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Intrinsic whole number bias in an indigenous population

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Abstract

Probabilities can be described by a numerator and a denominator and students and decision-makers are not indifferent to numerical values of the components. For instance, when people compare two equal ratios their choices gravitate to the option with larger number, even if they know both ratios are equal. To the date, however, it is unclear if whole number biases are present in other cultures. We tested a farming-foraging group living in the Bolivian rain forest in a simple 2AFC ratio comparison task. After appropriate training, the Tsimane were highly accurate in this task, confirming that visual proportional reasoning is present across cultures. Importantly, they had a strong tendency to favor large numbers in equal ratio comparisons, similar to what is found in educated populations. Even though our sample size is moderate (n=76), the whole number bias we found occurred under good proportional reasoning. The bias may be a general feature of cognition, rather than a cultural or education artifact, that may help humans solve ambiguous situations.

Keywords: Tsimane; Numerical cognition; Fraction; Probability; Whole number bias

Introduction

Detecting differences in discrete visual ratios is useful. They convey a variety of critical information, like how much units of food there is available per competitor or heading direction of a troop by a majority rule (Real, 1993; Strandburg-Peshkin, Farine, Couzin, & Crofoot, 2015). Infants, indigenous population without formal education, and non-human primates can act upon probabilities expressed by visual proportions (Denison & Xu, 2010; Fontanari, Gonzalez, Vallortigara, & Girotto, 2014; Rakoczy et al., 2014). The spontaneous mapping of visual ratios to probabilities in the context of no formal education suggests that this is a core cognitive feature akin to detectors of abstract numerosity and geometry relations found across cultures and species (Carey & Spelke, 1994; Spelke & Lee, 2012)

Discrete probability comparisons, however, suffer from numerosity interferences (Reyna & Brainerd, 2008). It is much easier to compare ratios when the largest one happens to have the larger numerosity. It is unclear if this is caused by cultural characteristics shared by Western, Educated, Industrialized, Rich, and Democratic people (WEIRD) (Henrich, Heine, & Norenzayan, 2010) or if sticking to numerosity is a general feature of how quotients are compared in the mind (Alonso-Diaz, Piantadosi, Hayden, & Cantlon, 2018). The latter option is what we call an intrinsic whole number bias: a pull towards numerical magnitude even though ratio estimates are available. The presence of ratio estimates is critical because it distinguishes it from denominator-neglect or any other strategy used to cover up the inability to compute the value of the fraction.

Previous work probing proportional reasoning in non-WEIRD people, found that the Kaqchikel and K'iche', two indigenous Mayan groups in Guatemala, had refined probabilistic abilities in the absence of formal probability education (Fontanari et al., 2014). Of importance, one of the experiments (Exp. 2) revealed that proportional reasoning was not affected by the numerosity of the options. Participants excelled in comparing 0.25 against 0.75, both when the larger probability had more or fewer number of winners.

Experiment 2 of Fontanari et al., 2014 established probabilistic cognition with no formal education but there were no indications in their study of a whole-number bias, and their analyses nor experimental design tried to uncover one. In fact, to the best of our knowledge, there is no evidence of the whole number bias outside WEIRD populations (perhaps in other species, but not across the WEIRD-NON WEIRD divide). There are at least three hypothesis. Our hypothesis is that it should be similar in NON-WEIRD humans because is a reflection of the inner workings of basic perceptual proportional choice (Alonso-Diaz et al., 2018). A second hypothesis is that the whole-number bias is a mistake caused by deficient education (Reyna & Brainerd, 2008). Under this hypothesis, the whole-number bias should be notably stronger in the NON-WEIRD humans because they lack formal education on probability principles. The third and final hypothesis is that the bias only appears in WEIRD humans because of specific cultural practices (e.g how they learn probabilities and fractions).

