

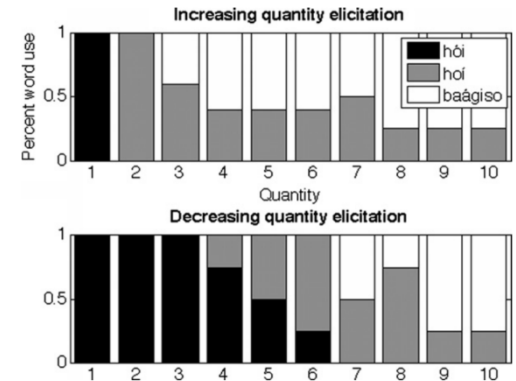
How Numerical Bootstrapping Fails: Linguistic Markers and Perceptions of Numerosity

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Are Small N-knowers like Pirahã Adults?

- Children in counting cultures can typically recite extensive rote count number sequences before the number words map onto actual numerosities (Gelman & Gallistel, 1978). In learning to count, they go through number-knower stages that reflect knowledge of small number semantics before incrementally developing fuller numerical competence and knowledge of the incremental mapping properties (Wynn, 1990; 1992)
- Pirahã adults lack exact number words, but *hói* (falling tone) and *hoí* (rising tone) can typically denote “one” and “two”’s. Frank et al (2008) showed that the numerical reference for these terms differs according to whether they are used in an ascending or descending count sequence (see below).
- In non-verbal numerical tasks, adult Pirahã show evidence of small-number exact representations (1-to-3) and approximation for larger quantities (Gordon, 2004; Frank et al., 2008; Everett & Madora, 2012) reflecting a distinction between small number and large number numerical representations that is common across multiple populations in situations where counting or exact verbal encoding is not possible



The Numerical Cognition Test Battery

1. Fifty-six 2 to 4 year olds were given a battery of numerical cognition tasks including standard give-a-number and rote counting tasks.
2. Other tasks were adapted from Pirahã batteries from Gordon (2004) and Frank et al. (2008). These included: Ascending and Descending Counts; Parallel and Orthogonal 1-1 matching; Nuts-in-a-can
3. We compared children at different number-knower levels to the performance of Pirahã adults on these tasks
4. Number knower status was divided into NK-I (0-2 knowers, n=24) and NK-II (3-5+ knowers, n=27)

Research Questions

1. Do 2-4 year olds show Piraha-like patterns of responding to non-verbal numerical cognition tasks (1-1 matching, hidden quantities)?
2. Are NK-I or NK-II knowers more similar to the Piraha adults?
 - a. NK-I Similarity indicates a single language factor with no role for development
 - b. NK-II Similarity indicates both language and developmental/cognitive factors
3. Do children, like the Piraha, show asymmetries in their performance in the Ascending vs. Descending enumeration task (cf. Frank et al. 2008)?
4. Does Performance on the Ascending/Descending enumeration task correlate with children's rote-counting ability or is it independent?
5. Do children show evidence of an approximate number system (ANS) for large numbers (>3); for all numbers (1-10) or not at all?

Give-a-Number (Wynn, 1992) and Rote Counting

- To Determine N-knower status, children were asked to give “Cookie Monster” a number of cookies (n= 1 - 5) over 3 trials per number
- For rote counting, children were asked to count as high as they can without referents



Knower	N	0, N = 7¹	1, N = 6¹	2, N = 11¹	3, N = 2¹	4, N = 5¹	5, N = 15¹	p-value²
Age	46	36 (30, 36)	38 (36, 40)	38 (36, 47)	44 (43, 45)	36 (36, 45)	44 (40, 48)	0.054
Count	38	8 (6, 11)	12 (11, 14)	9 (6, 10)	10 (10, 10)	10 (8, 11)	20 (11, 30)	0.011

¹ Statistics presented: median (IQR)

