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The influence of number line estimation precision and numeracy on risky financial decision making

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This study examined whether different aspects of mathematical proficiency influence one's ability to make adaptive financial decisions. "Numeracy" refers to the ability to process numerical and probabilistic information and is commonly reported as an important factor which contributes to financial decision-making ability. The precision of mental number representation (MNR), measured with the number line estimation (NLE) task has been reported to be another critical factor. This study aimed to examine the contribution of these mathematical proficiencies while controlling for the influence of fluid intelligence, math anxiety and personality factors. In our decision-making task, participants chose between two options offering probabilistic monetary gain or loss. Sensitivity to expected value was measured as an index for the ability to discriminate between optimal versus suboptimal options. Partial correlation and hierarchical regression analyses revealed that NLE precision better explained EV sensitivity compared to numeracy, after controlling for all covariates. These results suggest that individuals with more precise MNR are capable of making more rational financial decisions. We also propose that the measurement of "numeracy," which is commonly used interchangeably with general mathematical proficiency, should include more diverse aspects of mathematical cognition including basic understanding of number magnitude.

Keywords: Number line estimation; Numeracy; Financial risky decision making; Expected value; Loss aversion; Framing effect.

The ability to understand and process numerical information is critical in the modern society. Indeed, many studies have found that a good understanding of numbers is associated with higher income and better risk comprehension in making decisions related to health and finance (Dickert, Kleber, Peters, & Slovic, 2011; Reyna, Nelson, Han, & Dieckmann, 2009). Among various factors that influence decision making, previous research commonly focused on numeracy. Numeracy represents an understanding of basic numerical and probabilistic concepts (Peters et al., 2006). The numeracy scale developed by Lipkus, Samsa, and Rimer (2001) is dominantly used in the literature.

Recent studies reported that numeracy serves as a good predictor of adaptive decision making in diverse contexts. For example, numeracy influences decision making in uncertain situations (e.g. risky-choice decision making) often studied with variants of the Asian disease problems (Tversky & Kahneman, 1981). In the classical form of this task, participants are given a hypothetical scenario (e.g. an outbreak of deadly disease and 600 lives at risk) and are asked to choose between two alternatives, where one gives a sure outcome (e.g. Vaccine A results in saving 200 people) and the other gives a probabilistic outcome (e.g. Vaccine B results in either saving all 600 people with 1/3 probability or none with 2/3 probability). The important part of this task is the content frames of the two alternatives; gains (e.g. lives saved) or losses (e.g. lives killed). The phenomenon in which people show susceptibility to the content frame when making risky choices is known as the risky-choice framing effect (Kühberger, 1998). Specifically, people tend to be risk aversive when options are presented as gains and risk seeking when options are presented as losses (this phenomenon is termed "loss aversion"; Kühberger, 1998). According to the prospect theory (Tversky & Kahneman, 1981), such phenomenon results from subjective evaluation of expected value (hereafter, EV). Therefore, decision making can be seriously compromised if one has a poor understanding of numerical quantity and EV. In fact, high versus low numeracy groups show different degrees of the framing effect (Peters & Levin, 2008). (See discussion for a different perspective based on the fuzzy-trace theory [FTT].)

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Jasper et al. demonstrated that the high numeracy group better distinguishes between advantageous versus disadvantageous risk taking (Jasper, Bhattacharya, Levin, Jones, & Bossard, 2013). In their study, the high numeracy group showed higher sensitivity to EV compared to the low numeracy group and the disparity between groups was maximised when taking risks was disadvantageous, especially in the loss frame condition. This finding suggests that numeracy influences one's ability to make adaptive financial decisions especially when losses are at stake. The authors added that the difference between high versus low numeracy groups may be aggravated in the loss frame due to elevation of anxiety (Jasper et al., 2013).

Although numeracy was found to be an important factor that contributes to adaptive decision making regarding risky choices, high skewness of the scores from the numeracy scale can be a substantial limitation especially when used with highly educated participants (Galesic & Garcia-Retamero, 2010; Jasper et al., 2013; Patalano, Saltiel, Machlin, & Barth, 2015; Peters & Levin, 2008; Peters et al., 2006). Furthermore, measurement of "numeracy" by the numeracy scale is limited in that only 11 items assessing the ability to process probabilistic information are included. Therefore, in this study, we included an additional measure of mathematical proficiency, the number line estimation (NLE) task which captures the precision of one's mental number representation (MNR).