We tested a 2AFC ratio comparison task in the Tsimane', a farming-foraging group living in the Bolivian rain forest (Huanca, 2008). A wealth of studies have been done on the Tsimane's cognitive and decision making processes (Apaza et al., 2003; Apaza et al., 2002; Godoy & Jacobson, 1999; Godoy, Jacobson, & Wilkie, 1998; Henrich et al., 2010; Kirby et al., 2002; McDermott, Schultz, Undurraga, & Godoy, 2016; Piantadosi, Kidd, & Aslin, 2014; Reyes-Garcıa et al., 2003). Their aptitude to probabilistic cognition, however, has not been properly researched. The Tsimane are fairly isolated, with low literacy, and no formal instruction on probability principles. We hypothesized the existence of probabilistic reasoning in the Tsimane. Perhaps more important, a detectable bias towards more numerous options in equal ratio trials.

To detect a whole-number bias, we will exploit the fact that when ratios are equal participants should be indifferent to the numerosity of the options and pick randomly; but this is not observed empirically (Denes-Raj, Epstein, & Cole, 1995) even when the proportions are known to be equal (Alonso-Diaz et al., 2018). To be clear, the bias is not exclusive to equal ratio trials. Also, we are not suggesting that only on them probabilistic reasoning fails. The bias towards larger numerosities is intricate and with many explanations (Alonso-Diaz et al., 2018). We are using equal ratio trials as a methodological tool to detect the bias in an indigenous population.

The originality of our work is that we seek an intrinsic whole number bias, one that is detected under appropriate probabilistic reasoning (Alonso-Diaz et al., 2018). To prove good reasoning we will use congruent (the larger probability has larger numerosity), incongruent (the larger probability has smaller numerosity) and equal ratio trials. Congruent and incongruent trials will help us discard illusory Stroop effects by which the irrelevant dimension of numerosity could affect ratio estimates by changing the subjective psychophysical properties of the alternatives (Barth, 2008). In simple words, if the Tsimane are successful in both congruent and incongruent trials we can be sure that they tried to pick the best ratio, not the one with more numerosity.

Their choice on equal ratio trials will be a metric on how intense the bias is. If it is considerably larger or smaller, then we can conclude that cultural practices (e.g. formal education) affect the bias. If it is similar, then it is consistent with being a generic human adaptation (Alonso-Diaz & Penagos, under review).

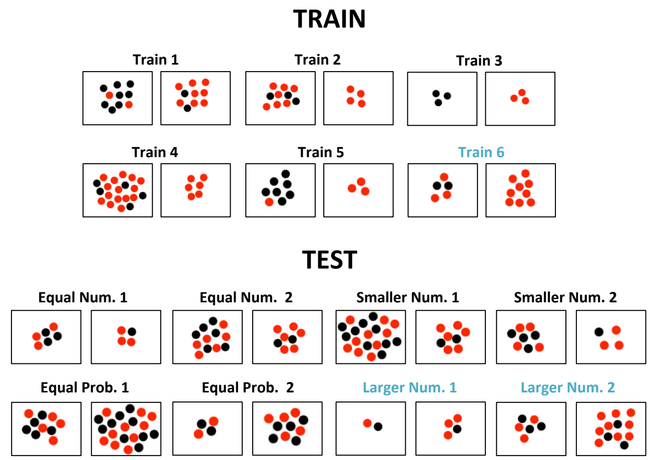

Figure 1: Training and test trials. The ratios of winners (red) to losers (black) in Test trials were 0.5 and 0.75. The titles in the Test images indicate whether the largest ratio had equal, smaller, or larger number of winners or if both options had equal probability. Cyan titles indicate stimulus that just a subsample of Tsimane observed (n=24). If a participant is successful in all control trials (Equal, Smaller, and Larger Num.), we would be more confident that the bias in Equal Prob. trials is intrinsic i.e. it can appear under proper proportional reasoning.

Methods

The study procedures were approved by the Gran Consejo Tsimane' (Tsimane' grand council), as well as institutional IRBs. Tomás Huanca and the Centro Boliviano de Investigación y de Desarrollo Socio Integral (CBIDSI) provided logistic support (translators, transportation, and general expertise about the Tsimane community).

