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Assessing "Economic Value": Symbolic-Number Mappings Predict Risky and Riskless Valuations

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Abstract

Diminishing marginal utility (DMU) is a basic tenet of economic and psychological models of judgment and choice, but its determinants are little understood. In the research reported here, we tested whether insensitivities in valuations of dollar amounts (e.g., $40, $100) may be due to inexact mappings of symbolic numbers (i.e., "40," "100") onto mental magnitudes. In three studies, we demonstrated that inexact mappings appear to guide valuation and mediate numeracy's relations with riskless valuations (Studies 1 and 1a) and risky choices (Study 2). The results highlight the fundamental notion that individuals' valuations of $100 depend critically on how individuals perceive and map the symbolic quantity "100." This notion has implications for conceptualizations of value, risk aversion, intertemporal choice, and dual-process theories of decision making. Normative implications are also briefly discussed.

Keywords

decision making, numerical cognition, valuation, numeracy, risk aversion, intertemporal choice, dual processes, individual differences, mathematical ability

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Understanding how individuals value objects (e.g., money, goods, services) is fundamental for understanding choice. In the research presented here, we extended prior research on numeracy and decision making (e.g., Peters, 2012; Peters et al., 2006) to examine a low-level cognitive mechanism that may guide valuation. A basic tenet of economic and psychological models of judgment and choice is that individuals generally exhibit diminishing marginal utility (DMU; Bernoulli, 1738/1954; Kahneman & Tversky, 1979; Von Neumann & Morgenstern, 1947). Just as each additional spoonful of sugar provides a smaller taste sensation than the previous spoonful, an additional dollar of wealth provides less utility than the previous dollar. We propose that DMU (the extent of curvature in utility and value functions within choice models) is due not only to individuals' expectations of value for numbers of dollars or goods but also to how the brain maps symbolic numbers onto mental magnitudes.

Mapping Subjective-Magnitude Representations

Considerable research has demonstrated that humans and common laboratory animals process numeric magnitudes in a manner similar to other physical magnitudes (i.e., perceptions of numbers adhere to psychophysical laws; Dehaene, Izard, Spelke, & Pica, 2008; Feigenson, Dehaene, & Spelke, 2004; Halberda, Mazzocco, & Feigenson, 2008; Nieder, Freedman, & Miller, 2002; Piazza, Pica, Izard, Spelke, & Dehaene, 2013; Siegler & Opfer, 2003; Whalen, Gallistel, & Gelman, 1999). Individuals perceive numeric magnitude inexactly; they show an effect of numeric distance, whereby they are better able to discriminate far-apart values (5 vs. 9) than close-together values (5 vs. 6; Moyer & Landauer, 1967). They also show an effect of size, such that the ease with which people distinguish magnitudes at the same numerical distance (e.g., 5 and 15 vs. 90 and 100) decreases curvilinearly as magnitudes increase (Parkman, 1971). These discriminability effects are thought to arise from inexactness in internal magnitude representations and related inexactness in the mapping of symbolic numbers to those mental magnitudes (Chesney & Matthew, 2013; Izard & Dehaene, 2008; Rips, 2013; Siegler & Opfer,

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2003). Several models of these effects exist (the accumulator model, Gallistel & Gelman, 2000; the compressed-number-line model, Dehaene, 1992; the numerosity-code model, Butterworth, 2010) and make similar predictions about behavioral decisions (Peters, Slovic, Västfjäll, & Mertz, 2008).

We propose that valuations of prospects logically must depend on the numbers expressing the prospects. Therefore, inexact mappings of symbolic numbers onto mental magnitudes may underlie the curvilinear shape of utility and value functions in judgments and decisions. Specifically, we hypothesized that individuals with more exact symbolic-number mappings would exhibit less DMU than would those with less exact mappings:

> Hypothesis 1 (H1). More exact symbolic-number mappings will be associated with more linear (less curved) value functions.

Curvilinear discriminability of numeric magnitude is at odds with modern society's base-10 system of formalized mathematical operations. Being better able to distinguish numeric magnitudes and accurately map symbolic numbers onto representations on a visual number line (a related skill; see Barth & Paladino, 2011) has been linked to improved numeric ability in correlational and (in particular, for number-line mapping) experimental studies (Booth & Siegler, 2008; Halberda et al., 2008; Peters et al., 2008; Siegler & Opfer, 2003). In turn, greater numeracy has been associated with superior decision making, as exemplified by, for instance, lower risk aversion and more expected-value-consistent choices among gambles (Cokely & Kelley, 2009; Frederick, 2005; Reyna, Nelson, Han, & Dieckmann, 2009). We therefore expected the more numerate to exhibit more linear value functions than the less numerate; we additionally hypothesized that this relation would be due to the highly numerate having more exact symbolic-number mappings:

> Hypothesis 2 (H2). More exact symbolic-number mappings will mediate the relation between greater numeracy and less DMU.

