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Caleb Everett

Independent cross-cultural data reveal linguistic effects on basic numerical cognition

Abstract: The role of numeric language in basic numerical cognition is explored via the consideration of results obtained in two recent independent studies, one with Nicaraguan homesigners and one with speakers of Pirahã. Attention is drawn to remarkable parallels between the relevant findings, parallels that provide compelling evidence that adults without access to numeric language face difficulties when simply attempting to differentiate quantities greater than three.

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Caleb Everett: Department of Anthropology, University of Miami, USA. E-mail: caleb@miami.edu

The precise recognition of exact quantities greater than three is fundamental to human numerical thought. While other species share our ability to exactly distinguish quantities as high as three (Feigenson et al. 2004), there is so far no evidence that they share humans' precise conceptualization of larger quantities. It has been suggested that this precision owes itself in large measure to language, more specifically that numeric language allows for the ligature between two genetically endowed abilities served by distinct neurophysiological substrates, one for the precise recognition of smaller quantities and the other for the approximate recognition of larger quantities (Feigenson et al. 2004; Condry and Spelke 2008). Some initial evidence for this linguistic influence came from studies of Amazonian cultures with anumeric or nearly anumeric languages. Results suggested that members of these groups, the Pirahã and the Mundurukú, struggle with the mental manipulation and even the mere recognition of quantities over three, judging from their performance on a variety of numerical cognition tasks (Gordon 2004; Pica et al. 2004). In the case of the nearly anumeric Mundurukú, a subtraction-based task revealed that their ability to precisely differentiate quantities was deleteriously affected for amounts greater than three, with the proportion of correct responses correlating negatively with quantity size (Pica et al. 2004).

The Pirahã, who speak a language lacking any precise number words (Everett 2005; Frank et al. 2008), employed analog estimation strategies when simply matching arrays of quantities exceeding three, i.e. even when no subtraction was required of a task. Initial results suggested this was true even in the case of a basic matching task in which adult speakers were presented with a linear array of stimuli and asked to produce a novel array equal in number to the original. In the case of this task, Gordon (2004) found that their performance deteriorated for larger quantities. This deterioration also characterized their performance on a variety of other quantity matching tasks, including one in which the stimuli were presented in a linear array and then hidden prior to the subjects' production of a matching array. Gordon (2004) observed that the Pirahã responses revealed a pattern of analog estimation, rather than task incomprehension, as reflected in the relatively constant coefficient of variation (standard deviation of responses divided by mean, for each target number) of 0.15 for quantities greater than three. A coefficient of this magnitude is generally indicative of analog estimation (Weber's law).

The Pirahãs' failure to precisely recognize quantities over three was attributed to linguistic factors in Gordon (2004). Subsequently, this interpretation was called into question for two principal reasons. First, it was noted that the Pirahã results may owe themselves to general cultural factors, rather than to specifically linguistic ones, and that contrastable cross-cultural findings were required for the Pirahã data to be properly interpreted (Casasanto 2005). In addition, a follow-up study (Frank et al. 2008) among the Pirahã failed to replicate the most notable finding in Gordon (2004), namely that the people fail to precisely differentiate quantities over three in a task requiring no manipulation or recall of stimuli. Consequently, the role of completely anumeric language in the inhibition of numerical cognition has remained unclear. While it seems clear that number words serve as an important 'cognitive technology' (Frank et al. 2008) in the mental transposition and recall of quantities beyond three, the role of numeric language in the mere recognition of one-to-one correspondences for quantities greater than three remains a matter of some debate. This debate persists in large measure because adult populations without numeric language and without documented neurocognitive impairments are quite rare. An extensive typological survey suggests that, aside from Pirahã, there are no well-documented cases of completely anumeric language (Hammarström 2010); that is, cases in which a language lacks both number terms and a grammatical system of number. For instance, some Australian aboriginal languages have very limited ordinal and cardinal number systems but ubiquitously index precisely the amount of smaller quantities through the utilization of grammatical-number distinctions such as singular, dual, and trial.

Despite the typological obstacles to research requiring anumeric populations, recent independent studies may help to resolve the role of numeric language vis-à-vis quantity recognition. These studies were undertaken in two disparate cultures, each of which relies on an anumeric communication system. They were conducted independently, prior to publication of either set of findings. In the case of one study (Spaepen et al. 2011), a series of tasks was carried out with four deaf Nicaraguan homesigners. These homesigners do not utilize symbols for precise numbers. Yet they are embedded in a numerate culture that does not present obstacles to the acquisition of numerical concepts, as evidenced by their ability to preferentially value larger denominations of the local currency. Nevertheless, the homesigners struggle with the mere recognition of exact quantities, as evidenced by the results of several quantity matching tasks. For one task, homesigners' were presented with a card with a quantity of depicted figures, and asked to represent the amount in question via manual gestures. While these gestures were accurate for lower quantities, many errors were obtained for higher ones, and the magnitude of those errors correlated positively with the number of depicted items. In short, the homesigners employed analog estimation.