Numerical magnitudes are thought to be represented as a mental number line, which refers to the internal representation of numerical magnitude with a left-to-right spatial arrangement (smaller numbers represented on the left and larger numbers on the right, in left-to-right reading cultures; Dehaene, Bossini, & Giraux, 1993). The NLE task is commonly used to measure the precision of MNR (Siegler & Booth, 2004). In the NLE task, participants are asked to estimate the spatial position corresponding to the magnitude of a given number on a number line (Figure 2). Accurate NLE performance reflects higher precision of MNR. Throughout development, children show transition from logarithmic (overestimation in small and underestimation in large number ranges) to linear pattern of estimation (Siegler & Booth, 2004). This gradual shift in children's NLE performance is known to be correlated with mathematical proficiency (Booth & Siegler, 2008). Although adults generally show a more linear representation of numerical magnitude compared to children, there are substantial individual differences in adult's NLE performance (Peters & Bjalkebring, 2015; Schley & Peters, 2014).

Individual differences in the precision of MNR may also be related to the ability to accurately represent monetary value and make rational economical decisions. Using the NLE task, Schley and Peters (2014) demonstrated that the valuation of monetary incentives was influenced by the ability to accurately represent number magnitude (Schley & Peters, 2014). However, the relationship between mathematical ability and decision making needs to be reexamined while controlling for other related factors, such as fluid intelligence, math anxiety (MA) and personality factors which have been sporadically reported to influence decision making. Some studies used Grade Point Average or working memory score as a proxy for general intelligence (Jasper et al., 2013; ; Peters & Levin, 2008; Peters et al., 2006), while others did not control for intelligence at all (Patalano et al., 2015; Schley & Peters, 2014). Considering that decision-making process is highly related to intelligence (Bruine de Bruin, Parker, & Fischhoff, 2007) as well as mathematical proficiency (Primi, Ferrão, & Almeida, 2010), it is important to control for the influence of such confounding factors. In addition, most previous studies did not control for the effect of MA or personality factors. Emotional responses to mathematical information (i.e. feeling anxious when dealing with numbers) are known to affect math performance (Lee & Cho, 2017). Furthermore, behavioural sensitivity to reward and punishment was reported to be highly correlated with financial decision making (Lauriola, Russo, Lucidi, Violani, & Levin, 2005). Therefore, this study administered the Raven's Advanced Progressive Matrices (RAPM) test (Arthur & Day, 1994), MA scale and the Behavioural Inhibition System and Behavioural Approach System (BIS/BAS) scale to effectively control for the influence of fluid intelligence, MA and personality factors, while examining the relationship between mathematical proficiency and decision making. Furthermore, the NLE task was examined with an expanded number range to capture sufficient individual variability. This study is the first to examine the influence of two distinct aspects of mathematical proficiency on financial decision making, while efficiently controlling for a wide range of confounding variables which had been commonly ignored in this line of research.

The purpose of this study was to examine whether different aspects of mathematical proficiency (i.e. numeracy and the precision of MNR) affect decision-making ability while controlling for the influence of fluid intelligence, MA and personality factors. In addition, we used an expanded range of numbers for the NLE task. Our decision-making task was designed with variation in two factors; EV and Frame (Gain vs. Loss). On each trial, the participant was asked to choose between two options (i.e. sure vs. risky option) that differed in the EV of monetary gain or loss. Our method urges participants to go beyond calculation of EV[1] and to make a choice by confronting

[1]Our task design contrasts with that of Peters and Bjalkebring (2015) in which participants were asked to calculate a monetary amount equivalent to a certain risky option (e.g. "How much money would you need to win for sure in order to be indifferent between it and the gamble above?"). In this case, the dependent variable only reflects the accuracy of EV calculation.

Figure 1. An example trial of the EQ condition of the (A) Gain and (B) Loss Frames. Top panels show how the sure (left) versus risky (right) option was presented. Bottom panels show how the outcome of the decision was presented (assuming choice of the sure option).

them with a decision-making situation. We hypothesised that individuals with higher NLE precision will make more rational decisions based on EV (i.e. taking risks only when it is advantageous to do so), especially when monetary losses are at stake.