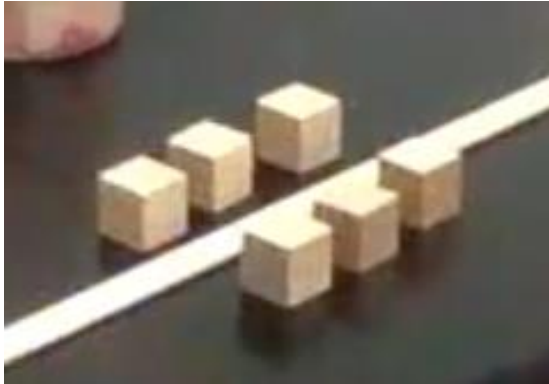
² Statistical tests performed: Kruskal-Wallis test

Ex: 44 (43, 45) means the median age = 44 mts, (43-45) = interquartile range

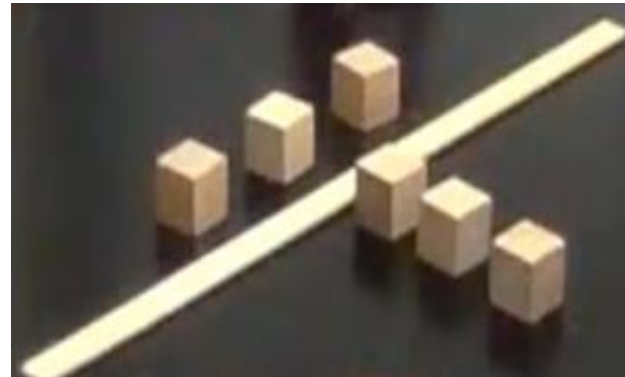
Task: Parallel and Orthogonal 1-to-1 Match



Parallel Test: The experimenter presented a line of blocks ($n= 2,4,6,8$) parallel to a dividing stick and the child was asked to make a line that was “the same”



Orthogonal Test: The experimenter presented a line of blocks ($n= 2,4,6,8$) orthogonal to the dividing stick and the child was asked to make a line parallel to the dividing stick that was “the same”



Results: Parallel and Orthogonal 1-to-1 Match

Observations:

- We divided children into 0-2 knowers (dotted line) and 3-5+ knowers (solid line)
- In both analyses the sloping performance on this task resembled that of Pirahã adults
- Unlike the Pirahã adults, children did not perform perfectly for small numbers (1,2,3)

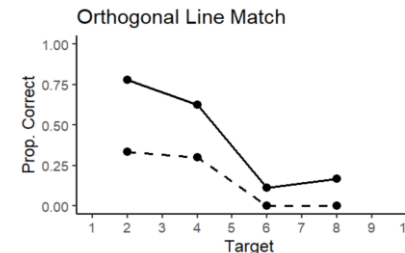
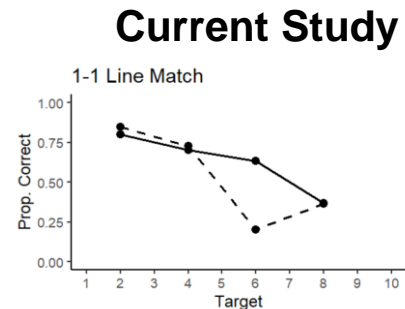
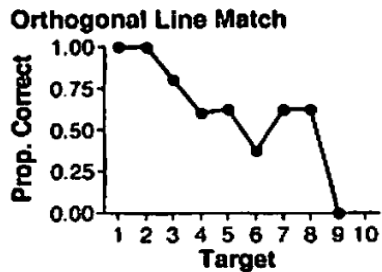
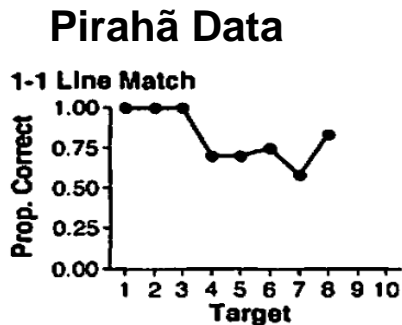


Figure 3: Proportion of correct responses for Piraha (left) and 0-2 knowers (right dotted-line) and 3-5 knowers (right solid-line).

