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Individual Differences in Conflict Detection, Numeracy, and Processing Preference

Audrey Weil
Callie Jaycox
Jessie Ngo
Washington College

Conflict detection is a phenomenon in which an individual detects when there is a difference between an intuitive and a logical response. Few studies have investigated the underlying factors that contribute to conflict detection. Possible factors include a preference and an ability to use numerical information during a judgment task. In the present study, participants estimated subjective probabilities, and completed the Subjective Numeracy Scale and the Fuzzy Processing Preference Index which assess numerical ability and preference for using numerical information respectively. We found no differences between detectors and non-detectors in terms of numeracy or processing preference, suggesting that conflict detection is not influenced by either an ability or tendency to use and understand numerical information.

Keywords: Conflict Detection, Numeracy, FPPI, Probability Judgement

Author Note
Correspondence should be addressed to Audrey Weil, Washington College, 300 Washington Ave, Chestertown, MD, 21620.
Phone: 410-778-7734, Email: Aweil2@washcoll.edu

For the past several decades, judgment and reasoning researchers have used questions that pit logic and intuition against each other to understand how people reason. To illustrate, let us take the classic bat and ball problem by Frederick (2005), which reads as follows: "A bat and a ball together cost $1.10. The bat costs $1 more than the ball. How much does the ball cost?" When first presented with this problem, most people will answer that the ball costs 10 cents. However, while this answer is intuitively appealing, it is incorrect. If the ball cost 10 cents, and the bat is $1 more, then the bat and ball together must cost $1.20. In this instance the correct answer would be that the ball costs 5 cents and the bat costs $1.05. Here we can see how an intuitive answer, 10 cents, conflicts with the logical answer of 5 cents.

When responding to problems like this, some people seem to implicitly detect this conflict between logic and intuition (De Neys, 2012). This conflict detection is evidenced by a number of things such as lower confidence (De Neys et al., 2011), autonomic arousal (De Neys et al., 2010), and activation of neural regions associated with detecting and monitoring conflicting information and responses (De Neys et al., 2008; Vartanian et al., 2018). Numerous studies have shown that conflict detection tends to be a widely experienced phenomenon. However, very little is known about what leads some to detect conflict and not others.

Recent work has demonstrated that people with a more analytic cognitive style or greater knowledge of logical principles are more likely to experience conflict detection (Pennycook, Cheyne, Barr, Koehler, & Fugelsang, 2014). Both are also significant predictors of judgment and reasoning ability (Stanovich & West, 2008; Trippas et al., 2015).

Therefore, it seems feasible that predictors of judgment and reasoning ability, especially in the face of conflicting information like in the example above, may also be predictors of conflict detection. One such potential predictor that has yet to be fully explored is numeracy, or the ability to use and understand numerical information.

It has become increasingly apparent that numeracy plays an important role in judgement and reasoning (Klaczynski & Felmban, 2018; Liberali et al., 2012; Peters et al., 2006). Having higher numeracy predicts many of the skills needed for accurate judgment such as an understanding of ratios, a decreased susceptibility to being misled by different styles of presenting information, and a greater ability to understand risk outcomes (Peters et al., 2006; Reyna et al., 2009). Recent work has posited that the importance of numeracy in probability judgment is due to the fact that both rely on probabilistic reasoning and an ability to integrate different kinds of information (i.e. quantitative and qualitative) into the judgment process (Cokely et al., 2018). To date, only one study has investigated the role of numeracy in conflict detection, which found that numeracy was a weak predictor of detection efficiency, or their rate of detecting conflict divided by their rate of biased answers (Šrol & De Neys, 2020). However, no work has been done to fully establish relationship between numeracy and rates of conflict detection. Therefore, the present study seeks to investigate this relationship more directly while exploring other related predictors of judgement and reasoning ability.

