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Research Paper

The Correlation of Numeracy and Raw Estimations

Weiqian Lilith Yan

Abstract
Numeracy has been referred to as the ability to work with numbers (Cokely & Kelley, 2009). Objective numeracy, specifically, is a measure of participants' ability in numerical calculations (Peters et al., 2006). Research has shown that people with high numeracy skills are generally better at calculation speed and accuracy. We planned to test the idea of how people with high numeracy, who commonly own a better sense of estimating the calculation when provided with specific numbers, will perform without calculations. Strikingly, the present study found that participants who were more numerate actually performed worse on random number estimation when presented with absolutely no clues. We found a positive correlation between participants' objective numeracy scores and the distance of their estimation to the correct answer in a series of three estimation tasks. The results, to a certain extent, have questioned the assumed stereotype regarding the connection between objective numeracy and number estimation. This assertion might hold when participants are provided with specific values, leading to estimations primarily grounded in calculations. However, in instances where no information is presented, it has been observed that a high level of objective numeracy does not necessarily correlate with increased accuracy in their estimates. Instead, it predicts worse performance.

Keywords: *Numeracy, Objective numeracy, Numeric Estimation*

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I. Introduction

Numeracy was referred to as the "array of mathematically related proficiencies that are evident in adults' lives…including a connection to context, purpose, or use… for active participation in the democratic process and… in the global economy" (Ginsburg, Manly, Schmitt, 2006). Higher numeracy has been shown to lead to better medical decisions and predictions (Peters et al., 2022). Further, those higher in numeracy have been shown to be better at predicting uncertain events by more accurately using reasoning and evaluation of feelings (Sobkow et al. 2019). Additionally, rationality, using a normative way of decision-making by thinking about what decision and why the decision should be made, can also positively correlate with one's numeracy skills (Cokely, 2016). Undoubtedly, a common feature among individuals higher in numeracy is rationality in the decision-making process and their reflecting on and contemplating the information they receive. People's numeracy skills have shown significance in other psychological or cognitive thinking such as anchoring (Yoon & Fong, 2015) and framing (Peters, 2006).

In most of the cases, people with greater numeracy make better predictions. For example, in a study by Dieckmann and colleagues (2009), they found that more numerate participants perform better at risk prediction. In their study, they provided participants with a risk likelihood assessment for a terrorist attack (with numbers such as 5%, 15%, and 25%) along with an intelligence report with or without a highly descriptive narration about the attack (Dieckmann et al. 2009). When the participants were asked to estimate the risk, the less numerate ones had a much higher estimation than the percentages given and were more biased by the narrative description compared to those with higher numeracy (Dieckmann et al. 2009). That is, a higher numeracy enables people to a better and more stable predictions when receiving some numeric information.

As stated above, the individual's numeracy level positively correlates with one's rationality, then raised a question: How about when the question is asked suddenly with no information or clues at all? Will they perform better than the low-numeracy people as well? This research study aims to test whether the positive correlation between numeracy and calculation accuracy also contributes to a correlation between numeracy and people's numeric sense, for example, height, distance, etc. In this experiment, we first asked 3 questions to make raw estimations based on absolute no clues upon distance, height, and numbers. We then tested participants in objective numeracy to investigate whether those lower or higher in numeracy would provide more accurate estimations. Our hypothesis was that when asked a numeric question suddenly without any available information, participants with higher objective numeracy would exhibit a more accurate raw estimation compared to the ones with lower objective numeracy.

Methods

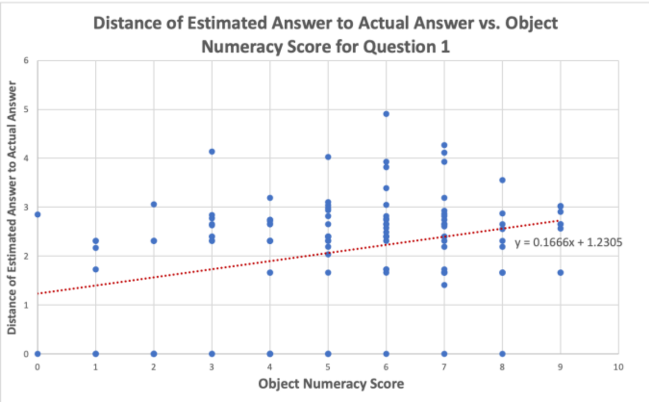
Participants. 131 participants attended this research via Amazon's Mechanical Turk. Among them, 84 participants (64.1% of the total) were male while 47 were female (35.9%). Their ages range from 25 to 74 years old. 108 were White / Caucasian (82.4%); 10 were Black or African American (7.6%); 9 were Asian / Pacific Islander (6.9%); 4 were Hispanic (3.1%). All participants were located in the United States.