MATERIALS AND METHODS

Participants

Sixty-nine college students (35 males, mean age = 20.22) participated. All had normal or corrected to normal vision with no history of psychiatric disorders. Written, informed consent was obtained. All protocols of the study were approved by the Institutional Review Board.

Tasks and procedure

The following tasks (or tests) were administered: (a) a financial risky decision-making task, (b) a 100,000 scale NLE task, (c) an abbreviated version of the RAPM test (12-item version validated by Arthur & Day, 1994), (d) the Expanded Numeracy Scale (Table S1 in Appendix S1; Lipkus et al., 2001), (e) Korean Mathematics Anxiety Rating Scale (Chang & Cho, 2013) and (f) Korean BIS/BAS scale (Kim & Kim, 2001). The entire session took 45–60 minutes.

Risky decision-making task

A decision-making task was designed to measure the ability to make optimal financial decisions based on the EV of monetary gain or loss. In each trial, participants were provided with a certain amount of endowment along with two options associated with monetary gains or losses (in the Gain vs. Loss Frame condition, respectively). Participants were asked to indicate their preference between two choices; i.e. a "sure" option and a "risky" option. The sure option provided the participant 100% chance of keeping (or losing) a partial amount of the endowment. The risky option provided less than 100% chance, of keeping (or losing) the entire endowment. In the Gain condition, choosing the risky option could result in either keeping all or none of the endowment. The left versus right position of the two options was counter-balanced across trials. After a choice was made, feedback on how much of the endowment the participant won was presented. While choosing the sure option led to an amount identical to what had been guaranteed (Figure 1), choosing the risky option led to probabilistic outcome with either all or none of the endowment. Details regarding specific probabilities and monetary outcome are described in Table S2 in Appendix S1.

There were two within-subject conditions; Frame (Gain vs. Loss) and EV level (Figure 1). EV level differed depending on whether it was advantageous, neutral or disadvantageous to choose the risky option over the sure option. The trials in which choosing the risky option yielded higher versus lower EV than the sure option were categorised as the Risk Advantageous (RA) versus Risk Disadvantageous (RD) condition, respectively. Trials in which the EVs of the two options were equivalent comprised the Equivalent (EQ) condition. The experimental session consisted of six blocks with 20 Gain or Loss trials per block.

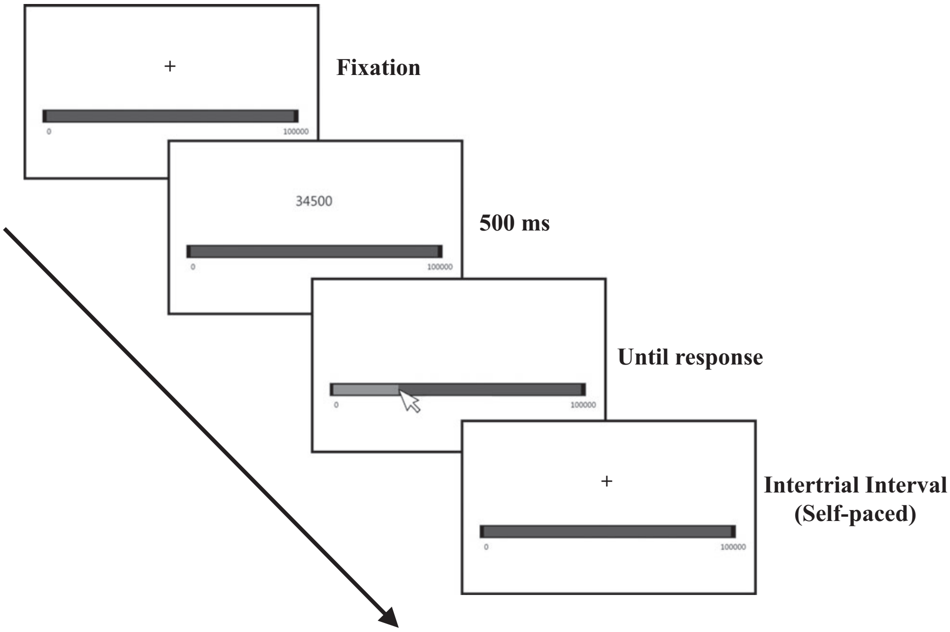

Figure 2. An example trial-and-task procedure of the NLE task.

