Left Digit Effect in Number Line Estimation with Leading Zero and Ten-Thousands Target Numerals

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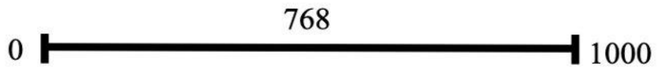
Introduction

• Number line estimation (NLE) tasks are common research and teaching tools.



• Analysis of NLE performance usually focuses on overall magnitudes of numerals being estimated. But recent studies show that leftmost digits disproportionately influence participants' estimates in both children and adults.[1]
• One way to demonstrate this is to compare placements for target numerals with similar magnitudes but different leftmost digits (like 698 and 702). These should be placed similarly on a 0-1000 number line, but in fact people place 698 much too far to the left. This systematic bias appears in number line estimation and in other contexts. It's known as a **Left Digit Effect (LDE)** or left digit bias.

General Approach

Participants complete number line estimation tasks in person at our lab on a computer. Characteristics of the target numerals to be estimated, or the response line, are varied across conditions or studies to test hypotheses about the nature of left digit effects.

Example instructions for a basic 0-1000 task as pictured above:

"In this section of the study, 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 where you think the number should go."

In the present studies, our adult participants completed two blocks of 50 trials each. Each block corresponded to a different number line condition. The block completed first was counterbalanced between participants.

Each participant saw 50 target numerals per block (1 per trial). Numerals were presented in a pseudorandom order. 16 of the target numerals were from hundreds pairs: eight pairs of numerals at hundreds boundaries, where numbers were similar in magnitude, but had different leftmost digits (i.e., 398/403). These numbers were not presented together but were paired for analysis purposes only. The remaining 34 numerals were non-boundary values: additional target numerals that did not fall at hundreds boundaries (i.e., **831, 714, 952**)

Study Measures

Difference scores = *average difference between placements for hundreds pairs, 1 per condition per participant.* **Difference scores > 0 indicate a left digit effect.**
Percent Absolute Error (PAE) calculated using all target numerals for each number line range (higher PAE = lower accuracy). PAE = |*estimate – target numeral*|/1000
Outliers: Target number placements >2 standard deviations from mean estimate.

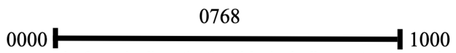
Research Questions

1. Is the LDE truly a left digit effect? Will it persist or disappear for these hundreds-place digits if we add meaningless leading leftmost zeros (e.g. 0698 vs. 0702)?
2. Will the effect persist for these hundreds-place digits if we add leading digits that are meaningful but do not change in the context of our task? (e.g. 10698 vs. 10702 on a 10000-11000 line)?

Experiment 1

Question: Does the LDE persist for hundreds-place digits when the leftmost digit of a number is a meaningless leading zero in the thousands place?

Method: Participants experienced two conditions, one on a number line in which each number was presented with a zero as its leftmost digit (Leading Zeroes condition) and one on a standard number line (No Leading Zeroes condition)



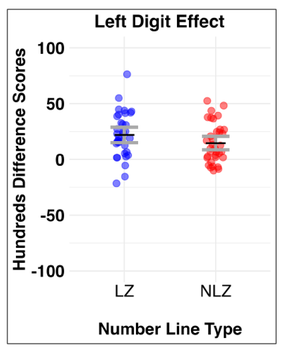
An example of a number line estimation trial using leading zero target numerals.