Procedure. All the participants voluntarily chose to complete an online survey on Amazon Mechanical Turk, and their privacy was protected by Amazon Mechanical Turk. To remain anonymous, no questions were asked on behalf of the participant's names, jobs, emails, etc. The survey consisted of two parts. 1) Estimations. 2) A 9-question test for objective numeracy (Weller et al., 2013). Finally, they were given demographic questions.

Estimations. For this part, participants were asked to answer 3 basic questions requiring their rough numeric estimations without any contexts beforehand. The three questions were; . 1) What will you assume the height of the Empire State Building? 2)How many times has Phantom of the Opera performed? 3)What do you think is the distance between London and Paris?

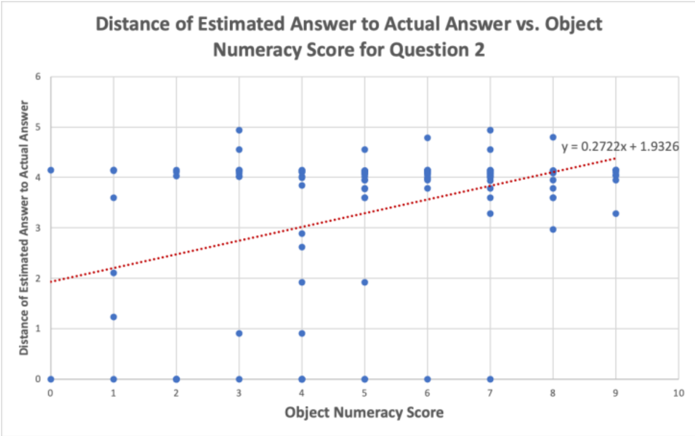
Objective Numeracy Scale. For this part, the participants were asked to answer nine questions that either originated from Weller's eight-item Objective Numeracy Scale or were designed to mimic it (Weller, 2013; e.g. If the chance of getting a disease is 10%, how many people would be expected to get the disease: Out of 1000?) All questions had been used in prior research on numeracy (Falco et al., 2019).

II. Results



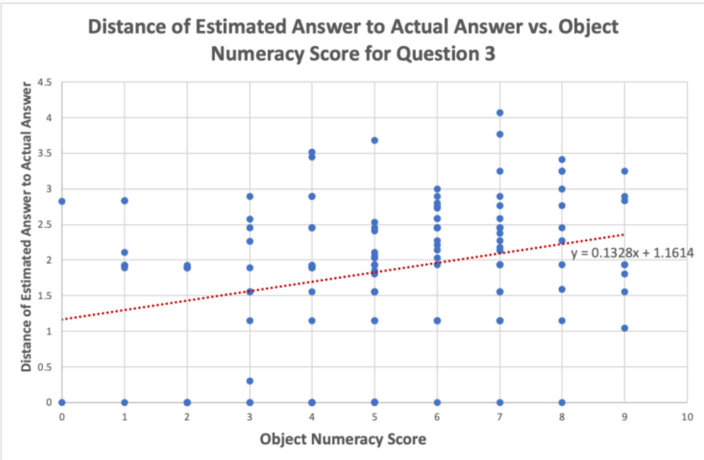
Graph 1.1 What will you assume the height of the Empire State Building?

For Estimate 1, we asked "What will you assume the height of the Empire State Building?" We collected the responses, and the 131 participants had a mean answer of 2,547.29 feet (SE = 7613.81). The actual answer was 1,454 feet according to the official *Empire State Building* website (Facts & Figures | Empire State Building, n.d.). The 3 sets of data were all transformed by taking the log of the difference between participants' estimates and the true values. After calculating the log distance of each participant's answer to the actual answer (how "off" their estimations are) in correlation with the participant's objective Numeracy score, there was a positive correlation of r-value equals to 0.32 and $p < 0.01$, suggesting that the data is highly statistically significant.



Graph 1.2 How many times has Phantom of the Opera performed?

For Estimate 2, we asked "How many times has Phantom of the Opera performed?" We had answers with a 9445.32 (times) average (SE = 16,871.48) while the actual answer, according to the official Rolling Stone's website, was 13,917 times (Kreps, 2022). By comparing the distance of their estimates to the actual answer vs. numeracy scores, we received a positive correlation with $r = 0.40$ and $p < 0.01$.



Graph 1.3 What do you think is the distance between London and Paris?

For Estimate 3, we asked "What do you think is the distance between London and Paris?" The mean answer for this question was 662.05 miles (SE = 1,295.48). The actual answer was 214 miles based on information from *distancecalculator.net.* (Distance from London to Paris, n.d.) By comparing the distance of their estimates to the actual answer vs. numeracy scores, we received another positive correlation with $r = 0.29$, $p < 0.01$, again showing the statistical significance of the data.