The dependent variables (DVs) of interest were EV sensitivity and Risk Propensity (RP). First, EV sensitivity was measured by subtracting the proportion of risky choices made in RD trials from those in RA trials. Therefore, EV sensitivity represents the ability to make rational decisions based on EV; i.e. EV sensitivity increases as the participant chooses more risky options in the RA trials and less risky options in the RD trials. Second, RP indicates one's inclination to choose the risky option over the sure option. RP was calculated by dividing the number of risky choices by the total number of choices.

NLE task

Participants were instructed to estimate the spatial position of a number onto a horizontal number line marked with 0 and 100,000 on each end (Figure 2). The main experiment started after five practice trials. The numbers used in practice trials and the main experiment are listed in Table S3 in Appendix S1. A number was presented for 500 ms and then a cursor appeared at the centre. Participants responded by clicking on a location on the number line that corresponds to the magnitude of the number. Upon responding, the participant was provided with feedback showing the difference between their estimation and the correct answer during practice trials. No feedback was provided during the main experiment.

Mean Percentage Absolute Error (PAE) was calculated as the DV. The PAE is the absolute difference between the correct answer and the participant's estimation divided by the scale of the number line (i.e. 100,000). Mean PAE indicates the average error made in number estimation (i.e. higher PAE represents lower precision). Participants were divided into high-precision and low-precision (low PAE and high PAE, respectively) groups based on a median.

RESULTS

Descriptive statistics of performance is shown in Table S4 in Appendix S1.

Correlational analysis

Spearman's instead of Pearson's correlation analysis was conducted given that the assumption of normality was violated for Numeracy. Correlation analyses revealed that PAE was correlated with EV sensitivity in both Gain and Loss Frames (Gain: $r = -.31$, $p < .01$, Loss: $r = -.28$, $p < .05$; Table 1). In other words, individuals who were less accurate on the NLE task made less optimal choices (poorer EV sensitivity), regardless of Frame. The Numeracy score was also correlated with EV sensitivity in the Gain and Loss Frames (Gain: $r = .36$, $p < .01$; Loss: $r = .29$, $p = .05$). Additionally, while PAE was not correlated with any of the covariates, Numeracy scores were correlated with MA, $r = -.24$, $p < .05$ and BAS-Fun Seeking (hereafter, BAS-FS), $r = -.32$, $p < .01$. (i.e. lower numeracy participants had higher MA and BAS-FS scores). Furthermore, all BAS subscales, Reward Responsiveness, Drive (hereafter, BAS-RR and BAS-D, respectively) and Fun Seeking was correlated with EV sensitivity in the Loss frame (i.e. people with

TABLE 1
Bivariate correlation coefficients between all measurements

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Numeracy	1.00									
2. PAE	−.12	1.00								
3. EV sensitivity to Gain	.36**	−.31**	1.00							
4. EV sensitivity to Loss	.29**	−.28*	.43**	1.00						
5. RAPM	.16	−.10	.05	.23*	1.00					
6. Math Anxiety	−.24*	−.06	−.12	−.20	−.16	1.00				
7. BAS-Reward Responsiveness	.13	.02	.15	.24*	.24*	.05	1.00			
8. BAS-Drive	.07	.18	.15	.29 *	.00	−.08	.47**	1.00		
9. BAS-Fun Seeking	.32**	−.15	.19	.35**	.01	−.22	.44**	.56**	1.00	
10. BIS	−.19	−.05	−.11	−.08	.11	.36**	.26*	−.22	−.34**	1.00

*$p < .05$. **$p < .01$.

