individual target numerals around hundreds boundaries (e.g., 398/403 vs. 699/703) to investigate whether the effect is reliably observed for each boundary pair, and also asked if individual participants reliably showed the effect. In sum, across two studies, we considered the generalizability of the left digit effect across contexts, stimuli, and individuals, with a focus on the implications of findings for understanding the source of the effect and ways to reduce it.

Experiment 1

Adults completed two blocks of a non-speeded NLE task with target numerals between 0 and 1000. Each block consisted of a typical forward-oriented number line from 0 (left) to 1000 (right) or an atypical reverse-oriented number line from 1000 (left) to 0 (right). Target numerals fell around hundreds boundaries (e.g., 699 and 703), fifties boundaries (e.g., 249 and 252), and non-boundaries (e.g., 236). If leftmost digits do not exert a disproportional influence on placements, target numerals around hundreds boundaries (e.g., 798 and 802) will be placed in approximately the same location on the line, with the larger numeral sometimes placed to the right and sometimes placed to the left of the smaller numeral (as occurs for numerals around fifties boundaries, which do not differ on the leftmost digit; Lai et al., 2018). This is because these magnitudes are likely indistinguishable on a physically small number line with a thousand-unit range. However, if leftmost digits disproportionally influence estimates, target numerals falling below hundreds boundaries (e.g., 798) will be placed too far to the left of target numerals falling above hundreds boundaries (e.g., 802), at least on the typical forward-oriented number line. Results from Experiment 1 will reveal whether or not the left digit bias extends to the reverse-oriented line and will broaden our understanding of the ways in which the spatial orientation of the number line affects estimation performance in adults.

Method

Participants

Eighty-six undergraduates (ages 18-23; 64 women, 21 men, 1 undisclosed) participated for introductory psychology course credit. We excluded one additional participant who failed to complete one or more blocks of the number line task. The session lasted approximately 30 minutes.

Stimuli

Customized stimuli were created in the iPad application EstimationLine (Version 3) and presented on a 9.7-inch Apple iPad Air (screen resolution of 2048 x 1536 pixels). Each trial included, in the center of the screen, a black 16.65 cm horizontal line with small vertical lines at each end (extending 1.4 cm above and below the horizontal line) and endpoints labeled (from left-to-right) 0 and 1000 or 1000 and 0. Target numerals (1.5 cm tall) were centered horizontally 6.7 cm above the number line. A green rectangular icon (labeled "Go") and a red rectangular icon (labeled "Done") were located in the lower left and lower right corners, respectively (1.1 cm above the bottom of the screen).

In each block, the same 120 target numerals were presented one at a time in a different randomized order for each participant and within each block. Target numerals fell on either side of a hundreds boundary (nine pairs: 98/102, 199/202, 298/302, 398/403, 499/502, 597/601, 699/703, 798/802, 899/901), fifties boundary (10 pairs: 47/50, 145/152, 249/252, 348/352, 446/451, 546/552, 649/659, 749/751, 842/856, 945/953), or were unrelated to a boundary (82 non-boundary values, e.g., 236, 361, 413). Non-boundary values were evenly sampled from each hundreds range (i.e., 0-100, 200-300, 300-400, etc.). As in Lai et al. (2018), paired numerals were jittered around boundaries (i.e., we did not limit target numerals to those precisely one unit away from a boundary like 199/201 or 599/601) to avoid potentially conveying information about the experiment's purpose. Paired numerals functioned as "pairs" in the design and analyses only; they were not presented together during the task.

Design and Procedure

Participants completed two blocks (one forward-oriented 0-1000 line and one reverse-oriented 1000-0 line) of 120 trials each (one additional practice trial with the number '270' was given at the start of each block). Block order was counterbalanced. The experimenter began each block by saying, "In this game, you will see a number line from 0-1000 [1000-0]. 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 line." Identical written instructions appeared on the screen. Participants tapped the Continue icon to advance to the stimulus screen showing a blank number line and text reading "Where is" at the top (13.5 cm from the bottom). After the participant tapped the Go icon, the target numeral appeared. Participants selected a location on the line, and a vertical red line (approximately 1 cm long) appeared in the chosen location. Participants then pressed the Done icon to advance to the next trial.[1] Screen taps were converted to numbers between 0 to 1000 by the EstimationLine program, corresponding to the selected location along the response line. At the end of the first block, the program prompted participants to return the iPad to the experimenter, who then set up the iPad for the second block. EstimationLine is not time-constrained, and participants did not receive feedback.

Analyses

Following our preregistration, we excluded individual estimates if they exceeded two standard deviations from the group mean for a given target numeral (M = 3.8% of trials within each block). We calculated hundreds difference scores to measure the left digit effect (Lai et al., 2018). For each participant, we calculated *hundreds difference score = placement of larger number – placement of smaller number* for each pair of numerals around a hundreds boundary (e.g., the estimate for 703 minus the estimate for 699). Evidence of the left digit effect in this study comes from hundreds difference scores greater than zero. We excluded participants at this point if more than three paired estimates were missing within one or more blocks due to outlier removal or non-completion of both blocks (n = 10). Participants included in the final sample were 76 undergraduates (ages 18-23 years; 55 women, 20 men, 1 undisclosed).

We calculated individual fifties difference scores using participants' placements of numerals around fifties boundaries (e.g., the estimate for 659 minus the estimate for 649). In contrast to hundreds difference scores, we predicted that fifties difference scores would not differ from zero. We expected participants to place paired target numerals around fifties boundaries in approximately the same location on the line, given their shared leftmost digit. Finally, we averaged the individual difference scores for eight hundreds pairs and nine fifties pairs to yield one mean hundreds difference score and one mean fifties difference score for each participant.[2]

To measure overall accuracy error, we calculated percent absolute error (PAE) by dividing the absolute difference between a participants' estimate and the given target numeral by the numerical range, then multiplying the quotient by 100 to express a percentage: (*PAE = (|actual location − estimated location| / numerical range)*100,* see Siegler & Booth, 2004; Siegler & Opfer, 2003; Slusser et al., 2013). For analyses, we only included non-boundary target numerals and paired numerals around fifties boundaries to compute PAE in order to use independent datapoints to calculate PAE. However, it is worth pointing out that PAE is a broad measure that captures a wide range of potential influences on overall accuracy error. We used only hundreds boundary values to calculate our measure of the left digit effect (because those values provide a straightforward test of the effect), but there is no reason to assume that left digit bias is absent when participants estimate other target numerals. That is, overemphasis on leftmost digits is unlikely to be limited to numerals at hundreds boundaries. Therefore, our measure of PAE also likely includes contributions of error associated with a left digit effect.