Results: Parallel and Orthogonal 1-to-1 Match

Observations:

Mean and SD for Pirahã adults show responses approximating the correct match. The coefficient of variation for this performance stays relatively stable.

For our U.S. children, performance for 3-5 knowers is significantly greater than 0-2 knowers. Additionally, the coefficient of variation appears consistently lower in the later knowers

Pirahã Data

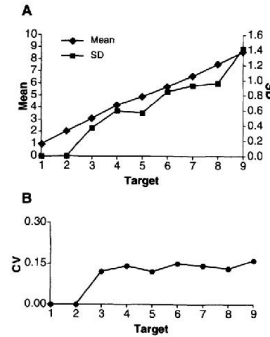
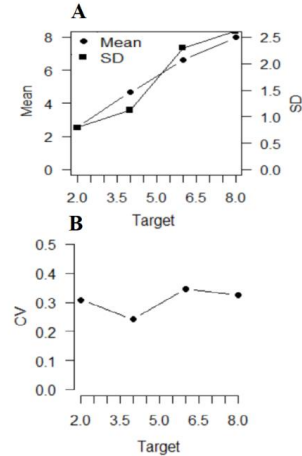


Fig. 2. (A) Mean accuracy and standard deviation of responses in matching tasks and (B) coefficient of variation. Figures for individual tasks and individual participants are available in the supporting online materials.

Current Study

0-2 Knowers



3-5 Knowers

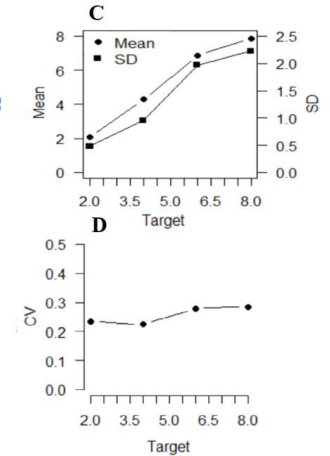


Figure 4: Figure on the left is pulled from Gordon (2004). Comparable plots are shown in plots A-D on the right. Plots show mean, standard deviation (A) and coefficient of variation (B) for 0-2 knowers. Plots B and D show the same information for 3-5 knowers.

Task: Nuts-in-a-Can

- Experimenter showed the child a set of blocks (n= 1, 2, 3, or 4) and put them in a container.
- Blocks were removed one at a time and the child was asked if there are any more left inside the container or if it was empty.



Results: Nuts-in-a-Can Task

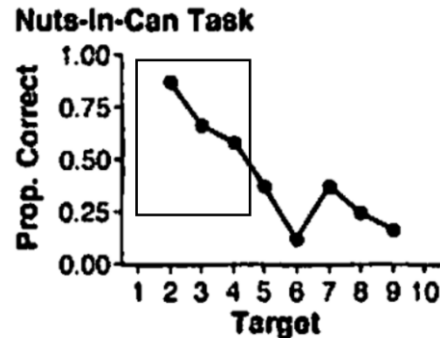
Observations:

- As in the case of Pirahã adults, children showed a steep drop in performance with increasing set size
- Pirahã adults resembled 3 to 5+ knowers on this task for the range tested (1-4)
- This suggests a combination of availability of number words and working memory as factors in this task

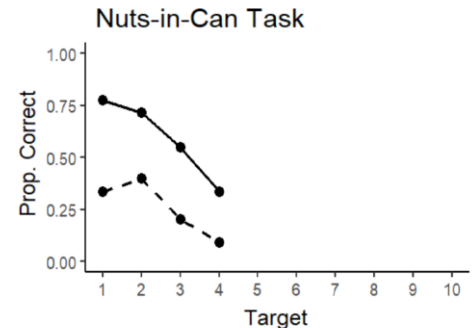
Notes:

