Telling People About the Left Digit Effect in Number Line Estimation Still Does Not Reduce the Effect

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Introduction

Number line estimation (NLE) tasks are widely used as assessment tools and as reliable predictors of math outcomes.[1] On a typical task, participants are asked to estimate the location of Arabic numerals on a bounded number line.

Recent evidence[2] reveals a novel source of error in NLE performance:

Left digit effect: Numbers with nearly identical magnitudes but different leftmost digits are estimated farther apart than their magnitudes alone would predict.

E.g., "602" is placed too far to the right of "599" on a 0-1000 line, despite their magnitudes being indistinguishable on the scale.

Studies have demonstrated the robustness of the left digit effect following a variety of NLE interventions including direct instruction about the effect, but the latter study was limited as it did not test whether the participants in the study fully attended to and understood the instruction.

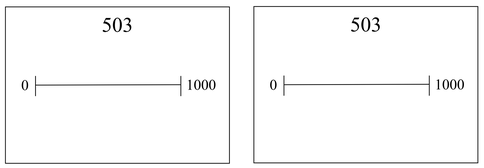
Here, we again provide direct instruction but we also assess participants understanding of the effect following the instruction, offering a more stringent test of whether the left digit effect might be reduced with direct instruction.

Study Methods

Participants: Adults (N = 143, ages 18-70, Prolific internet sample) were randomly assigned to one of the following two conditions.

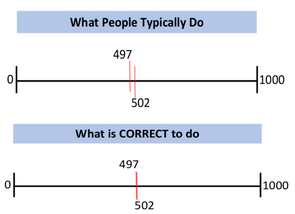
No Instruction Condition (n = 67, two blocks of 60 trials each):

"On each trial, you will see a number line labeled from 0 to 1000 and will be asked where you think some number should go on the line. Click on the line to indicate where the number should go."



Instruction Condition (n = 76, same except with instruction between blocks):

Between-block instructions: *"In this task, people often exhibit what is called a left digit effect. This means they tend to place numbers of similar magnitude but different leftmost digits (like 497 & 502) farther apart on the number line than they should. They do not do this for numbers of similar magnitude with the same left digit (like 502 & 507)."*



Participants in the Instruction Condition who did not correctly answer two multiple choice questions about the instructions within three tries (n = 1) were eliminated from the study.

In both conditions (to assess effort following possible intervention):

- Participants rated their level of effort in each block
- Response times (RTs) were collected by block

Also collected but not analyzed here, participants: described the strategies they used; defined the left digit effect or were told about it (depending on condition); rated the likelihood they showed a left digit effect.

Target numerals were grouped (for analyses) into one of the following:

- **Hundreds pairs**: numerals falling around 100's boundary (e.g., 498, 501)
- **Fifties pairs**: numerals falling around 50's boundary (e.g., 348, 353)
- Non-boundary values (e.g., 725)

Hundreds pairs were critical trials for assessing left digit effect, and fifties pairs served as controls; non-boundary values were used to compute overall error. Numerals were in a different random order for each block and participant.

Preregistered Measures and Predictions

Left Digit Effect

For each pair of target numerals, we calculated an individual difference score: *(placement of larger numeral – placement of smaller numeral)*. We then calculated one average hundreds difference score and one average fifties difference score per participant.

hundreds difference score > 0 indicates a left digit effect

- **If instruction reduces the left digit effect** → Across blocks, hundreds difference scores will decrease more in the Instruction than in the No Instruction Condition.
- **If instruction *does not* reduce the left digit effect**. → Any decrease in hundreds difference scores across blocks will be the same in both conditions.

Overall Error

To measure overall error, we calculated percent absolute error (PAE): $|placement\ of\ numeral - correct\ location|/1000$. A smaller PAE indicates lower overall error.

- **If instruction reduces overall error** → Across blocks, PAE will decrease more in the Instruction than in the No Instruction Condition.
- **If instruction *does not* reduce overall error** → Any decrease in PAE across blocks will be the same in both conditions.

Demographic Variables

Is the hundreds difference score or PAE related to age, gender, education, or income?

Preliminary Results

Left Digit Effect

A robust left digit effect was observed. Hundreds difference scores were different from 0 in each block of the No Instruction and Instruction Conditions (ts > 7, ps < .001). In contrast, also as predicted, fifties difference scores did not differ from 0 (ps > .20).