In the case of another task, an array of stimuli were presented to the homesigners and they attempted to match the number of stimuli with a novel array, while their view of the original array remained unobstructed. In a third task, the array was hidden after brief presentation, prior to matching. These latter tasks are identical to the two aforementioned tasks first utilized in Gordon (2004), and also employed in subsequent work among the Pirahã (Frank et al. 2008; Everett and Madora 2012). For both tasks, the Nicaraguan homesigners' quantity matching was 100% accurate for quantities less than four. Crucially, though, in the case of the basic quantity recognition task accuracy fell to 61% for quantities exceeding three. In the case of the hidden matching task, accuracy fell to 50% for such larger quantities. In addition, the magnitude of the homesigners' errors in the latter task increased in accordance with the number of stimuli presented in target arrays. (In the former, the signers' performance benefitted somewhat from matching their fingers with specific targets in the arrays, though such matching was clearly not exact.) Uneducated Nicaraguans speaking a numeric language (Spanish) and deaf speakers of a sign language with numbers outperformed the anumeric homesigners. The difference between homesigners and each of these control groups was significant according to a mixed-models logistic regression ($p < .001$ in each case). These results led Spaepen et al. (2011) to conclude that the homesigners "cannot reliably make the number of items in a second set match the number in a target set if the sets contain more than three items."

We would like to draw attention to a simple yet, we believe, important point: This conclusion is strikingly similar to that offered in the most recent study among the Pirahã (Everett and Madora 2012), as are the experimental results presented in the two studies. This similarity has so far gone undocumented, since the studies were conducted independently and contemporaneously. Two of the tasks utilized by Everett and Madora (2012) are identical to the two just described for Nicaraguan homesigners, conveniently allowing for contrast of the results across both populations. While Everett and Madora (2012) do not present their findings in the same manner as Spaepen et al. (2011), analysis of the results in the former study reveals that the fourteen adult Pirahã participants matched quantities correctly in 100% of trials involving three or fewer stimuli. Careful inspection of their data suggests as well that, in the case of the basic quantity-recognition task, the Pirahãs' ratio of correct responses fell to 59% for quantities greater than three. For the hidden matching task, that proportion fell to 41%. These figures closely resemble those obtained among the Nicaraguan homesigners, and this fact seems unlikely to be a coincidence. Furthermore, the magnitude of Pirahã errors also increased in accordance with the number of target stimuli. Coefficient of variation approximated 0.15 for all quantities, as in the first study on Pirahã numerical cognition (Gordon 2004), once again in keeping with analog-estimation strategies. (Coefficient of variation is not provided in Spaepen et al. (2011).)

Significantly, dissimilar results were obtained for Pirahã who had been familiarized with neologisms for quantities greater than three. Two Pirahã that had previously learned such words gave 100% correct responses for all tested quantities greater than three for the basic quantity recognition task. In addition, a previous study found that fourteen adult Pirahã in one village were also adept at this basic matching task, regardless of quantity (Frank et al. 2008). As noted in Everett and Madora (2012), however, the adults in that village had been familiarized with innovated number words prior to the research conducted for that study. They note as well that the disparity of basic quantity recognition skills between Pirahã familiar and unfamiliar with the number-word neologisms was significant according to a two-tailed by-participants t-test ($t(13) = 6.62$, $p = .000$).

The results in Gordon (2004), Frank et al. (2008), and Everett and Madora (2012) reveal that most Pirahã tested so far struggle with the mere recognition of exact quantities greater than three. Those whose experimental results are not consistent with this conclusion have a documented history of exposure to number-term neologisms. In short, taken in concert, the studies on Pirahã numerical cognition now suggest more convincingly that knowledge of number words substantively enhances basic quantity recognition and differentiation. At the least this seems the most plausible interpretation of the results presented in the three studies in question. (All of the studies suggest definitively that the people struggle with tasks requiring the manipulation and recall of exact quantities.)

The parallels between the findings in Spaepen et al. (2011) and Everett and Madora (2012) merit attention. They demonstrate that members of a non-indigenous Central-American culture and an autochthonous culture in Amazonia have remarkably consonant difficulties discriminating quantities greater than three during the same basic matching tasks. The disparities between the groups' cultures and ecologies indicate that this consonance is likely due to the only clear potential causal factor evident in both cases: a lack of recourse to number words and associated counting strategies. This claim is consistent with prominent hypotheses on the ontogeny of numerical cognition, based on developmental data and data gleaned from populations of other primates and non-primates (see e.g. Condry and Spelke 2008; Feigenson et al. 2004). The similarity of the recent results obtained with Nicaraguans and Pirahãs provides critical additional evidence for the notion that numeric language plays a key role in uniting two innate number 'senses' (Dehaene et al. 1999), dedicated to the exact recognition of smaller quantities and the approximation of larger quantities, respectively.

Our interpretation of the commonalities in the recent Nicaraguan and Pirahã data is buttressed by the fact that intra-cultural, inter-speaker improvements in quantity recognition abilities surface in accordance with participants' knowledge of number words, in the case of both groups. Considered synergistically, the parallels in these recent cross-cultural findings offer extremely compelling evidence that numeric language plays an essential role in enabling even very basic quantity recognition. In addition, the consistency of these results with the findings obtained with a different set of tasks among a nearly anumeric population, the Mundurukú (Pica et al. 2004), is worth underscoring. The evidence obtained with members of these populations suggests strongly that speakers' access to precise number terminology, or lack thereof, impacts numerical cognition in truly fundamental ways.

The pertinent findings highlight one way in which linguistic dissimilarities, in this case the presence/absence of numeric language, may foster cross-population disparities in nonlinguistic cognition. The cognitive disparities in this case can be mitigated more readily than a rigid Whorfian framework might be expected to predict, given that the nonlinguistic facet of cognition in question is apparently altered via the acquisition of lexical items. Yet, paradoxically perhaps, the disparities in question have profound consequences, fundamentally impacting the manner in which people construe numerosity and, *ipso facto*, quantities of items naturally encountered in their physical ecologies.

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