- Children were asked to complete this task only up to 4 hidden items.
- *Comparison is broken into 0-2 knowers (dotted line) vs 3-5 knowers (solid line).*

Pirahã Data



Current Study



Task: Ascending and Descending Enumeration

(based on Pirahã study by Frank et al., 2008)

Ascending Task: Blocks were laid out one at a time starting with 1 and incrementing up to 10

Descending Task: Blocks were laid out starting with 10 and decrementing down to 1

Half the children did the ascending followed by descending, and half performed descending followed by ascending

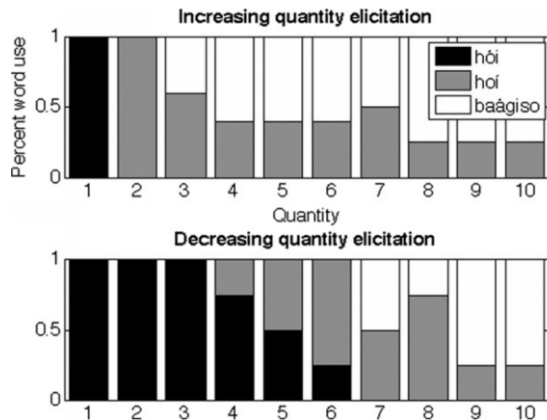
About 2/3 children counted out on each quantity (1-10), whereas others sequentially enumerated amount without recounting



Quantities denoted by Number Words in the Ascending vs. Descending Task



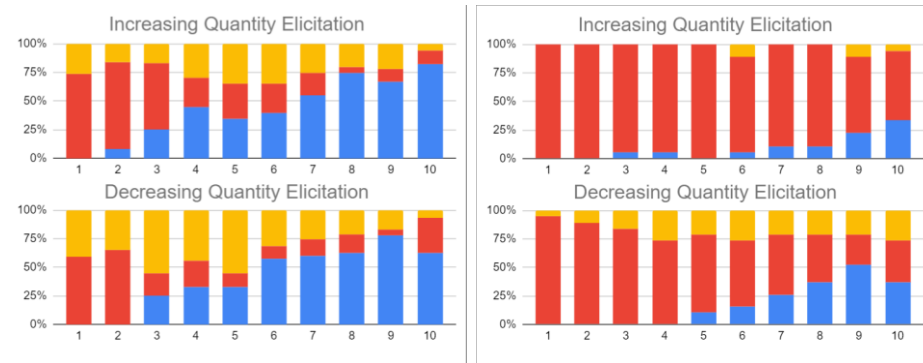
Pirahã adults



2- 4-year-old children (US)