TABLE 2
Partial correlation coefficients controlling for all covariates

Variables	*1*	*2*	*3*	*4*
1. Numeracy	1.00			
2. PAE	−.04	1.00		
3. EV sensitivity to Gain	.32*	−.35**	1.00	
4. EV sensitivity to Loss	.18	−.31*	.40**	1.00

*$p < .05$. **$p < .01$.

stronger tendency to seek rewards made more optimal choices based on EV in the Loss Frame). Given that numeracy was correlated with most of the covariates, additional analysis of partial correlation was conducted to rule out possible influence of the covariates. In the partial correlation analysis controlling for all covariates, the correlation between numeracy and EV sensitivity was reduced (Gain: $r = .32$, $p < .05$; Table 2) or eliminated (Loss: $r = .18$, $p =$ n.s; Table 2), whereas the relationship between NLE performance and EV sensitivity remained largely unchanged (Gain: $r = .35$, $p < .01$; Loss: $r = .31$, $p < .05$; Table 2).

Hierarchical regression

Hierarchical regression was conducted to compare how well numeracy and PAE explains variance in EV sensitivity, while controlling for all covariates, separately for Gain and Loss frames. The numeracy score and PAE were converted into rank orders. Therefore, RAPM, MA, BAS/BIS, the rank order of Numeracy scores and PAE were entered in order as predictors. PAE explained a significant proportion of variance in EV sensitivity for both Gain, $\Delta R^2 = .10$, $F(1, 60) = 7.12$, $p < .01$, and Loss frames, $\Delta R^2 = .07$, $F(1, 62) = 6.11$, $p < .05$. The standardised regression coefficient for PAE was significant (Table S5 in Appendix S1). On the other hand, numeracy only explained a significant proportion of variance in EV sensitivity for the Gain, $\Delta R^2 = .07$, $F(1, 61) = 4.58$, $p < .05$, but not Loss Frames, $\Delta R^2 = .03$, $F(1, 61) = .20$, $p =$ n.s. Similar results were obtained in an additional analysis in which the predictors were entered in the following order; (a) RAPM accuracy, (b) MA, (c) BIS/BAS, (d) PAE, (f) Numeracy (Table S6 in Appendix S1).

Mixed repeated-measures analysis of variance (RM ANOVA)

A $2 \times 3 \times 2$ mixed RM ANOVA on RP was conducted with Frame (Gain, Loss) and EV level (RA, EQ and RD) as within-subject factors and NLE precision group (high- vs. low-precision) as the between-subject factor. There was a significant main effect of Frame, $F(1, 67) = 5.19$, $p < .05$, $\eta_p^2 = .08$; i.e. participants took more risks in the Loss compared to the Gain Frame, manifesting the "Framing Effect." A significant main effect of EV level was also observed, $F(2, 66) = 239.45$, $p < .01$, $\eta_p^2 = .88$; participants were more or less likely to take risks depending on the EV level. No main effect of Group was found, $F(1, 67) = .23$, $p = .63$, i.e. RP did not differ between groups. Furthermore, the analysis revealed three interaction effects. First, a three-way interaction was found between EV sensitivity, Frame and Group, $F(2, 66) = 3.56$, $p < .05$, $\eta_p^2 = .10$. *Post-hoc t*-test revealed a simple main effect of group in the RD condition of the Loss Frame, $t(67) = 2.60$, $p < .05$, $d = .63$, supporting the hypothesis that the influence of NLE precision on risky decision making would be greater in the Loss versus Gain Frame. Second, the two-way interaction between EV level and Group was significant, $F(2, 66) = 5.02$, $p < .01$, $\eta_p^2 = .13$. *Post-hoc t*-test showed that the simple main effect of Group was significant only in the RD condition, $t(67) = 2.46$, $p < .05$, $d = .59$ (i.e. the Low Precision Group was more willing to take risks compared to the High Precision Group in the RD condition). The two-way interaction between Frame and EV level was also significant, $F(2, 66) = 13.46$, $p < .01$, $\eta_p^2 = .29$. *Post-hoc t*-tests revealed simple main effects of Frame in the RA and EQ conditions demonstrating the "Framing Effect" (i.e. participants tended to take more risks in the Loss vs.

Gain Frame in RA and EQ conditions, RA: $t(68) = -3.67$, $p < .01$, $d = -.41$; EQ: $t(68) = -3.19$, $p < .01$, $d = -.46$.).