We preregistered all reported analyses involving hundreds difference scores unless otherwise noted. Reported analyses involving fifties difference scores and overall accuracy error (PAE) were not preregistered but are consistent with Experiment 2 and past work (Lai et al., 2018; see also Williams et al., 2020).

1) In the first version of the task, participants (n = 33 in analyzed data) could adjust their estimate as many times as they wished due to programming error. This task feature was corrected during data collection, and the remaining participants (n = 43 in analyzed data) could not adjust their estimate after their initial selection (consistent with our preregistered design). There were no differences in overall PAE, $t(74) = 0.80$, $p = .859$, or average hundreds difference score, $t(74) = -0.30$, $p = .530$, between task versions, and no reported findings would change if task version were included as a factor in analyses.

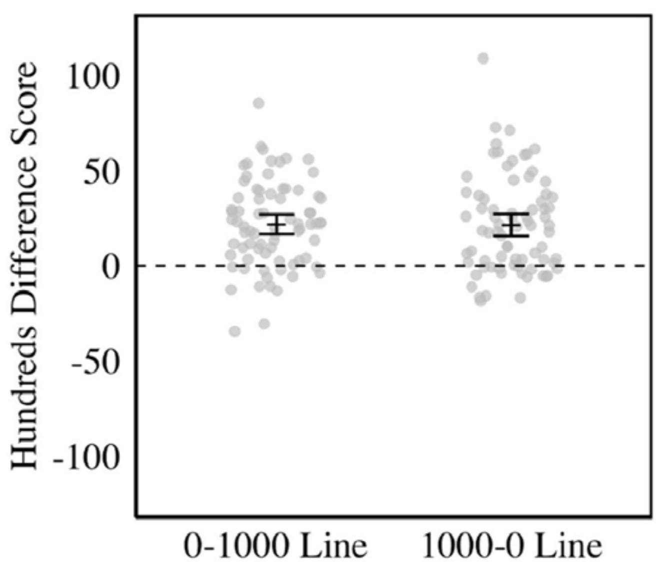
2) To limit primary analyses to three-digit numbers, we excluded paired numerals around the first hundreds boundary (98/102) and the first fifties boundary (47/50) from all analyses. When we included these pairs in analyses, the findings remained the same.

Results and Discussion

Overall accuracy error was consistent with previous studies (0-1000 PAE: M = 3.35%; 1000-0 PAE: M = 3.28%; Lai et al., 2018; Luwel et al., 2018)[3]. We conducted a mixed model ANOVA to assess whether PAE differed as a function of the between-subjects independent variables of gender (male, female) and task order (1000-0/0-1000, 0-1000/1000-0) or the within-subjects variable of line orientation (0-1000, 1000-0). Consistent with past work, our analysis revealed no main effects or interactions of these variables on PAE (Fs < 1.94, ps > .168) except that men had lower PAE than women (M_{men} = 3.0% vs. M_{women} = 3.4%; $F(1, 71) = 4.59$, $p = .036$, $\eta_p^2 = .06$). We next asked if there was a left digit effect for the 0-1000 line and the 1000-0 line. For each line orientation, we conducted one-sample t-tests (two-tailed) to determine if mean hundreds difference scores or mean fifties difference scores were reliably greater than zero. A large left digit effect was observed: Hundreds difference scores were greater than zero on both the 0-1000 line (M = 21.74, SD = 22.57, $t(75)$ = 8.40, p < .001, Cohen's d = 0.96) and the 1000-0 line (M = 21.48, SD = 25.28, $t(75)$ = 7.41, p < .001, Cohen's d = 0.85). See Figure 1 for participants' hundreds difference scores on each line. As predicted, fifties difference scores were not reliably different from zero for the 0-1000 line (M = 2.83, SD = 15.08, $t(75)$ = 1.64, p = .106) though this was not the case for the 1000-0 line, where fifties difference scores were small but reliably greater than zero (M = 3.55, SD = 15.6, $t(75)$ = 1.99, p = .050, Cohen's d = 0.23). We return to the latter in the General Discussion.

Figure 1

Individuals' Mean Hundreds Difference Scores



Note. Scores reflect the average difference between estimates of numerals like 798 and 802 (e.g., the placement of 802 minus the placement of 798; see Analyses for details). Hundreds difference scores greater than zero indicate a left digit effect. Black bars represent the mean hundreds difference score on each line, with 95% confidence intervals. The distance between points along the x-axis is irrelevant; we only produced this spread to more clearly show individual scores.

We next asked if there was an influence of the spatial orientation of the number line on the left digit effect. In following our preregistration (even though we found no effect of line orientation), we included only the first block of trials in these analyses because we had previously considered that there might be practice effects on performance. We conducted an independent-samples t-test comparing hundreds difference scores (first block only) between the 0-1000

3) Including the hundreds boundary pairs in the PAE calculation does not change the pattern of findings (0-1000 PAE: M = 3.35%; 1000-0 PAE: M = 3.32%).

line and the 1000-0 line. There was no difference in the left digit effect between the 0-1000 line (M = 22.78, SD = 21.25; n = 40) and the 1000-0 line (M = 18.18, SD = 26.71; n = 36; $t(74) = 0.84$, p = .406). Because we earlier found a statistically significant fifties difference score for the 1000-0 line, we also ran the analysis as a mixed ANOVA with type of difference score as a within-subjects variable and line orientation as a between-subjects variable. We found a main effect of score type ($F(1, 74) = 52.96$, $p < .001$, $\eta_p^2 = .426$) such that hundreds difference scores (M = 20.60, SD = 23.94) were overall greater than fifties difference scores (M = 4.62, SD = 15.23). We did not find an interaction with line orientation ($F(1, 74)$ = .066, p = .798, η_p^2 = .001). We also ran a mixed ANOVA using all data from both blocks. We found no main effects or interactions related to line orientation, task order, or gender (Fs < 1.35, ps > .121) on the left digit effect, consistent with the preregistered analysis of the first block of trials. These findings suggest that leftmost digits play a prominent role in guiding individual estimates regardless of the spatial orientation of the number line.