The instruction intervention did not reduce the left digit effect. There was no condition by block interaction for the hundreds difference score (F(1, 133) = 0.04, MSE = 329.69, p = .847). There was also no main effect of either condition or block (ps > .15).

Overall Error

Direct instruction did not reduce overall error. There was no condition by block interaction for PAE (F(1, 133) = 1.06, MSE < 0.01, p = .306). There was a main effect of block (F(1, 133) = 4.42, MSE < 0.01, p = .037), but not condition (p > .90).

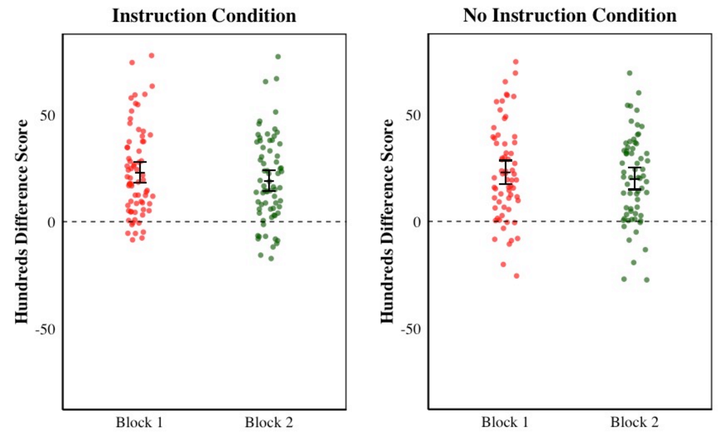
Table 1. *NLE Performance Measures by Condition and Block*

		Block 1	Block 2
No Instruction (n = 65)	100s	22.98 (22.19)	20.07 (20.53)
	50s	0.87 (15.00)	-0.26 (12.35)
	PAE	4.07 (1.52)	3.79 (1.55)
	RT	3.32 (0.20)	2.79 (0.19)
	Effort	8.65 (0.16)	8.02 (0.18)
Instruction (n = 70)	100s	23.03 (20.55)	19.27 (20.18)
	50s	1.99 (15.65)	-1.30 (14.86)
	PAE	4.01 (1.51)	3.91 (1.38)
	RT	3.24 (0.19)	3.15 (0.18)
	Effort	8.30 (0.15)	8.64 (0.17)

SDs are in parentheses. PAEs are represented as percentages. RT is Response Time.

Results

Figure 1. *Average Hundreds Difference Score by Condition and Block*



Response Time and Effort by Condition

Participants in the No Instruction Condition sped up more across blocks than those in the Instruction Condition. There was a condition by block interaction for response time (F(1,133) = 5.77, MSE = 133.00, p = .018), and a main effect of block (F(1,133) = 11.69, MSE = 133.00, p = .001), but no main effect of condition (p > .50). Additionally, **participants in the Instruction Condition put more effort into the second block**. There was a condition by block interaction for effort (F(1,133) = 5.77, MSE = 133.00, p = .018), but no main effect of block or condition (ps > .17). Both of these findings, in conjunction with the multiple choice responses, support that those in the Instruction Condition understood the effect and were trying to reduce it.

Demographic Variables

As age increased, hundreds difference score decreased (r(131) = -.33, p < .01) and PAE decreased (r(133) = -.17, p =.044). As income increased, PAE decreased (r(128) = -.20, p =.024). There were no other statistically significant correlations with hundreds difference score or PAE.

Discussion and Conclusions

- The left digit effect is robustly observed in adults' NLE: leftmost digits, not just the magnitudes of target numerals, influence estimates.
- This work replicates previous findings of the effect[2] and provides further evidence that the bias cannot be easily reduced,[3,4] even when participants understand the effect and are actively trying to reduce it.
- The work replicates a previous finding (from ongoing work) that the left digit effect might decrease with age.
- Open ended responses are yet to be coded and analyzed to better understand strategies that people use to try to reduce the left digit effect.

References and Acknowledgments

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4. Kayton, K., Williams, K., Stenbaek, C., Gwiazda, G., Bondhus, C., Green, J., Fischer, G., Barth, H., & Patalano, A. L. (under review). Summary accuracy feedback in number line estimation does not reduce the left digit effect.

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