DISCUSSION

This study is the first to test and compare the influence of distinct mathematical proficiencies on financial decision-making ability while controlling for diverse confounding variables. The numeracy scale and the NLE task were used to measure mathematical proficiency. While numeracy measured by the numeracy scale (Lipkus et al., 2001) reflects one's understanding of probability, NLE performance reflects the precision of MNR. When covariates were not controlled for, there were strong correlations between EV sensitivity and both measures of mathematical proficiency. In the partial correlation analysis controlling for all covariates, the relationship between EV sensitivity and numeracy was selectively reduced. Similarly, in hierarchical regression controlling for all covariates, NLE precision (but not Numeracy) predicted EV sensitivity in both Gain and Loss Frames. Therefore, the results emphasise the importance of controlling for the influence of fluid intelligence, MA and personality factors in examining the influence of mathematical proficiency on risky decision-making ability.

EV sensitivity is better explained by NLE precision compared to numeracy

Numeracy was significantly correlated with EV sensitivity but a follow-up test of partial correlation resulted in a reduction of correlation between the numeracy score and EV sensitivities. This result somewhat deviates from those of Chesney, Bjalkebring, and Peters (2015) or Peters and Bjalkebring (2015) (however, these studies did not control for the influence of confounding covariates). The difference between the result of previous studies and ours is likely due to high correlation between the numeracy score and covariates. In addition, the differential strength of the correlation between EV sensitivity and numeracy versus NLE precision may reflect a qualitative difference in the underlying mental processes reflected in the two measures given the differential correlations with the covariates. In fact, only the numeracy score, but not NLE precision was significantly correlated with the MA and BAS scores. This implies that the numeracy scale measures not only mathematical proficiency but may also reflect affective and personality traits that are likely to be related to decision making. In contrast, NLE precision seems to be a relatively purer measure of numerical proficiency (independent of MA or personality traits) compared to the numeracy score. Considering these findings, the relationship between numeracy and decision-making ability in previous studies may have been influenced by MA or personality traits. Furthermore, hierarchical regression analysis revealed that NLE precision (but not Numeracy) explained variance in EV sensitivity in both Gain and Loss Frames, when all covariates were accounted for. Taken together, NLE precision can be considered a purer measure of basic mathematical proficiency which predicts unique variance in the ability to make rational financial decisions.

One of the focuses of this study was to demonstrate that the measurement of "numeracy" by the numeracy scale (Lipkus et al., 2001) should not be taken as the golden standard by including another measure of mathematical proficiency which captures the accuracy of MNR. The definition of "numeracy" includes a broad range of mathematical abilities, yet individual tests of numeracy tend to assess distinct, limited aspects of math ability. This heterogeneity may cause confusion and discrepancy across reports of numeracy (Reyna et al., 2009).

This study demonstrated that the basic ability to estimate number magnitude predicts decision-making ability to a stronger degree compared to the numeracy score measured by the numeracy scale (Lipkus et al., 2001). The present results emphasise the need to use a measure of "Numeracy" which does justice to its definition by capturing diverse aspects of mathematical ability from basic understanding of number magnitude to high-level mathematical reasoning.

High NLE precision (low PAE) group shows less loss aversion

Loss aversion refers to the phenomenon where losses loom larger compared to an equivalent amount of gain. The value function described in the prospect theory (Tversky & Kahneman, 1981) states that the subjective value of losses is greater than that of the same amount of gains. Therefore, when people are faced with a sure versus risky loss option, participants tend to take risks to avoid losses because the risky option offers an opportunity to avoid them.

The three-way interaction from the mixed RM ANOVA (Figure 3) revealed that the difference between High- versus Low Precision Group was significant only in the Loss Frame, especially in the RD trials. In other words, participants with a more precise MNR were better able to avoid choosing disadvantageous risky options in the Loss Frame. In contrast, the Low Precision Group tended to choose risky options even when they offered worse EV compared to the sure option, possibly due to higher loss aversion (disadvantageous risky options may have seemed subjectively more attractive compared to the sure option). These findings are in accordance with those of Schley and Peters (2014) in which a significant negative correlation between NLE precision and loss aversion was found. This is also consistent with the findings of Jasper et al. (2013), where less numerate individuals revealed higher loss aversion in disadvantageous risk taking.