Overall accuracy error was similar regardless of the spatial orientation of the number line in Experiment 1. A left digit effect emerged with large effect sizes on both the 0-1000 and 1000-0 number lines: Target numerals with similar overall magnitudes but different leftmost hundreds-place digits (e.g., 798 and 802) were placed farther apart on the number line than their overall magnitudes predict, and participants placed the larger numeral to the right of the smaller numeral, on average. Consistent with prior research and our predictions, participants placed paired numerals with the same hundreds-place digits but different tens-place digits (e.g., 546 and 552) in approximately the same location on the 0-1000 line. On the 1000-0 line, participants placed these paired numerals in different locations, but the effect size was small (much smaller than the left digit effect). Thus, we conclude that adults' number line estimates are heavily influenced by the leftmost digits of target numerals, even in an atypical reverse-oriented 1000-0 number line estimation task.

Experiment 2

In Experiment 1, we investigated the robustness of the left digit effect in NLE by testing the extent to which the effect arises in the context of an atypical reverse-oriented number line. The goal of Experiment 2 was to test whether the left digit effect persists in the context of a trial-by-trial corrective feedback intervention. Also of interest was whether corrective feedback reduces overall accuracy error. The purpose of the study was not to train a particular strategy for reducing the left digit effect but, rather, to assess the malleability of the effect using a common approach aimed at improving performance generally. Participants completed three blocks of the non-speeded forward-oriented NLE task with target numerals between 0 and 1000 (identical to those used in Experiment 1). During the middle block, participants received either trial-by-trial corrective feedback or no feedback. If feedback improves overall performance or reduces the left digit effect, we expect to see one or both of the following for participants who receive feedback: a reduction in overall accuracy error and a reduction in the left digit effect (i.e., a decrease in the distance between estimates of targets around hundreds boundary values like 798 and 802).

Method

Participants

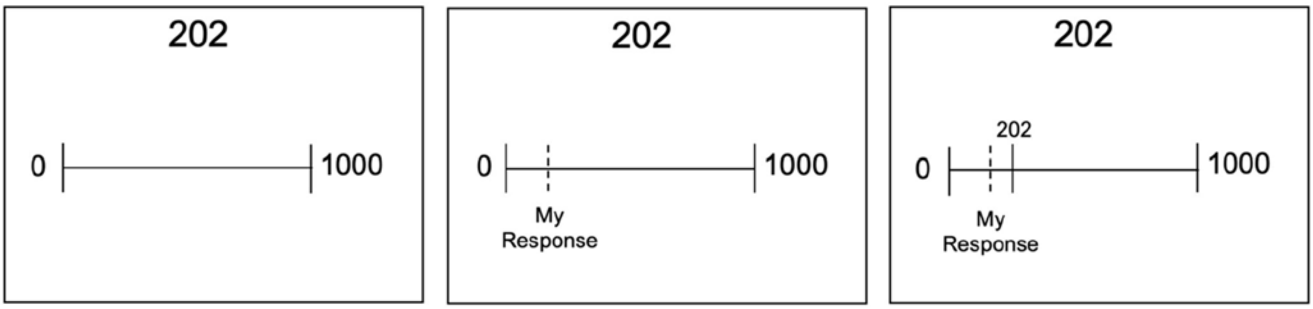
One hundred thirty-two undergraduates (ages 18-23; 76 women, 56 men) participated for introductory psychology course credit. We excluded seven additional participants for failing to complete one or more blocks of the number line task. The session lasted approximately one hour, during which time participants completed (in this order): a decision making task, the number line task, and several additional cognitive tasks and scale measures. The decision making task and other measures are unrelated to the present report, so we will not discuss them further.

Stimuli

Stimuli were adapted from Experiment 1 for PsychoPy3 and presented on a 27-inch iMac (screen resolution: 5120 x 2880 pixels). Similar to Experiment 1, each trial included, in the center of the screen, a black 10 cm horizontal line with small vertical lines at each end (extending 0.4 cm above and below the horizontal line) and endpoints labeled (from left-to-right) 0 and 1000. Target numerals (1 cm tall) were centered horizontally 4 cm above the number line (Figure 2).

Figure 2

Schematic Representation of the Frame-by-Frame Procedure of a Feedback Trial



Note. The dashed line (in red in the actual task) labeled "My Response" represents the estimated location, and the solid line labeled with the target numeral represents the correct location.

In each block, the same 120 target numerals were presented one at a time in a different randomized order for each participant and within each block. Target numerals were the same as in Experiment 1 and consisted of nine pairs on either side of a hundreds boundary, 10 pairs around fifties boundaries, and 82 non-boundary values (see Experiment 1 Stimuli for details).

Design and Procedure

Participants completed three blocks of 120 trials each. Written instructions were given at the start of each block, and participants were instructed to respond as quickly and as accurately as possible. Participants estimated the location of a target numeral on the response line with a mouse click (they could not change their response once they made a selection). A vertical red line (1 cm long) then appeared in the chosen location (see Figure 2, first and second panels). A small rectangular icon (labeled "Next") also appeared centered, approximately 1.1 cm above the bottom of the screen, which participants clicked to advance to the next trial. As in Experiment 1, mouse clicks were converted to numbers between 0 to 1000.

Participants were randomly assigned to the feedback (n = 66) or no feedback (n = 66) condition. The feedback condition consisted of two identical blocks separated by a middle block that included trial-by-trial corrective feedback. In the feedback block, following each participant's response, a number line marked with both the estimated location (vertical red line; 1 cm long) and the correct location (vertical black line; 1 cm long) was shown (see Figure 2, third panel). The no feedback condition consisted of three identical blocks (no trial-by-trial corrective feedback in the middle block).