Participants. We evaluated two groups of Tsimane. This was not an explicit design strategy but rather reflects the dynamics of field-work (details below). The first group received verbal instructions in their native language (n=86, 60 females, M age = 34.13 years, s.d. = 15.09, Education M = 3.18 years, s.d. = 3.28). The second received non-verbal training version (n=78, 53 Females, Age M = 31.884 years; s.d. = 14.528; Education M = 4.012 years, s.d. = 4.037). 76 Tsimane succeed non-verbal training (two subjects failed the training stage). We only present the results for the Tsimane who did non-verbal training (see Alonso-Diaz, 2017 for the verbal-training sample). Each Tsimane did many cognitive tasks sequentially including language, numerosity, color perception, and the probability task reported here.

Materials and Procedure. Participants saw two images, one to the left and another to the right side. Each image was presented in individual laminated sheets (legal size) that contained a mix of red and black dots (Fig. 1). Participants had to select the option with best chances of winning (red). The best option was randomly placed on either side. The Tsimane heard a verbal instruction in their native language.

The behavior of the initial 86 Tsimane (those who only received verbal instructions) was hard to classify as either following ratio or numerosity (an analysis of this subsample is provided in Alonso-Diaz, 2017). To make sure it was not related to translation issues, halfway during field research we included non-verbal training with feedback. After verbal instructions we randomly presented six pair of training images until all were correct i.e. we cycled through them until all responses were correct and most Tsimane were quick dispatching training. Training trials were mostly trivial (5 out of 6) in that one side only had winners (Fig. 1), randomly placed to the left or right side. The intention of trivial trials was to deter number-based strategies: the correct option had the same, fewer, or more winners than the wrong side. We presented test trials (Fig. 1) in pseudo-random order with no feedback.

Of the 76 participants with non-verbal training, 52 did three types of test trials: 1) both ratios had equal number of winners, 2) the best ratio had smaller number of winners, and 3) ratios were identical but one had more winners (Figure 1). To further discard a strategy of low-number of losers (the confound present in Fontanari et al., 2014 Maya's study), the last 24 Tsimane saw the same images as the 52 but also new Test images with identical number of losers (blacks) (and also one more training image, Fig. 1 cyan color).

Data analysis. We will use the following acronyms: EN = both ratios had equal numerator; SN = larger ratio had smaller numerator; LN = larger ratio had larger numerator; EP = both images had equal probability. In EP accuracy reflects the proportion of choices favoring the option with larger numerosity

Binomial tests evaluated if performance was greater than chance. In control trials (EN, SN, and LN), chance means picking the larger ratio more than 50% of the times. In test trials (EP), chance means picking the option with larger numerosity more than 50% of the times. In the binomial tests we used the total number of choices. Because each Tsimane made two choices on each trial type (Fig. 1), n = 2 times sample size.

We classified each Tsimane's behavior according to one of the following potential strategies: consistently picked A) More winners; B) Fewer winners; C) More total number of balls; D) Fewer total number of balls; E) More losers; F) Fewer losers; G) Larger ratio; H) Other. Some behaviors were ambiguous as they could be consistent with more than one strategy. For instance, in the stimuli presented to the subsample of 52 Tsimane (the one similar to Fontanari et al., 2014), being correct in all trials and selecting the option with fewer losers when both ratios were equal will necessarily occur if the agent decides based on fewer losers or the larger ratio. When such coding conflicts occurred, we used the unambiguous behavior. In the example, we would code the Tsimane as following a strategy that picks fewer losers because a strategy of only ratios will be random when both bags have equal ratio.