0- to 2-knowers

3- to 5-knowers

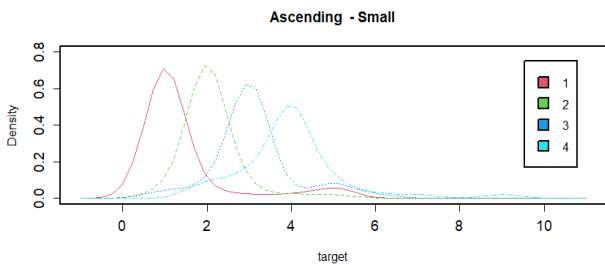


Yellow = Larger, Red = Equal, Blue = Smaller

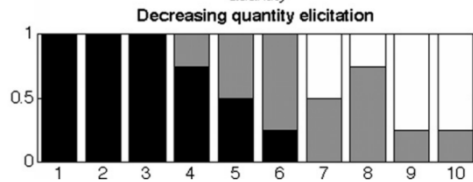
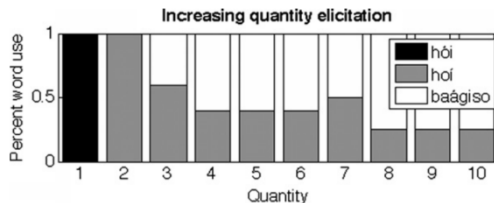
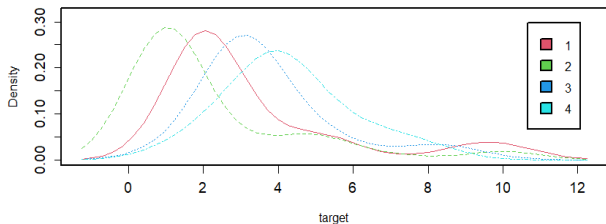
- On the Ascending task, Piraha use *hoí* to always denote $n=1$ (with *hoí* being used for $n = 2-10$ and *ba'agiso* for $n = 3-10$). For the Descending Task, *hoí* was not used only for 1, but for $n=1-6$ (see black bars on left figures)
- Children in this study were divided into 0-2 knowers and 3-5+ knowers. RED bars represent correct responses and are flanked by BLUE (= use of smaller integer) and YELLOW (= use of larger integer) We did not find differences in the ascending vs. descending task. For example, children did not show a greater spread of use larger numbers (YELLOW) on the descending enumeration compared to the ascending enumeration. In this way they did not resemble the Pirahã adults

Spread of Denotation Asymmetries in Ascending and Descending Enumeration for Approximate Integer Meanings

For **small integers (1-4)**, children show less dispersion in their Approximate Integer Meanings (AIMS)

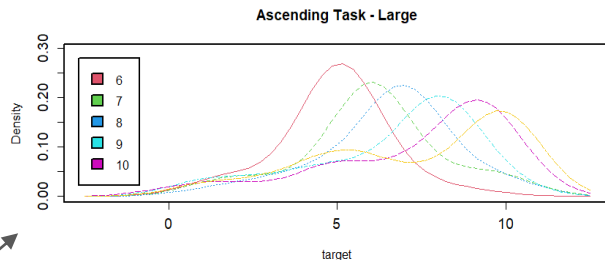


Descending Task - Small

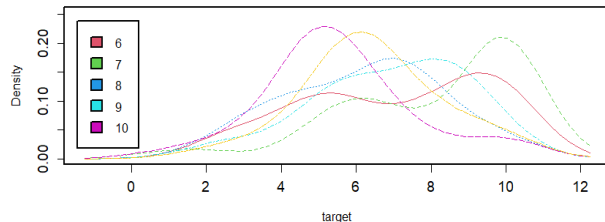


Children showed less dispersion in their Approximate Integer Meanings (AIMS) for the Ascending task compared to the Descending task