Analyses

We preregistered all analyses unless noted otherwise. Again, we excluded individual estimates if they exceeded two standard deviations from the group mean for a given target numeral (M = 3.6% of trials within each block). Identical to our approach in Experiment 1, for each participant we calculated one mean hundreds difference score and one mean fifties difference score.[4] Participants were excluded from analyses at this point if more than three hundreds pairs were missing from one or more blocks due to outlier removal (n = 10). Participants included in the final sample were 122 undergraduates (67 women, 55 men). We measured overall accuracy error by calculating percent absolute error (PAE; see Experiment 1 Analyses for details).

Recall that fifties difference scores should not differ from zero, and hundreds difference scores greater than zero indicate a left digit effect. If feedback reduces the left digit effect, the mean hundreds difference scores should decrease

4) We again excluded paired numerals around the first hundreds boundary (98/102) and the first fifties boundary (47/50) in Experiment 2 from all main analyses. The findings remain the same if we include these pairs.

more from Block 1 to Block 3 for participants who receive trial-by-trial corrective feedback than participants who receive no feedback. If feedback does not reduce the left digit effect, any change in mean hundreds difference scores between blocks should be similar across participants regardless of whether they receive feedback. Additionally, if feedback reduces overall accuracy error, PAE should decrease more from Block 1 to Block 3 for participants who receive feedback compared to participants who receive no feedback. If feedback does not reduce overall accuracy error, any change in PAE between blocks should be similar across participants regardless of whether they receive feedback.

Results and Discussion

Overall accuracy error was consistent with Experiment 1 in both the feedback and no feedback conditions (for descriptive statistics, see Table 1).

Table 1

Descriptive Statistics for Experiment 2

Measure	Block 1	Block 2	Block 3
Feedback Condition (*n* = 64)			
Hundreds difference score	23.31 (22.65)[a]	17.09 (20.54)[a]	17.94 (21.59)[a]
Fifties difference score	-0.50 (18.93)	-0.52 (15.25)	-6.43 (19.04)
Percent absolute error	3.89 (1.21)	3.17 (1.22)	3.44 (1.39)
No Feedback Condition (*n* = 58)			
Hundreds difference score	25.85 (19.32)[a]	21.52 (20.12)[a]	21.42 (20.12)[a]
Fifties difference score	2.15 (14.49)	1.85 (18.66)	-2.09 (17.89)
Percent absolute error	3.90 (0.99)	3.81 (1.17)	3.71 (1.25)

Note. Standard deviations appear in parentheses.
[a]Hundreds difference scores are reliably greater than zero, indicating a left digit effect.

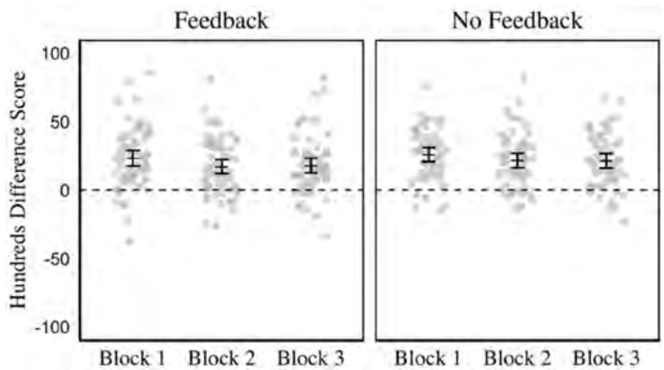
We first asked if there was evidence of a left digit effect. As shown in Table 1, one-sample t-tests (two-tailed) revealed that mean hundreds difference scores were reliably greater than zero in all three blocks of both the feedback and no feedback condition (ts = 6.65 − 10.19, ps < .001, ds = 0.83 − 1.34).[5] This finding is consistent with our findings in Experiment 1 and demonstrates that leftmost digits influence task performance, even when participants receive trial-by-trial corrective feedback (see also Figure 3). Fifties difference scores did not differ from zero (ts < 1.13, ps > .026), with the exception that the mean fifties score was reliably less than zero in the third block of the feedback condition ($t(63) = -2.70$, $p = .009$, $d = -0.34$).

To test our main prediction about the influence of feedback on the left digit effect, we conducted a mixed ANOVA for each of the three dependent measures, with one between-subjects independent variable (condition: feedback, no feedback) and one within-subjects variable (block: first, second, third). We predicted that if feedback reduces the left digit effect, a condition by block interaction would emerge for hundreds difference scores; we found none ($F(2,240) = 0.06$, $MSE = 424.9$, $p = .940$). There was no difference in the left digit effect between performance in the feedback and no feedback condition (see Figure 3). We did not observe a condition by block interaction for fifties difference scores either ($F(2,240) = 0.12$, $MSE = 291.2$, $p = .889$). We also predicted that if feedback reduces overall accuracy error, a condition by block interaction for PAE would emerge. Consistent with this prediction, a condition by block interaction was observed for PAE ($F(2,240) = 6.52$, $MSE < 0.01$, $p = .002$, $\eta_p^2 = .05$); PAE decreased across blocks much more sharply in the feedback condition (especially from Block 1 to Block 2 based on the descriptive data; see Table 1). These findings suggest that the left digit effect cannot be corrected with trial-by-trial feedback, even though this intervention may be effective for reducing error more generally.

5) The finding of a left digit effect here (Block 1) was previously reported in Williams et al., 2020 but is reported again here for comparison with Blocks 2 and 3. The data from Blocks 2 and 3 were not previously analyzed or reported.

Figure 3

Individuals' Mean Hundreds Difference Scores in Each Block of the Feedback (Left) and No Feedback (Right) Condition



Note. Scores reflect the average difference between estimates of numerals like 798 and 802 (e.g., the placement of 802 minus the placement of 708; see also Experiment 1 Analyses). Hundreds difference scores greater than zero indicate a left digit effect. Black bars represent the group average and 95% confidence intervals. The distance between points along the x-axis is irrelevant; the spread of scores is only to show individual scores more clearly.