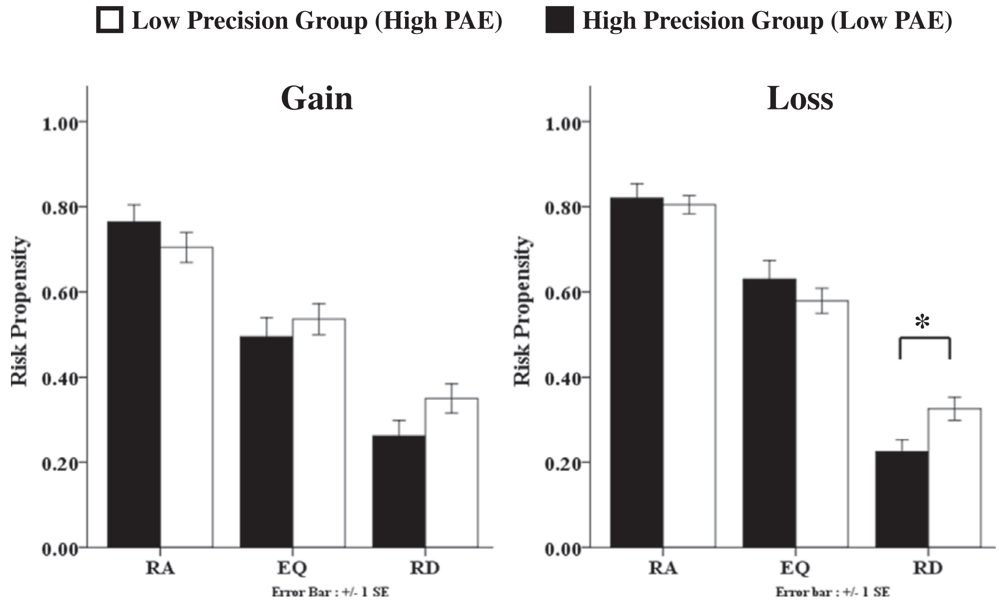

Figure 3. Risk propensity of High (white bars) versus Low (black bars) NLE Precision Groups depending on EV level (RA, EQ, RD) in the Gain (left) and Loss (right) Frames.

Theoretical implications

According to Schley (2015), the subjective value of monetary gain or loss is determined via two joint processes; subjective *perception* of the amount of gain or loss, and the subjective *evaluation* of the perceived amount. For example, when people represent the value of $37,500, the magnitude of the number 37,500 is perceived first. The magnitude of 37,500 may be perceived accurately or may be over- or under-estimated depending on the precision of one's MNR. Then, the monetary value of the perceived magnitude (i.e. $37,500) is evaluated. The revised value function by Schley (2015) reflects how the accuracy of MNR contributes to the subjective representation of monetary gain or loss. (cf. The original value function by (Tversky & Kahneman, 1981) does not consider how individual differences in MNR can affect the evaluation of monetary gain or loss.) This study supports Schley (2015)'s model by demonstrating that people with lower precision of MNR make less optimal financial choices especially when losses are at stake.

These results can also be explained by the FTT (Reyna & Brainerd, 1991). Unlike standard theories of decision making which assume that adaptive decision making requires computing trade-offs between gains versus losses, the FTT contrasts between such mathematical computations (i.e. verbatim processing) from intuition-based gist processing and emphasises the merits of the latter. FTT describes mental representations as a continuum from verbatim to gist. Gist includes both categorical and ordinal representations. For example, in a decision-making task, a categorical and ordinal gist would represent amounts of gain as "some versus none" and "less versus more," respectively. According to Reyna, Wilhelms, McCormick, and Weldon (2015), mature adults tend to avoid risks during decision making by relying on a categorical gist (e.g. "no risk is better than some risk"). Adolescents and less mature adults may take more risks if they base their decision on an ordinal gist (e.g. "less risk is better than more risk."). Although both principles express negative views of risk, the ordinal principle makes finer distinctions, thus being closer to verbatim processing on the continuum from gist to verbatim.