Results

Tsimane's accuracy in test trials was high (Fig. 2A; EN: 149/152 = 0.98 trials correct, $p < 0.001$; SN: 143/152 = 0.94, $p < 0.001$; LN: 40/48 = 0.83, $p < 0.001$; EP: 66/152 = 0.43, $p = 0.12$). Fig. 2A seems to suggest that in equal probability trials (EP) the Tsimane did not tend to pick the bag with larger numerosity. A closer look reveals that the majority of Tsimane behave in accordance to a ratio-based strategy (n = 36), followed by strategies that follow small number of balls (n = 26), other unidentifiable strategy (n = 8), low number of losers (n = 4), and large number of winners (n = 2) (Fig. 2B). The diversity of strategies is only normal in such unnatural task. Interestingly, we detected a large number bias in equal probability trials in Tsimane' whose performance was flawless in EN, SN, and LN test trials (52/72 = 0.72 trials favored the option with more winners, $p < 0.001$). As a reminder, EN, SN, and LN were control trials for a simple numerosity-based behavior. For instance, a Tsimane who had only followed large numerosities would have failed in both SN trials because in those trials the larger probability had smaller numerosity. This means that the manifestation of the whole number bias in equal ratio trials is hardly explained by a straightforward behavior based on numerical cardinalities in those who did not fail in EN, SN, and LN trials.

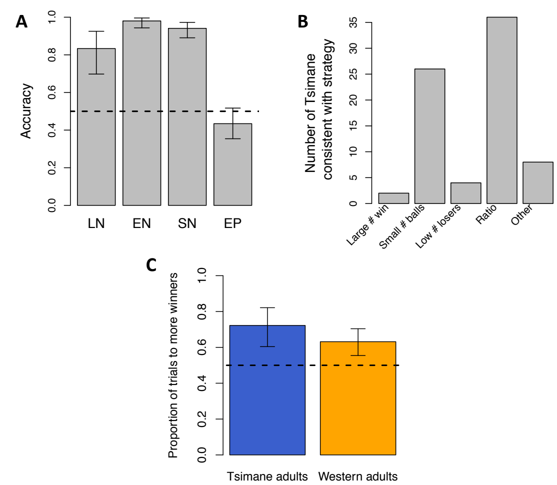

Figure 2: Accuracy (A), distribution of strategies (B), and whole number bias in the Tsimane who were reliably coded as following a ratio-based strategy (C). In A: LN: the best ratio had the large numerator (winners); EN: both ratios had equal numerator; SN: the best ratio had small numerator; EP: both options had equal probability. In EP accuracy reflects the proportion of choices favoring the option with larger numerosity. Dashed line is chance. Error bars are 95% confidence intervals of a binomial test (all p<0.05, except EP).

The rate of the bias is comparable to the one found in American adults doing a similar one-shot task. (Fig. 2C; χ^2 (1) = 1.469, $p = 0.225$; American data in (Alonso-Diaz et al., 2018)). The Tsimane whose behavior is consistent with ratio use (n=36) exhibit the same intuition to favor large numbers in ambiguous contexts. We emphasize that in the other strategies is hard to classify the bias as such because it is baked in the actual definition e.g. in a "large # win" strategy the task is solved following winners. We argue that the theoretically relevant bias is when appropriate proportional reasoning is present.

As it was mentioned in the methods, some participants did additional trials in which both images had identical number of losers. The reason for this was to discard a losers-based behavior. An analysis of these two subsamples reveals a similar pattern. In the subsample that did not see images with identical number of losers (n=52) they had a behavior above chance in all control trials (chance means picking the larger probability) and in equal probability trials (chance means picking the the image with larger numerosity) (i.e. all binomial tests p<0.05) confirming the presence of a whole number bias. Of those 52, 48 had perfect performance in control trials and also revealed a whole number bias in equal probability trials albeit not significant (30/48 = 0.625, p = 0.11). This first subsample was clearly trying to solve the task through ratio-based strategies because they succeeded in SN, LN, and EN trials. However, when faced with equal ratio trials they showed a whole-number bias. This does not necessarily mean that in equal ratio trials their proportional reasoning shuts down (Alonso-Diaz et al., 2018); our experimental design cannot solve that question.