We also found main effects of block in both feedback and no feedback conditions, consistent with practice-related changes in performance. For both hundreds difference scores (F(2,240) = 3.29, MSE = 1053.3, p = .039, η_p^2 = .03) and PAE (F(2,240) = 11.39, MSE = 5.4, p < .001, η_p^2 = .09), error decreased in the second block and remained similar in the third block. Unexpectedly, for the fifties difference scores, there were also potential practice-related changes (F(2,240) = 3.49, MSE = 1017.1, p = .032, η_p^2 = .03). Fifties differences scores, which were just above zero in the first two blocks, were negative in the third block (i.e., participants placed lower values in the pair to the *right* of the larger value in the pair). We consider this finding further in the General Discussion. For all three dependent measures, there was no main effect of condition (Fs < 2.644, ps > .107). There were also no gender differences in performance on any measure (Fs < .309, ps > .579).

To summarize Experiment 2, we observed a robust left digit effect: Participants placed target numerals with similar overall magnitudes, but different leftmost hundreds-place digits farther apart on the number line than their magnitudes would predict (e.g., 703 was placed too far to the right of 699). This is consistent with our findings in Experiment 1. As predicted, participants placed target numerals with similar overall magnitudes but different tens-place digits (e.g., 648/653) in the same place, on average. This pattern was consistent across participants who received trial-by-trial accuracy feedback and those who did not, suggesting that the left digit effect is not easily corrected with simple feedback. Overall accuracy error followed a different pattern: It was reduced to a greater extent in the feedback condition than in the no feedback condition, suggesting that corrective feedback may be more effective for reducing error from sources other than those contributing to the left digit effect.

These findings are the first to suggest that the left digit effect in NLE is not malleable in the face of trial-by-trial corrective feedback. Although this type of feedback reduced overall accuracy error but not the left digit effect, these findings do not rule out the general possibility of designing a training intervention to correct a left digit bias in children's or adults' NLE performance. In the General Discussion, we consider several possible directions for future studies to investigate other forms of feedback aimed at reducing the left digit effect.

Combined Exploratory Analyses

To summarize the two experiments reported here, we found a robust left digit effect in Experiment 1 on the typical forward-oriented 0-1000 and atypical reverse-oriented 1000-0 NLE tasks, and we found that the trial-by-trial corrective feedback implemented in Experiment 2 did not reduce the left digit effect. We then combined the data from both experiments to conduct exploratory analyses investigating the generalizability of the left digit effect at the level of individual pairs of target numerals and individual participants. Specifically, we used the data from Experiment 1 (collapsed across task order because we did not find task order effects on performance, $N = 76$) and Block 1 of Experiment 2 (collapsed across conditions because Block 1 occurred before the introduction of the feedback intervention, $N = 122$). For these data, we already know that participants' average hundreds difference scores were positive in 89% of cases across participants, evidence of the left digit effect. In post hoc exploratory analyses, we wanted to go beyond these descriptive data to better understand how often the effect emerges for individual boundary pairs and participants using inferential statistical tests.

We first considered how often we could observe the left digit effect for individual pairs of numerals around target boundaries. To do this, we conducted a single-sample *t*-test (one-tailed) on the hundreds difference score for each of the eight critical pairs. In Experiment 1, hundreds difference scores were significantly greater than zero (after correcting for multiple comparisons, adjusted alpha = .006) for six pairs on the 0-1000 line (all *t*s > 3.00, *p*s < .001, *d*s > 0.35; see Figure 4a) excluding pairs around boundaries 200 ($p = .216$) and 500 ($p = .007$). On the 1000-0 line, the effect emerged for seven pairs (all *t*s > 2.59, *p*s < .005, *d*s > 0.31; see Figure 4b) excluding the pair around the boundary 200 ($p = .063$; see Table A1 in Appendix for descriptive statistics).[6] In the first block of Experiment 2, the effect emerged for seven pairs (all *t*s > 2.94, *p*s < .005, *d*s > 0.28; see Figure 4c), excluding the pair around the boundary 200 ($p = .157$; see Table A2 in Appendix for descriptive statistics). To summarize, we found that the effect emerged for all target pairs except that it consistently did not emerge for target numerals around 200.

We then considered whether we could detect the left digit effect at the level of individual participants by applying an inferential statistical test to each participant's data for each NLE task. Similar to the analysis conducted above for target pairs, we performed single-sample *t*-tests (one-tailed, alpha = .05) on each participant's individual hundreds difference scores. On average, hundreds difference scores were reliably greater than zero for 24% of participants ($n = 18$) on the 0-1000 line in Experiment 1, for 36% ($n = 27$) on the 1000-0 line in Experiment 1, and for 21% ($n = 26$) in the first block of Experiment 2.[7] These findings illustrate that even when using an inferential test to draw conclusions about the presence of a left digit effect with individual data (rather than simply counting the number of positive average hundreds difference scores), we can detect a left digit effect for about 26% of individual participants.

We also conducted one additional analysis using individual participant data to identify adults who consistently show a left digit effect. Rather than focusing on the overall magnitude of individuals' hundreds difference scores (as we did in the last analysis), we considered how many times a participant showed a positive hundreds difference score across target pairs. For each participant, we counted the number of target pairs with positive hundreds difference scores (up to 8 total). We then conducted a binomial test of statistical significance (test proportion = .50, one-tailed alpha = .05) to assess whether an individual's pattern of data showed a consistent left digit effect. This analysis sets a very high bar in that, for a pattern to reach statistical significance, an individual must have a positive hundreds difference score for at least 7 out of 8 target pairs.[8] In Experiment 1, 13% of participants ($n = 10$) on the 0-1000 NL and 20% of participants ($n = 15$) on the 1000-0 NL showed a significant left digit effect by this criterion. In Experiment 2, 18% of participants ($n = 22$) showed a significant left digit effect in the first block of the task. Overall, about 19% of participants met this high standard, which is not negligible given the nature of the analysis and the small number of target pairs. (The average participant had a positive hundreds difference score on about 66%, or 5.3 out of 8 target pairs, a number constituting well more than half of the trials but still somewhat lower than the criterion for statistical significance here.)