In the context of our risky-choice decision-making task, the FTT would predict the following behaviour. In the gain frame, the options can be encoded as categorical gists: "gain some money for sure" or "gain some money or maybe gain nothing." The simple intuition that "gaining money is good" favours the sure option. In the loss frame, the options can be encoded as: "lose some money for sure" or "lose some money or maybe lose nothing," and the simple intuition that "losing money is bad" favours losing nothing. Thus, the loss aversion and framing effect observed in this study can be explained by the FTT (further discussion regarding framing effect and reflection effect can be found in Appendix S1).

In FTT, gist-based processing is considered as the advanced mode of processing. FTT assumes that people prefer to use the fuzziest gist representation first, only to rely on more precise, numerical information when required by the task at hand. In our study, variation in EV between options in the RA and RD condition required participants to use numerical information to make optimal choices. However, individuals with low precision of

MNR (high PAE) failed to base their decision on EV of the options manifesting risk-taking behaviour even when it was disadvantageous to do so (i.e. they could not transition from the crude gist-based processing to more detail-oriented gist or verbatim processing). The fact that the group with low precision showed that greater loss aversion (Figure 3) is consistent with the prediction of FTT. Specifically, the Low Precision Group may have represented the given options as a categorical gist (thereby preferring "lose some or maybe loose none" to "lose some for sure"), while the high precision group may have based their decisions based on an ordinal gist (thereby preferring "lose less money for sure" to "lose more money or maybe loose nothing") or possibly verbatim processing of numerical information (thereby preferring "lose $30 for sure" to "lose $70 money or maybe loose nothing for 50:50 chance").

However, although the Low Precision Group may have based their decision on categorical gist-based processing, it does not seem to reflect an advanced mode of information processing compared to ordinal gist or verbatim processing. Rather, it seems that the Low Precision Group failed to extract detailed differences in EVs (even when our task requires them to do so), resulting in more risk-taking decisions in risk disadvantageous situations. Further research is required to examine how an individual's numerical ability including the precision of MNR and experimental context influence how options are evaluated among a continuum from gist to verbatim representations.

Limitations

While this study underscores the importance of mathematical proficiency on financial risky decision making, the results are not without limitations. First, in the NLE task, number stimuli were presented for a duration of 500 ms which may impose load on the phonological loop for maintenance of information. However, the demand on subvocal rehearsal should not have been large enough to interfere with the estimation of number magnitude given that there were only a few digits to remember (e.g. 34,200, 57,600, etc. Note, the last two digits were always zero). In addition, we cannot exclude the possibility that proportional processing or use of fractions may have been involved in the NLE task. However, given that EV sensitivity requires discrimination of EV based on probability and monetary value which are both numerical representations, we expect that EV sensitivity should be more strongly related to the precision of MNR above and beyond proportional processing or use of fractions. Nonetheless, we believe that the detailed nature of the cognitive processes involved in the NLE task (e.g. to what extent proportional processing or computation of fractions are involved and how it relates to the ability to process probabilistic information) should be uncovered and addressed by future studies. Finally, the relatively weaker influence of numeracy on decision-making ability in this study should be carefully interpreted considering that our participants were well-educated young adults. It is possible that in a population with more diverse educational backgrounds, the numeracy score may exert stronger influence on decision-making ability.

CONCLUSION

The present study found that the precision of number estimation more strongly and reliably relates to risky decision-making ability compared to the Numeracy score. A significant correlation was observed between NLE precision and EV sensitivity for both Gain and Loss frames, while the correlation between EV sensitivity and Numeracy was reduced (Gain frame) or eliminated (Loss frame) after controlling for related covariates. Furthermore, hierarchical regression analysis revealed that the precision of NLE better explained variance in EV sensitivity compared to Numeracy in both Gain and Loss Frames, even after controlling for the influence of fluid intelligence, MA and BIS/BAS scores. In addition, individuals with less precise MNR manifested stronger loss aversion and made less optimal choices.

The present study demonstrates that the precision of MNR strongly influences (more so than Numeracy scores) how well an individual makes rational decisions in risky situations, even after controlling for the influence of fluid intelligence, MA and personality factors. Future studies utilising estimation of both positive and negative numbers are required to further examine how the precision of both positive and negative MNR distort the value function of monetary gains and losses, and how this relates to individual differences in risky, financial decision-making ability.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Supporting information.

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