Despite the importance of numeracy in judgment and reasoning, an ability to understand and apply numerical information is often not enough to reason effectively. In part, this is due to most people preferring to make judgments based on qualitative information and ignore the quantitative information, even if they have high numeracy (Weil et al., 2015). In light of this nuance, we choose to include another measure in the present study called the Fuzzy Processing Preference Index (FPPI; Wolfe & Fisher, 2013). This index uses base-rate problems to assess participant's tendency to incorporate numerical base-rates into their judgment process. Participants who give more weight to these base-rates will score more highly on the FPPI.

In this experiment, we examined the relationship between numeracy, processing preference, and conflict detection for subjective probability problems. Based on previous work establishing a possible role of numerical abilities in conflict detection, we hypothesized that both subjective numeracy and FPPI scores would predict greater levels of conflict detection in probability problems.

Method

Participants

A total of 103 undergraduate students from Washington College participated in this experiment. Participation was voluntary, and all participants were compensated with course credit upon completion.

Materials

Numeracy

Numeracy was assessed using the Subjective Numeracy Scale (SNS; Fagerlin et al., 2007). This scale consists of eight self-recorded questions on numerical ability and preference. The questions require no computation to answer; instead, the questions require participants to rate their ability to perform certain tasks and their preferences for information consumption on a 6-point Likert scale. For example, a question regarding numerical ability might ask a participant to rate how good they are at working with fractions, while a question focusing on numerical preference might ask how helpful they find tables and graphs when reading a news story. The validity of the SNS is supported by its positive correlations with measures of objective numeracy such as the S-TOFHLA and WRAT4, as well as its ability to predict better risk comprehension and utility elicitations (McNaughton et al., 2011; Zikmund-Fisher et al., 2007). Additionally, the Cronbach's alpha of the SNS has been consistently above .8, suggesting reliability (McNaughton et al., 2011; Šrol & De Neys, 2020).

FPPI

FPPI was used to identify participants' preference for making judgments based on quantitative or qualitative information. This index is comprised of 19 base-rate problems in which quantitative and qualitative information bias a participant's answer in opposite directions.

For example, a scenario might read:

> At Cloverdale High School 10% of the seniors go on to college. Bob is a senior at Cloverdale High. He gets mostly As and Bs in school and is well liked by his teachers.
> What is the probability that Bob will go to college?

Participants who reported higher probabilities for Bob were considered to have a preference for qualitative information. Since the numerical value provided does not support a high likelihood of going to college, individuals who indicated a higher probability were more likely to have focused on the verbal information provided. Similarly, those who reported lower probabilities were considered to have preference for quantitative information due to their attention to the numerical base-rate. This index is both valid and reliable with a Cronbach's alpha ranging between .91 and .96 across multiple studies, and has correlated with logic index scores on syllogistic reasoning, performance on joint-probability problems, and rule-based process dissociation procedure (Weil et al., 2015; Wolfe & Fisher, 2013).

Judgement Task

During the judgement task, participants were presented with 16 subjective probability questions. Eight questions were congruent problems where both intuition and logic cued the same response. The other eight were incongruent problems where the logical answer conflicted with the intuitive answer. For example, here we see a standard congruent problem:

> Collin does not feel so great. He has a headache, a slight fever, and congestion. Which one of the following statements is most likely?
> 1) Collin will take some medicine.
> 2) Collin will take some medicine and go for a bike ride.

Here, both logic and intuition prompt the participant to pick the first option, making this a situation when there is no conflict detect. On the other hand, an incongruent problem may seen in the following example:

> Like many kids his age, Tommy has a sweet tooth. Today is Tommy's eighth birthday, and his mother is letting him eat or drink anything he would like for the special occasion.
> Which one of the following statements is most likely?
> 3) Tommy will eat broccoli on his birthday.
> 4) Tommy will eat cake and broccoli on his birthday.

Despite the fact that one probability (1) is always more likely than two probabilities (2), many participants will still choose the second option because it is more intuitively appealing, thus committing the conjunction fallacy (Tversky & Kahneman, 1983). In these problems, there is a conflict between the intuitive response (2) and the logical response (1) which may be implicitly detected by participants.