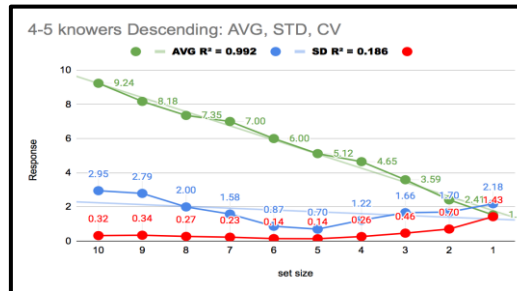
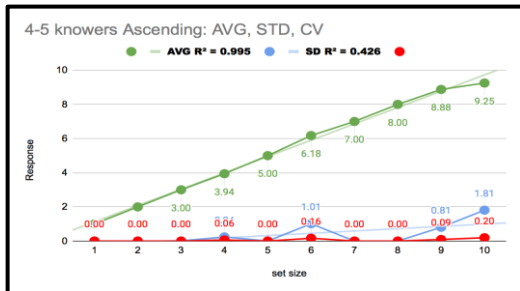
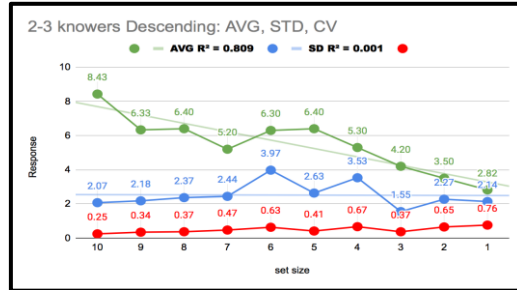
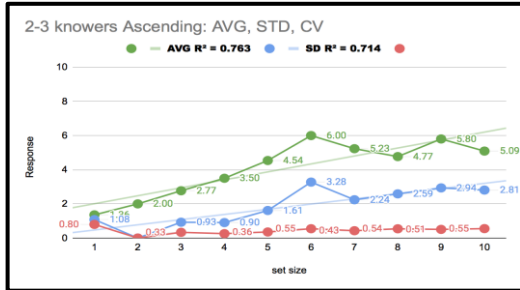
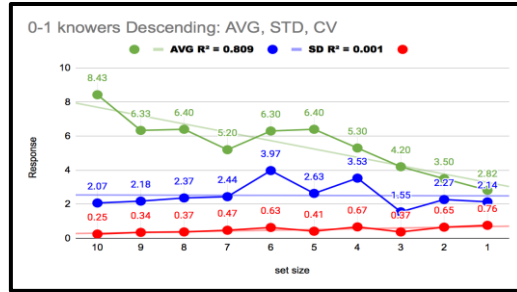
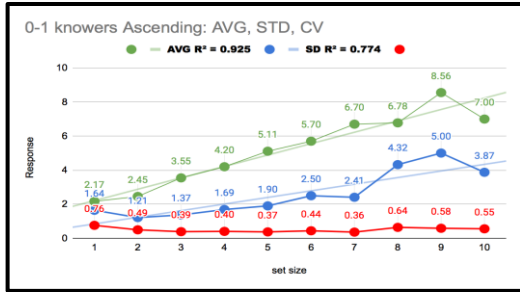
For **large integers (5-10)**, children show more dispersion in their Approximate Integer Meanings (AIMS)



Descending Task - Large



Approximate Integer Meanings (AIMS) are present for all quantities (1-10)



GREEN: Mean response (y-axis) to target quantity (x-axis)

BLUE: Standard Deviation

RED: SD/Mean = Coefficient of Variation

LEFT COLUMN = Ascending
RIGHT COLUMN = Descending

ROW 1 = 0-1 knowers
ROW 2 = 2-3 knowers
ROW 3 = 4+ knowers

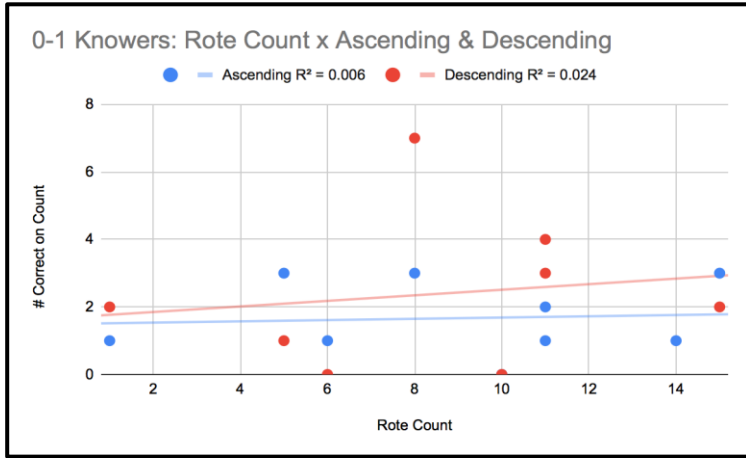
SUMMARY OF FINDINGS:

1. Scalar AIMS for all ages, with decreasing error with increasing N-knower status
2. There is no discontinuity between small-n (n=1-3) and large-n
3. SD is “flattened” in the descending task for large N= 10-7, which reflects subjects who had just completed the ascending (1-10) task