This theoretical relation between symbolic-number mappings and value has stark implications for conceptualizations of decision making. For example, the curvature of the value function (i.e., DMU) is thought to represent risk aversion. Empirical support for the current hypothesis, however, would suggest a modified interpretation. Consider an individual choosing guaranteed Option A ($40) over risky Option B (50% chance of $100, otherwise $0); this person would generally be interpreted as averse to Option B's uncertainty. However, given the current hypothesis, valuations of $40 and $100 will be based in part on mappings of the symbolic magnitudes "40" and "100." Those with less exact symbolic-number mappings will perceive "100" as subjectively less different from "40" than will those with more exact symbolic-number mappings. Thus, among individuals with less exact mappings, choosing Option A may indicate utility maximization rather than an aversion to risk.

In Study 1, we first tested the relation between symbolic-number mappings and DMU in a riskless paradigm. In Study 2, we examined whether the influence of symbolic-number mappings generalizes to a risky-choice paradigm. In both studies, we also investigated whether numeracy's influence on decisions was mediated by more exact symbolic-number mapping.

Study 1

Method

Participants (N = 76; 51.3% female, 48.7% male; mean age = 31.8 years, age range = 18–64 years) were recruited online from Amazon Mechanical Turk and were paid $0.50 for study completion. IP addresses were randomly checked to ensure that participants came from the United States only.

To assess valuations, we asked participants to indicate the furthest distance in miles they would be willing to drive (WTD) round-trip to receive a specified amount of money. Individuals often make similar judgments in daily life (e.g., "Should I drive farther to save $*X*?"). Participants were instructed to imagine that they possessed a car, a driver's license, and insurance, and that gas was free. Thus, WTD referred to the time and effort an individual would sacrifice to receive each of 12 dollar amounts ($5, $10, $15, $20, $30, $40, $50, $60, $70, $80, $90, and $100) presented in random order.

We used a common number-line task to measure symbolic-number mapping (Siegler & Opfer, 2003). In this task, participants were presented with 11 separate screens, each with a 120-mm horizontal line with anchors of 0 and 1,000. On each screen, participants were presented with 1 of 11 randomly ordered numbers (0.1, 0.8, 1.5, 9.5, 23.2, 89.3, 268, 442, 682, 834, and 925) and indicated the number's position on the line using the mouse. In addition, we measured numeracy using a recently developed eight-item scale (Weller, Dieckmann, Tusler, Mertz, & Peters, 2013) and collected demographic data (age, gender, income, education; see the Supplemental Material available online).

Results and discussion

To assess individual differences in symbolic-number-mapping ability, we calculated the mean absolute error of responses in the number-line task, a procedure similar to that used in previous studies (Opfer & Siegler, 2007).[1] More curvilinear functions will produce larger deviations than will less curvilinear functions in the mean-absolute-error measure. To assess mean absolute error, we first calculated for each participant the absolute deviation between each response on the 0-to-1,000 line and the objective number presented in the number-line task. We log-transformed the absolute deviations to normalize the data because of skew (raw mean deviation = 76.3, median deviation = 43.2). We then computed a symbolic-number-mapping score for each individual by averaging the deviations across the 11 stimuli and multiplying them by −1 so that higher scores indicated more exact mappings. In all studies, inferential analyses were conducted using continuous variables. As shown in Figure 1a, the Study 1 participants with larger absolute errors exhibited a response pattern compatible with having more curvilinear discriminability functions. Consistent with past research (e.g., Parkman, 1971), results showed that at higher objective magnitudes, deviations between objective magnitudes and subjective responses became larger, $r = .22$, $t(74) = 4.63$, $p < .0001$; similar results emerged with a multilevel model, $\beta = 0.001$, $t(759) = 4.72$, $p < .0001$.

To test H1 (that more linear value functions would be associated with more exact symbolic-number mappings), we created a log-log multilevel model predicting WTD responses using provided dollar amounts, symbolic-number-mapping scores, their interaction, and demographic variables (there were no significant unique effects of age, gender, education, or income on DMU; *ps* > .20). All variables were mean-centered. Both the intercept (representing average WTD) and the slope coefficient for dollar amounts (representing DMU) were allowed to vary across participants. The value function is typically expressed as a power function, $y = \alpha x^{\beta}$, where β is the degree of the function's curvature and α represents a scaling coefficient. Because we used a log-log multilevel model, the slope coefficient on dollar amounts indicates β in the value function, $\log(y) = \log(\alpha) + \beta(\log(x)) \rightarrow y = \alpha x^{\beta}$, where β coefficients less than 1 indicate less linear value functions. Thus, the slope coefficient of dollar amounts on WTD responses, $b = 0.86$, $t(819) = 29.36$, $p < .0001$, indicated the presence of DMU. There was no main effect of symbolic-number mappings on WTD judgments, $p > .10$. Therefore, participants with more exact mappings did not appear simply to value money more than did those with less exact mappings. In support of H1, the results indicated an interaction between objective dollar amounts and symbolic-number mappings in WTD predictions, $b = 0.13$, $t(819) = 3.59$, $p = .0003$. Participants with more exact mappings exhibited more