For all 3 questions, objective numeracy (ONS) was correlated with difference score as the table shown below:

	r	sig
Estimate 1	0.32	< 0.01***
Estimate 2	0.40	< 0.01***
Estimate 3	0.29	< 0.01***

Table 1.1 The correlation r and p values of 3 Estimates

*Corresponding Author: Weiqian Lilith Yan

This means that as participants' object numeracy score increases, the distance between their estimations to the right answer also increases. The larger distance indicates a less accurate estimation. Therefore, according to the data and graphs from this research, people with higher objective numeracy actually perform less accurate estimation without clues in advance for each of the three estimates. To investigate the data as a whole, we built a hierarchical linear regression model using the log distance between estimate and real value for each of the three estimates for all participants. We allowed slopes to vary by participant and question. We again found that the participants higher in numerary made estimates that were further away from the true value ($b = 0.19$, $p < .01$).

III. Discussion

The results obtained from this study reject the initial hypothesis that people with higher objective numeracy make more accurate raw estimations. As we expected there would be a better chance for high numeracy participants to have raw estimations closer to the correct answer. Conversely, people with higher ONS actually perform worse as shown by the data. Such an unexpected and somehow violating common-sense result is particularly intriguing because this suggests numeracy is not always the standard guaranteeing a better performance in dealing with numbers. This study reveals that in certain cases, such as when there are no numbers presented to them, their ability to fast and accurately calculate numbers does not predict a better raw estimation.

Admittedly, limitations do occur in this research. First, the size of participants might be relatively small with only 108 participants. A larger size would lead to a more convincing conclusion. While the current sample size has enabled preliminary insights, it is worth highlighting that a more expansive and robust participant pool could substantially bolster the robustness and generalizability of the study's findings. The augmentation of the participant base, thereby encompassing a more diverse range of perspectives and experiences, would invariably lend greater weight to the conclusions drawn from this investigation.

Second, only 3 questions asking for raw estimation might be too few to fully evaluate participants' abilities. Future research could expand upon this idea by using a larger sample size and more estimations. The results found in this study went against our initial hypothesis and were not expected. To further validate these findings, it would be helpful if future research was conducted with this as their original hypothesis and pre-registered their study.

Further, this study does not explore the mechanism behind why participants higher in objective numeracy make less accurate estimates and future research could shed more light on these mechanisms. This intriguing aspect remains a fertile ground for future investigations, wherein comprehensive research endeavors could potentially help better understand the cognitive or psychological processes contributing to this counterintuitive outcome. By delving deeper into the underlying mechanisms, subsequent studies have the potential to shed a more profound light on the intricate interplay between numerical aptitude and estimation accuracy, thus enriching our understanding of the intricate cognitive dynamics at play.

In summary, our results disagree with our original hypothesis that people with better objective numeracy show a greater ability on raw estimation. Our results in fact reflect a significant positive correlation between the distance of participants' estimates to the true answer vs. their numeracy level. This creates some doubt in the idea that those higher in numeracy are automatically better at a numeric task. In fact, if they are not able to perform numeric calculations they may perform worse. Therefore, it might happen that if you have a friend who can quickly calculate the amount of money that 15% tip needed for dinner without using a calculator, when discussing the height of the Eiffel Tower, that friend might provide an answer that is a bit "off".

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Appendix

Objective Numeracy Scale

Imagine that we flip a fair coin 1,000 times. What is your best guess about how many times the coin would come up heads in 1,000 flips?

In the BIG BUCKS LOTTERY, the chances of winning a $10.00 prize are 1%. What is your best guess about how many people would win a $10.00 prize if 1,000 people each buy a single ticket from BIG BUCKS?

In the ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets of ACME PUBLISHING SWEEPSTAKES win a car?

If the chance of getting a disease is 10%, how many people would be expected to get the disease: Out of 1000?

If the chance of getting a disease is 20 out of 100, this would be the same as having a ____% chance of getting the disease.

Out of 100 people in a small town 50 are members of a choir. Out of these 50 members in a choir 30 are women. Out of the 50 inhabitants that are not in a choir 20 are women. What is the probability that a randomly drawn woman is NOT a member of the choir?

Imagine we are throwing a die (6 sides, numbered 1 to 6). The probability that the die shows "1" is three times as high as the probability of each of the other numbers. Now imagine you would throw this die 80 times. On average, out of 80 throws how many times would the die show the number 1?

Imagine we are throwing a five-sided die 100 times. On average, out of 100 throws how many times would this five-sided die show an odd number (1, 3 or 5)?

In a forest 40% of mushrooms are red, 30% brown and 30% white. A red mushroom is poisonous with a probability of 10%. A mushroom that is not red is poisonous with a probability of 20%. What is the probability that a poisonous mushroom in the forest is red?