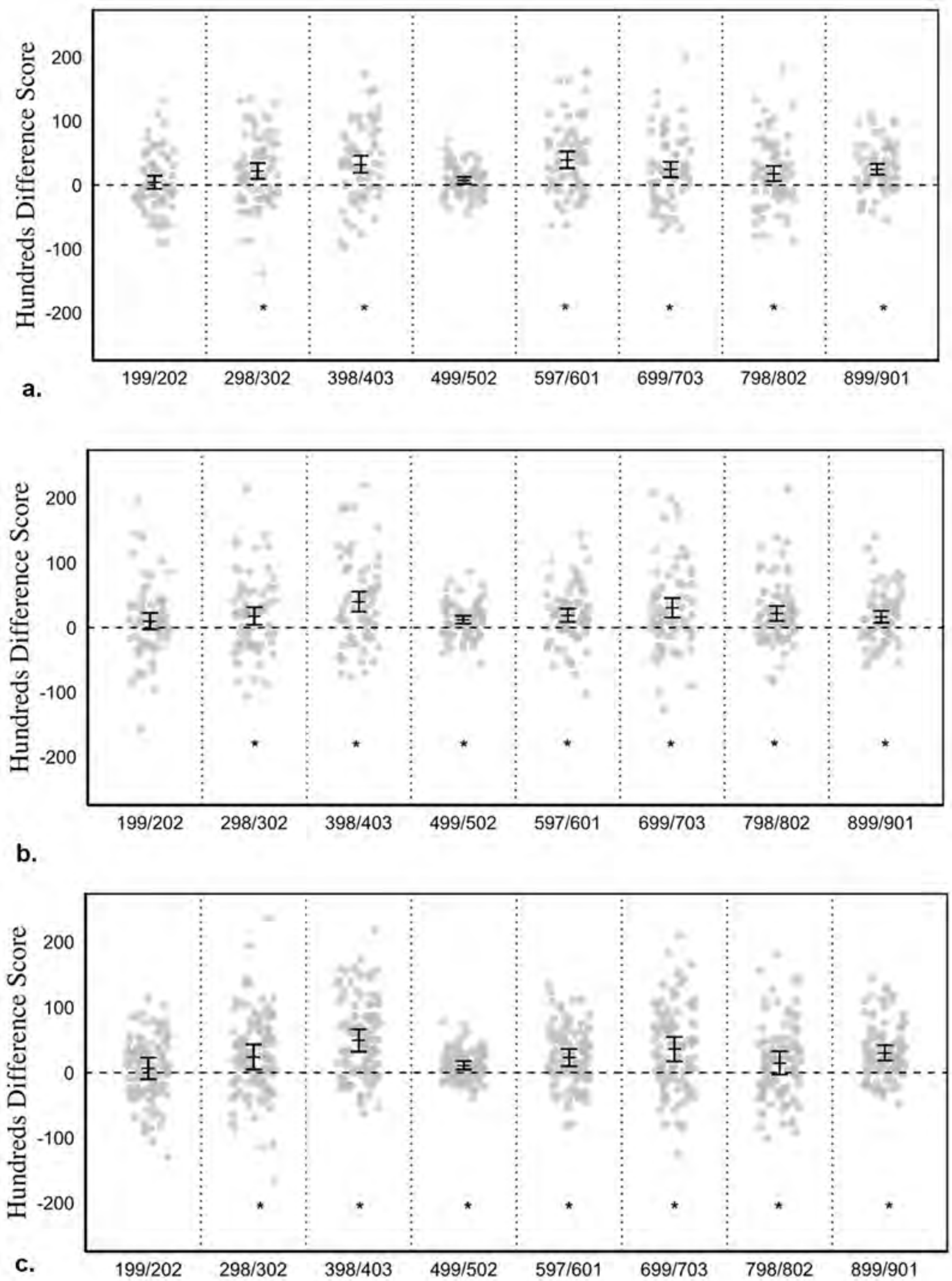
6) Some participants were missing estimates for < 3 pairs of numerals (and did not meet the criteria for exclusion from the final sample for analyses) and so the individual *n*s included in these analyses vary from pair to pair.

7) This analysis may underestimate the percentage of individuals showing a left digit effect, as earlier analyses suggest that the left digit effect might generally not be present for target numerals around 200.

8) For ease of explanation, this description assumes each participant completed all eight target pairs. However, if a participant completed fewer pairs due to outlier removal, the denominator was the total number of pairs available (and the criterion for statistical significance was that *all* hundreds differences scores had to be positive).

Figure 4

Individual Hundreds Difference Scores for Each Critical Pair



Note. (a) Forward (0-1000) Block of Experiment 1, (b) Reverse (1000-0) Block of Experiment 1, (c) First (Forward) Block of Experiment 2. Gray data points represent individual hundreds difference scores. Black bars represent the group average and 95% simultaneous confidence intervals (corrected for multiple comparisons, alpha = .006). The horizontal distance between points is irrelevant; the spread of scores was only produced to show individual scores more clearly.

**ps* < .006, indicating that participants' estimates, on average, produced hundreds difference scores significantly greater than zero for the pair of numbers.

The exploratory analyses offer two new findings. First, they reveal that the left digit effect emerges for target numerals around nearly all hundreds boundaries (except around the boundary 200). Also, whether we evaluate the average hundreds difference score, hundreds difference scores for individual target pairs, or the total number of positive hundreds difference scores to assess an individual's left digit effect, the effect can be detected in at least a subset of participants (ranging from 19% to 26% of participants depending on the measure). These preliminary findings provide some evidence that the left digit effect is not limited to a small subset of target pairs and that inferential tests may be valuable for identifying adults who show a particularly robust left digit effect.

General Discussion

Previous studies established the presence of the left digit effect in number line estimation: Children and adults place numerals like 798 and 802 (nearly indistinguishable magnitudes but different leftmost hundreds-place digits) too far apart on a 0-1000 number line (e.g., Lai et al., 2018). We conducted two experiments to address outstanding questions regarding: the generalizability of the left digit effect to an atypical reverse-oriented number line task, the malleability of the effect in response to trial-by-trial corrective feedback, and the extent to which the effect is widely observed across hundreds boundaries and individuals. In addressing these questions, the present work broadens our understanding of the conditions under which the effect arises, offers clues as to the source of the effect, and has practical implications for using interventions to reduce the left digit effect in adults.