Procedure

At the start of the experiment, participants were seated individually at a computer in a quiet room with up to 5 other participants and the experimenter. After giving their informed consent, participants were first asked to complete the probability judgment task. Probability problems were randomized and presented on Eprime 2.0. Participants were first presented with the description of the person, such as Tommy seen above, which they could read at their own pace. When they were ready to advance, participants pressed the space bar to advance to the next screen, where the two probabilities were presented. On this screen they were asked to press either 1 or 2 to indicate which probability they believed to be the most likely. In order to avoid participants simply pressing 1 as a default, 1 was correct half of the time for both congruent and incongruent problems. After each problem, participants rated their confidence in their answers on a scale of 1–9. Once finished, they then completed the FPPI and SNS measures. Both measures were presented as on online survey through Qualtrics. Upon completion of all three tasks, participants were debriefed and compensated with course credit. Successful completion of the experiment took approximately 20 minutes or less.

Table 1
Means (standard deviations) of accuracy, reaction time, and confidence for congruent, incongruent, and total trials.

Dependent Variables	Incongruent	Congruent	Total
Accuracy	.22(.16)	.90(.15)	.56(.16)
Reaction Time (ms)	6375.23(1917.40)	6514.54(2161.53)	6444.89(2039.47)
Confidence	6.90(1.61)	7.22 (1.90)	7.06(1.76)

Results

In order to assess participants' performance on the probability judgment task, we compared congruent and incongruent trials in terms of accuracy, reaction time, and confidence scores using three paired-samples *t*-tests. Reaction time was operationalized as the time between the presentation of the probabilities and their response of pressing either 1 or 2 key. As expected, we found that congruent trials, resulted in significantly higher accuracy compared to incongruent trials, $t(102) = 31.75, p < .001, d = 4.40$. Somewhat unexpectedly, there were no significant differences in reaction time, $t(102) = 1.21, p = .228, d = .11$, or confidence, $t(102) = 1.47, p = .145, d = .18$, between congruent and incongruent trials.

Building from previous work (Frey et al., 2018), participants in this experiment were coded as either conflict detectors or non-detectors. Conflict detectors were the participants who, on average, were less confident on incorrect incongruent trials than they were on correct congruent trials. Using this method, 51% of participants were coded as conflict detectors. In order to assess the relationship between conflict detection and judgment ability, we compared the differences in performance on the joint-probability problems between conflict detectors and non-detectors using three independent samples *t*-tests. We found no significant difference in accuracy, $t(101) = -.95, p = .343, d = .11$, reaction time $t(101) = -.61, p = .543, d = .12$, or confidence, $t(101) = 1.41, p = .162, d = .28$, between the participants who could detect conflict and those who could not. This is in line with previous research showing that an implicit ability to detect a conflict does not necessarily relate to an ability to act on that feeling (De Neys, 2014; Teovanović, 2019).

On average, participants had an FPPI score of .44 ($SD = .09$) out of 1, with higher numbers indicating a greater preference to incorporate base-rates into their judgment process. Consistent with prior work, most participants scored on the lower end of the spectrum, indicating that they preferred to reason with qualitative, rather than quantitative, information. To investigate the relationship between FPPI scores and numeracy ($M = 3.83$, $SD = 0.87$), we ran a correlation analysis, and found that they were not significantly correlated, $r(103) = .02, p = .888$. This suggests that these scales are tapping independent processes.

In order understand the relationship between conflict detection, numeracy, and FPPI scores, we calculated the effect size of conflict detection by subtracting each participant's average confidence for incorrect incongruent questions from their average confidence for correct congruent questions. Previous work has used this as a measure of participants' sensitivity to the conflict, and has found that individuals with higher conflict detection effect sizes tend to be more accurate, perhaps because of their increased sensitivity (Frey et al., 2017). We did not find a significant relationship between effect size and accuracy, $r(103) = .03, p = .735$, suggesting that there may be more nuance to the relationship between conflict detection effect size and accuracy than has been previous discussed. Similarly, we did not find a significant correlation between effect size and numeracy scores, $r(103) = .03, p = .733$, or FPPI scores, $r(103) = .11, p = .260$, supporting the conclusion that neither numeracy nor processing preference relate to conflict detection. Additionally, examination of scatterplots revealed no evidence of non-linear relationships between conflict detection effect size, subjective numeracy, or FPPI scores.