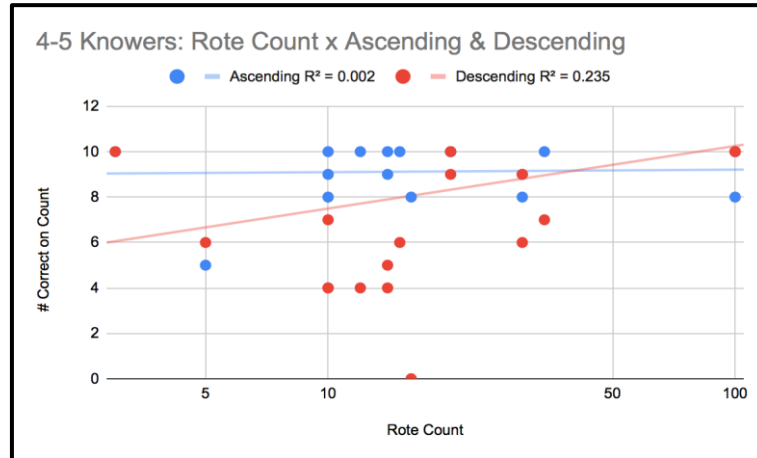
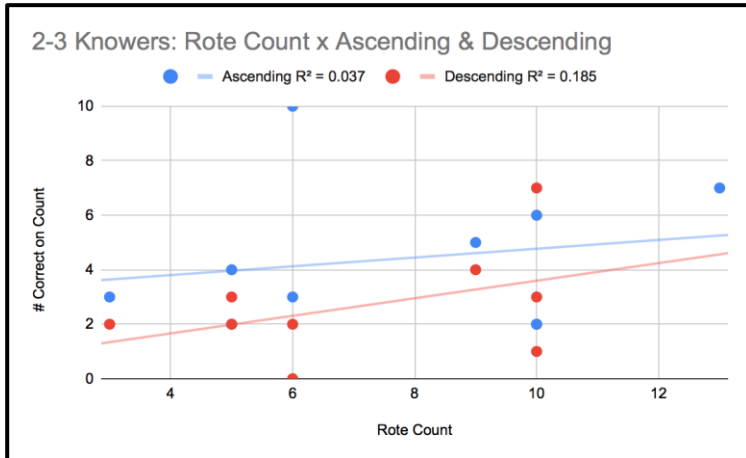
Summary: Ascending vs. Descending Enumeration Tasks

- Unlike the Piraha adults, children did not show clear asymmetries in ascending vs. descending counts except those that arise logically from the number space (i.e., small numbers have more larger straddlers, large numbers have more smaller straddlers)
- Unlike LeCorre & Carey (2007), we did find evidence for Approximate Integer Meanings (AIMS) above $n=4$ when responses were mapped to each of the integers. L&C (2007) used more complex, timed tasks, which may not have been appropriate for finding approximate numerical representations
- The present task is supported by being part of a sequential incremental sequence and there was clear scalarity to the responses
- The following slide shows that rote counting does not explain performance on the task

Lack of correlation for rote counting and Ascending/ Descending Enumeration performance



- In none of the N-knower groups did performance on rote counting predict performance on the ascending and descending enumeration tasks
- Therefore, Rote Counting ability, in itself, does not explain scalar properties of AIMS in this task



Conclusion

In **Non-Verbal quantitative tasks**, 2 to 4 year olds show qualitatively similar performance to Piraha adults, which may reflect a common effect of lack of exact integer systems to quantify over discrete numerosities. It may be the case that the completely impoverished number systems in the Piraha language leads to a kind of “failure to launch.” That is, aspects of exact numerical cognition that are bootstrapped by linguistic symbols are never triggered, and developmental differences are only minimally present in contrasting these populations.

When comparing the **Ascending vs. Descending tasks**, we did not find qualitative asymmetries between ascending and descending task comparable to those found in the Piraha by Frank et al. We did find clear evidence of Approximate Integer Meanings (AIMS) for all n-knower groups and for all quantities, ascending and descending. This is in contrast to previous findings using alternative tasks (LeCorre & Carey, 2007).

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