A summary of our findings is as follows. In Experiment 1, although overall accuracy error was low, a reliable left digit effect emerged with large effect sizes on both the typical forward-oriented 0-1000 line and the atypical reverse-oriented 1000-0 line, and line orientation had no effect on the magnitude of the effect. In Experiment 2, a left digit effect emerged with large effect sizes regardless of whether trial-by-trial accuracy feedback was presented in the middle block of a three-block task, even though overall accuracy error was reduced during and following feedback. Using combined data, the hundreds difference score was in the predicted direction for all boundaries and for the vast majority of participants. The studies show that the left digit effect generalizes to an atypical number line, and to a trial-by-trial feedback context, and that the effect is observable across boundaries and individual people.

The present findings offer clues as to sources of the left digit effect. In particular, they suggest that the effect is not likely driven by the left-to-right organization of the number line that is typical in Western cultures (see, e.g., Wood et al., 2008). Recall that Di Lonardo et al. (2020) found that, on the forward-oriented number line, adults showed a bias towards scanning from left to right and placed targets too far to the left. In contrast, on the reverse-oriented number line, when left-to-right scanning and low-to-high number scanning were decoupled (because the latter was from right-to-left), this placement bias was eliminated and overall accuracy error was reduced. In the present work, a different pattern emerged: we saw no reduction of the left digit effect on the reverse-oriented number line. We thus conclude that the effect is unlikely to be related to the orientation of the line or how the number line is scanned. We also did not see a reduction in overall accuracy error on the reverse-oriented number line, perhaps because we used different target numerals (e.g., more boundary values) than in past work (and so perhaps more overall error was due to the left digit bias here). In the future, it may be valuable to additionally consider the left digit effect in the context of other atypical number lines, such as vertically oriented lines (e.g., Mihulowicz et al., 2015) and noncanonical number ranges (e.g., 238-1238; Booth et al., 2014; Booth & Newton, 2012; Chesney & Matthews, 2013; Cohen & Blanc-Goldhammer, 2011; Hurst et al., 2014; Luwel et al., 2018; Peeters et al., 2016) to further test the generality of the effect and to gain additional clues as to its source.

The present findings also speak to the malleability of the left digit effect. The left digit effect was observed regardless of whether participants received trial-by-trial accuracy feedback or not, suggesting that the left digit effect is not easily corrected in the face of feedback. Past intervention studies focused on reducing the left digit effect used global feedback in the form of summary accuracy scores to motivate performance (Kayton et al., 2022), but did not use specific guidance for placements. In past intervention studies, as we found here as well, there was a reduction in overall accuracy error but no reduction in the left digit effect in the feedback relative to the no feedback condition. There is only one known past study that specifically used trial-by-trial feedback to improve number line estimation in adults, and this study did not consider the left digit effect. Specifically, Eyler et al. (2018) assessed the efficacy of a brief trial-by-trial feedback intervention (consisting of five trials with feedback) to reduce adults' overall accuracy error on a 0-1000 number line estimation task. Among participants who received the intervention, overall accuracy error decreased by approximately one-third from the pre-intervention block to the post-intervention block but only for a subset of participants with no college education. The present findings suggest that, even for highly educated individuals, trial-by-trial feedback can be valuable for reducing overall accuracy error, although future work is needed on whether these improvements are sustained.

The findings of our two studies are consistent with a leading proposal regarding the source of the left digit effect. The proposal is that rather than being directly related to strategies used to place numerals on number lines, bias may arise in the conversion of numerals to magnitudes more generally. Specifically, the leftmost digit might be overweighted during this conversion process (Thomas & Morwitz, 2005; see also Huber et al., 2016). That the left digit effect does not appear to be influenced by task characteristics, such as the spatial orientation of the number line, is consistent with the account, as is the finding that the present feedback intervention was not successful (in that the conversion process is thought to be relatively automatic for most adults; e.g., Dotan & Dehaene, 2013; but see Nuerk & Willmes, 2005). The proposal is also consistent with one study of speakers of Dutch (a language in which digits are articulated from right to left, as in "one and forty" for 41). Savelkouls and colleagues (2020) found no evidence of a left digit effect among Dutch participants, suggesting that the effect may depend on the order in which numbers are articulated in one's first language. Further, in a different study, the left digit effect was correlated with complex verbal skills in adults but not math skills (unlike overall accuracy error, which was correlated with math skills but not verbal skills; Williams et al., 2020). Together, these findings (plus see discussion on the left digit effect in domains beyond NLE) suggest the conversion of numbers to magnitudes as a potential source of the effect.

If the left digit effect were based on an overweighting of the individual digits that comprise target numerals, it remains possible that the effect could be reduced through the use of different interventions (beyond those that have been tested to date). For example, while motivational incentives have been unsuccessful, it might be that higher value incentives to perform more accurately (e.g., monetary incentives) could still reduce or eliminate the effect. In a study of consumers' comparisons of sale prices, higher-priced products (with four digits; e.g., $1,999 and $2,000) showed a weaker left-digit effect than did lower-priced products (with three-digits; e.g., $199 vs. $200; Lin & Wang, 2017). One interpretation of this finding was that when products are high in cost, consumers are more motivated to allocate their attention to all digits to maximize potential savings. Whether or not the finding would extend to the left digit effect in NLE, or whether there might be another way to increase attention to rightward digits in this context, is an open question. An alternative possibility is that individuals could be taught explicitly to make an adjustment to their biased initial estimates. That is, even if it were not possible to alter the overreliance on the leftmost digit, individuals could perhaps learn to adjust their initial inclinations about placements. In recent work (Patalano et al., 2023), the left digit effect was well-modeled as a compression of all placements within a leftmost digit range towards the lower boundary of the range (e.g., a compression of placements for 201-299 towards the placement of 100 and away from the placement of 200). This work suggests that it might be valuable to instruct individuals to adjust most placements rightward to offset the bias, and to do so to a greater degree the closer the target is to the upper boundary of the range. For example, one might adjust the placement of 205 a small amount rightward but 298 a large amount.