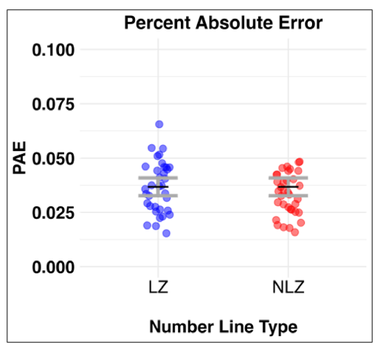
Experiment 1 Results

Participants: N = 35 (18 Leading/No Leading, 17 No Leading/Leading)

The following results are reported *excluding* outlier estimates

• Significant left digit effect in the Leading Zeros number line estimation (M = 21.930, $t(34)$ = 6.473, $p < 0.001$, d = 1.094) and the No Leading Zeros number line estimation (M = 14.650, $t(34)$ = 4.937, $p < 0.001$, d = 0.835).
• No significant difference in the size of the left digit effect between the Leading and No Leading Zeros estimations ($F(1,33)$ = 4.081, $p > 0.05$).
• Percent absolute error (PAE) was significantly larger in the Leading Zeros estimations (M = 0.037) relative to the No Leading Zeros estimations (M = 0.033; $t(34)$ = 2.979, p = .005).





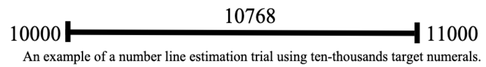
Experiment 1 Conclusions

• The LDE is still present and robust when numerals are presented with a zero as the leftmost digit. This suggests that the LDE is not a bias toward the literal leftmost digit, but rather the leftmost **meaningful** digit in a number.
• Percent absolute error is significantly higher for Leading Zeroes responses than No Leading Zeros responses.

Experiment 2

Question: Does the LDE persist for hundreds-place digits even when we add leftmost digits that are meaningful, but do not vary in the context of the task?

Method: Participants experienced two conditions, one on a number line in which each number was presented as a numeral in the ten-thousands (Ten-Thousands condition, e.g. 10698 vs. 10702 on a 0-10000 line) and one with leftmost zeroes (Leading Zeroes condition)



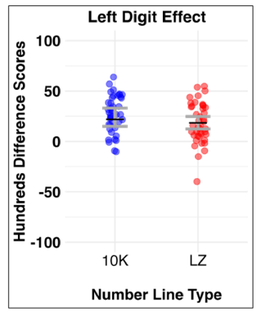
An example of a number line estimation trial using ten-thousands target numerals.

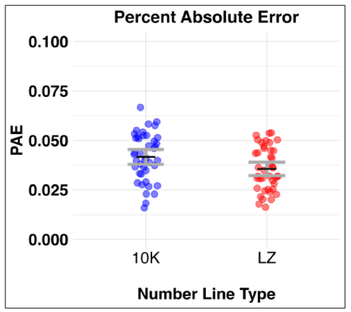
Experiment 2 Results

Participants: N = 42 (21 Leading/Ten-Thousands, 21 Ten-Thousands/Leading)

The following results are reported *excluding* outlier estimates

• Significant left digit effect in the Ten-Thousands number line estimation (M = 27.423, $t(41)$ = 9.822, $p < 0.001$, d = 1.516) and the Leading Zeros number line estimation (M = 18.583, $t(41)$ = 6.046, $p < 0.001$, d = 0.933).
• There was a significant difference in the size of the left digit effect between the Ten-Thousands and Leading Zeros estimations ($F(1,40)$ = 5.935, p = 0.019).
• Percent absolute error (PAE) was significantly larger in the Ten-Thousands number line estimations (M = 0.042) relative to the Leading Zeros estimations (M = 0.036; $t(41)$ = 5.402, $p < 0.001$, d = 0.792).





Conclusions

• In all three types of number lines there was a robust LDE observed.
• There was no difference in the size of the LDE between the Leading Zero and No Leading Zero number line estimations.
• Ten-Thousands estimates had, on average, a larger LDE than Leading Zero estimates.
• Leading Zero number line estimations had a significantly higher percent absolute error than the No Leading Zero estimations. Ten-Thousands estimations had a significantly higher percent absolute error than the Leading Zero estimations.
• **These findings suggest that the "left digit effect" does not arise from the literal left digit in a numeral, but rather the leftmost meaningful digit in a numeral which varies in the context of the task.**

References and Acknowledgements

1) Lai, M., Zax, A., & Barth, H. (2018). Digit identity influences numerical estimation in children and adults. Developmental science, 21, e12657.
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