Discussion

In this study we investigated the potential role individual differences in numeracy and processing preference had on participants' ability to detect conflict in a probability estimation task. We expected to find a relationship between these individual differences measures and conflict detection. However, neither numeracy nor processing preference was related to conflict detection. This suggests that the relationship between processing preference, numeracy, and conflict detection may be more complex than previously thought. From this work, it seems that a participant's ability or preference to use numerical information may not influence their tendency to detect conflicting information in subjective probability problems. Conflict detection has been touted as an implicit process (Bago & De Neys, 2017; 2019), so it is possible that more implicit individual differences may play a larger role in an individual's ability to detect conflicting information.

Of note, the findings from this study disagree with the previously found correlation between numeracy and conflict detection efficiency by Šrol & De Neys (2020). It is possible this discrepancy is due to differences in how numeracy was assessed by the two studies, as Šrol & De Neys included the Berlin Numeracy Test (Cokely et al., 2012) alongside the Subjective Numeracy Scale. Similarly, our study focused on conflict detection effect sizes in probability judgment tasks, whereas Šrol & De Neys focused on conflict detection efficiency in a wider variety of tasks. Looking at on the conflicting findings of these two studies, it is possible that individual differences in conflict detection are domain-specific. Numerous studies have found evidence of conflict detection across paradigms, but few have found predictors that span different tasks. In large part, this is due to conflict detection being understudied, and more studies are incorporating multiple types of judgment and reasoning problems in order to address this concern. It may be that numeracy and processing preference are simply unimportant in subjective probability estimation, but are critical in a task that relies more heavily on numeracy, such as the bat and ball problem included in Šrol & De Neys's study. At this point, it is clear that more work is needed to elucidate the underlying factors that cause some individuals to detect conflicting information.

A possible limitation with the present study is the lower than expected rate of conflict detectors. In prior work, the occurrence of conflict detectors is most commonly above 60% of participants. It is likely that the high confidence for both congruent and incongruent problems contributed to this low number. As previously mentioned, conflict detectors are coded based on an average difference in confidence between correct congruent and incorrect incongruent problems. Simply put, if participants were more confident in correct congruent problems than they were on incorrect incongruent problems, then they were coded as a conflict detector. With no significant difference in confidence between congruent and incongruent problems, fewer participants were coded as conflict detectors. It is possible that this may have impacted the results in unexpected ways. Additionally, limited statistical power due to a sample size of 103 may have influence the significance of one our analyses. Effect sizes for the correlations between conflict detection and the two individual differences measures were 0.33 for FPPI scores and 0.17 for subjective numeracy scores. Post hoc power analyses using G*power (Faul et al., 2007), with power set at 0.80, revealed that a sample size of approximately 66 participants would be needed to detect an effect for FPPI scores, well below our 103 participants. However, approximately 256 participants would be needed to detect an effect for subject numeracy scores.

One final point of concern in the present study is the presentation order of the tasks. All participants first complete the probability judgment task followed by the FPPI and the SNS. It's possible that participants were fatigued by the time they started the individual differences measures, and may have spent less time contemplating their answers than they normally would. However, participants tended to complete the judgment task in under eight minutes, and the entire experiment typically lasted no more than 20 minutes. Additionally, the tasks themselves are not overly taxing. With these factors in mind, cognitive fatigue on the individual differences measures likely did not influence the results.

The present work provides evidence that the role of numeracy and processing preference in conflict detection is not as straightforward as previously suggested. We demonstrate that numeracy and processing preference do not relate to conflict detection, suggesting that an ability and preference to use numbers does not influence participants' ability to implicitly detect a conflict between a logical and intuitive response in a subjective probability task. This work is one step in an ongoing endeavor to clarify the individual differences in conflict detection, and we look forward to future investigations in this area.

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