One non-central finding in the present work was unexpected. On the reverse-oriented 1000-0 number line task, and in the feedback block of the 0-1000 forward number line, participants placed numerals around fifties boundaries (e.g., 145 and 152) farther apart than expected, consistent with a left digit effect for the tens place (rather than the hundreds place). Hundreds digit effects are expected if the hundreds digit is overweighted relative to rightward digits (as is observed for hundreds pairs like 798 and 802). However, in a similar manner, tens digit effects can occur if the tens digit is overweighted relative to the ones digit (as was observed here for pairs like 145 and 152 in some blocks). It is possible that when the task is less familiar and more effortful, that individuals pay even less attention to the ones digit than usual, resulting in this pattern of overweighting the tens digit. That said, we do not make much of these findings pending future replication. We also note that one limitation of the present work is that the fifties pairs used in the studies here ($M \approx 6$ units apart) were on average farther apart than hundreds pairs ($M \approx 4$ units apart). So it is possible that if there were even a small overweighting of the tens digit, it would be seen more readily than an increase in the weighting of the hundreds digit. This design was based on past studies (e.g., Lai et al., 2018), and worked against our predictions, so does not challenge our central findings. However, it will still be desirable to match the spacing of fifties and hundreds pairs in future studies.

Across the two experiments reported here, nearly all participants showed a left digit effect in the predicted direction, although the magnitude of the effect varied across individuals, and, using various inferential tests, the effect was statistically significant in only a small number of cases. We attribute the latter to the high bar for statistical significance here rather than to some individuals being immune to the bias. Further work is needed to understand whether such differences at the individual level are stable across time. If they are, it will be possible to seek correlates of the effect to gain further clues as to how the effect arises, how it might be reduced, and whether it predicts other skills. The existing link between number line estimation performance and math competence is robust (see Ellis et al., 2021; see also Schneider et al., 2018 for review), but the variation across individuals introduced by the left digit effect still needs to be explored. One recent study found that overall accuracy error, but not the left digit effect, was reliably correlated with the math component of the SAT, and that, in at least one context, the left digit effect was instead correlated with a verbal component of the SAT (Williams et al., 2020). The finding suggests that the relationship between number line estimation performance and math skills may be more complex than past studies have suggested. Perhaps more importantly, the nature of this relationship may differ for overall accuracy error and the left digit effect. Such relationships are not yet well documented but do offer new research directions.

Taken together with previous work, including variations in required response speed, numerical range, presentation modality, and the range and size of the stimulus set (Lai et al., 2018; Williams et al., 2020, 2022), the present work extends our knowledge of the contexts in which the left digit effect is observed in NLE and provides some initial clues about the extent to which individual pairs of numerals and individual participants are more (or less) prone to the effect. However, the phenomenon of the left digit effect has relevance beyond the number line estimation task itself. The effect is widely demonstrated in consumer price judgments (Beracha & Seiler, 2015; Lin & Wang, 2017; MacKillop et al., 2014; Manning & Sprott, 2009; Thomas & Morwitz, 2005, 2009) and has been observed in other judgment contexts where numerical information must be evaluated, such as those involving nutritional labels (Choi et al., 2019), car odometer readings (Lacetera et al., 2012), consumer product reviews (Thomas & Morwitz, 2005), and medical records (Olenski et al., 2020). With ongoing efforts to link the left digit effect in number line estimation to other domains (Patalano et al., 2022), we hope that the number line estimation task will have valuable application for assessing, understanding, and ultimately reducing the left digit effect in everyday reasoning contexts.

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Competing Interests: The authors have declared that no competing interests exist.

Ethics Statement: This work has been carried out in accordance with relevant ethical principles and standards. IRB approval was obtained from Wesleyan University Ethics Committee.

Data Availability: The data will be made available for use in planned analyses upon request.

Supplementary Materials

The Supplementary Materials include the pre-registration protocols for Experiment 1 and Experiment 2 (see Barth et al., 2018; Bradley et al., 2019).

Index of Supplementary Materials

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Appendix

Table A1

Experiment 1 Descriptive Statistics for Each Hundreds Pair (N = 76)

	199/202	298/302	398/403	499/502	597/601	699/703	798/802	899/901
				0-1000 Line				
n	73	74	70	72	70	72	76	70
M	4.21	21.82	32.21	7.10	39.19	24.28	17.95	24.39
SD	45.44	53.73	58.01	23.81	56.55	53.19	51.66	37.13
t	0.79	3.49	4.65	2.53	5.80	3.87	3.03	5.49
p	.216	< .001*	< .001*	.007	< .001*	< .001*	.001*	< .001*
				1000-0 Line				
n	74	72	71	72	73	73	76	75
M	9.89	17.99	39.96	12.18	19.08	30.41	21.97	16.79
SD	55.03	58.96	67.55	26.91	45.14	65.77	49.73	40.16
t	1.55	2.59	4.98	3.84	3.61	3.95	3.85	3.62
p	.063	.005*	< .001*	< .001*	< .001*	< .001*	< .001*	< .001*

[a]Reported *t*-tests are one-tailed. Data are collapsed across task order for these analyses.

$^*p < .006$ (corrected for multiple comparisons).

Table A2

Experiment 2 Descriptive Statistics for Each Hundreds Pair (N = 122)

	199/202	298/302	398/403	499/502	597/601	699/703	798/802	899/901
				0-1000 Line				
n	112	114	117	115	113	114	114	117
M	6.37	24.02	49.52	11.16	23.15	36.04	14.88	30.34
SD	47.22	61.00	58.53	21.29	42.71	62.06	54.01	41.22
t	1.42	4.20	9.15	5.62	5.76	6.20	2.94	47.96
p	.157	< .001*	< .001*	< .001*	< .001*	< .001*	.004*	< .001*

[a]Reported *t*-tests are one-tailed. Data for these analyses were collapsed across task order.
*$p < .006$ (corrected for multiple comparisons).

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