In the second subsample, we can definitely discard a loser-based strategy (n = 24). Their behavior in control trials was different than chance (i.e. all binomial tests p<0.05), and revealed a whole number bias in equal probability trials (22/24 = 0.91 trials favored the option with more winners, p < 0.001). Thus, the effect was particularly present in those who we can discard any form of number-based strategy in SN, LN, and EN trials.

A caveat of our results is that even though significant, we had a small sample size (n=76), specially the ones that we can confidently discard a number-based strategy (n=24). Future work could increase sample size, but two things make us confident of the results. First, the whole number bias is not a controversial finding (e.g. Alonso-Diaz et al., 2018; Reyna and Brainerd, 2008). Second, the bias we reported was stringent, making sure that it was present under proper proportional reasoning.

Discussion

The Tsimane', similar to other populations (Mayas, human infants, non-human primates), are capable of visual proportional reasoning. Even though the task used was artificial, based on laminated sheets, it was possible to elicit ratio-based responses. Perhaps more relevant, in ambiguous trials, in which both options had equal probability, the intuition of adult Tsimane was in line with that of adult Americans: pick the option with larger numerosity. This was not a number-based strategy induced by lack of proportional abilities as they were very capable of solving congruent (larger prob. has more winners), incongruent (larger prob. has fewer winners), and trials where the large probability had the same number of winners as the wrong alternative.

Perhaps more insightful is that the bias was comparable in size between WEIRD and NON-WEIRD samples (Fig. 2C). Because we obtained the bias under good proportional reasoning and with equal ratio trials, it suggests that numerosity could be a generic cognitive tool to solve ambiguity, not merely a quick heuristic to substitute an inability to compute ratios as previously proposed. In fact, the bias could be a sign of adaptive agents (Alonso-Diaz & Penagos, under review).

The automatic activation and use of numerical values, despite appropriate visual proportional reasoning, is confirmable through more rigorous psychophysics tasks and computational models (Alonso-Diaz et al., 2018). What is suggestive of the Tsimane results is that number intrusions may not be a WEIRD phenomenon of developed economies (Henrich et al., 2010) but the outcome of some generic computation, perhaps influenced by the fact that larger numerosities elicit a greater sense of confidence and capture attention (Alonso-Diaz, 2017; Alonso-Diaz & Cantlon, 2018).

The intuition of relying in numerosities is usually observed during learning and manipulation of symbolic fractions (Ni & Zhou, 2005; Siegler, Fazio, Bailey, & Zhou, 2013). At the same time, there is growing evidence that perceptual and symbolic systems are not independent (Melnick, Harrison, Park, Bennetto, & Tadin, 2013), for instance the approximate number system correlates with formal math tests (Halberda, Mazzocco, & Feigenson, 2008). It is possible, then, that the effects of number in perceptual proportional reasoning transpire to symbolic education and decision-making settings where numerosity should not be employed.

An alternative explanation of our results is that the Tsimane tested were not fully illiterate (mean years of education 4.012) and some negative pedagogical influence in those years may have impacted behavior in our task. The main problem with this interpretation is that the Tsimane succeeded in ratio comparisons with different numerosity manipulations. If anything, the contra argument is also plausible: education might have helped them in solving the task. Rather, we argue that the intuition of relying in larger numerosities is a generic feature of cognition. The human mind is endowed with probabilistic knowledge. However, the mechanisms that lead to overt probabilistic behavior do not necessarily drop the numerical values, even when holistic ratio computations are available. Number intrusions seem to be present across cultures.

Another interesting result is that the Tsimane required non-verbal training to succeed in our task. The first subsample only received verbal instructions in their native language but their performance was lower than those who received non-verbal training (see Methods). It is hard to narrow down the reasons for such difference between verbal and non-verbal instructions but it is relevant for future studies on non-WEIRD populations.

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