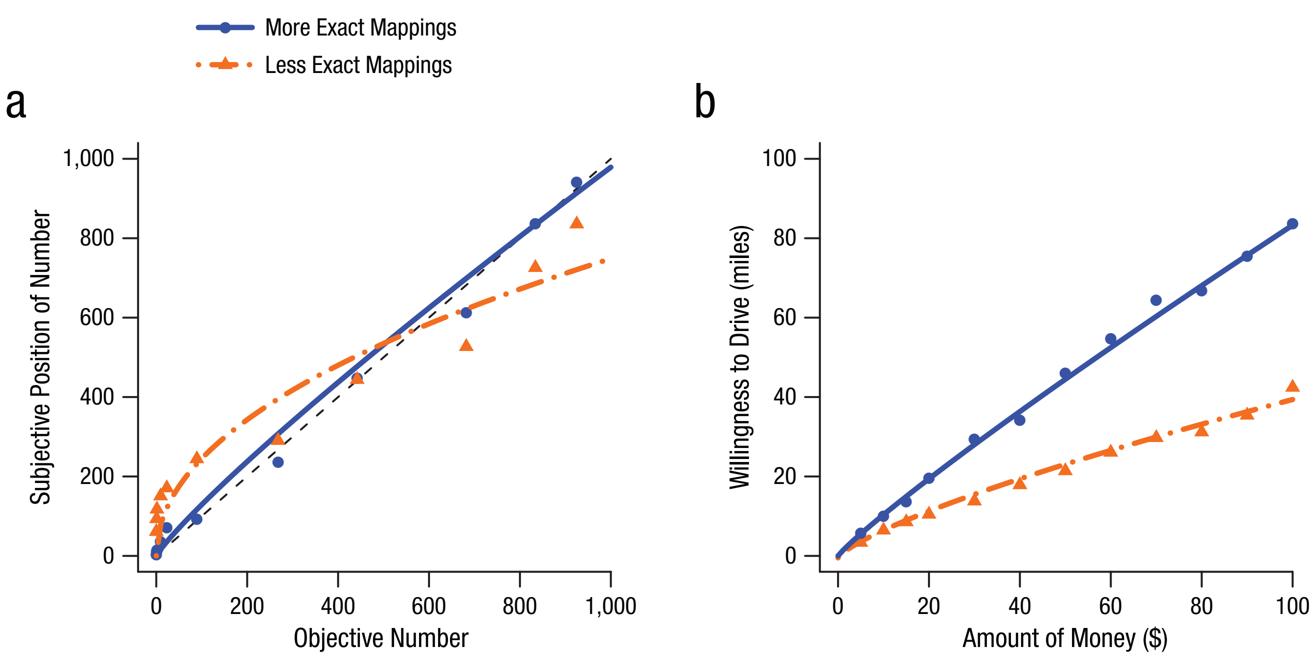

Fig. 1. Results from Study 1: plots showing the relations between symbolic-number mappings and valuations. The two plots show best-fitting curves (a) between symbolic-number mappings and objective magnitudes in the number-line task and (b) between average willingness-to-drive responses and provided dollar amounts in the valuation task. For each plot, the two curves represent the best-fitting power functions based on a median split of participants with more exact symbolic-number mappings (solid curve) and less exact symbolic-number mappings (dashed curve). The dashed black line in (a) represents perfect linearity.

Table 1. Multiple-Regression Results From Studies 1 and 2

	Study 1			Study 2		
Predictor	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	0.876*** (0.024)	0.873*** (0.025)	0.874*** (0.024)	0.685*** (0.017)	0.684*** (0.017)	0.684*** (0.017)
Symbolic-number-mapping score	0.084* (0.035)	0.116** (0.033)	0.091* (0.038)	0.071* (0.027)	0.070* (0.027)	0.068* (0.029)
Numeracy	0.018 (0.014)		0.019 (0.015)	0.003 (0.011)		0.002 (0.012)
Gender		–0.07 (0.054)	0.001 (0.054)		–0.046 (0.037)	–0.045 (0.039)
Age		–0.001 (0.002)	–0.001 (0.002)		–0.000 (0.002)	0.000 (0.002)
Income		–0.017 (0.022)	–0.020 (0.022)		–0.004 (0.015)	–0.005 (0.015)
Education		–0.002 (0.020)	–0.008 (0.021)		–0.002 (0.015)	–0.002 (0.015)

Note: Beta coefficients are shown predicting the value-function parameters in Study 1 (slope coefficient for dollar amounts in the log-log multilevel model) and Study 2 (Dynamic Experiments for Estimating Preferences value-function exponent), with standard errors in parentheses.
*$p < .05$. **$p < .01$. ***$p < .0001$.

linear value functions (less DMU) than did those with less exact mappings (see Fig. 1b). Inclusion of demographic variables did not substantially alter the model.

To investigate H2 (that more exact symbolic-number mappings would mediate any influence of numeracy on DMU), we first exported each participant's slope coefficient as an individual-difference measure of DMU. We then built simple regressions to test possible mediation. First, greater numeracy was related, in one analysis, to more exact symbolic-number mappings, $b = 0.22$, $t(74) = 5.87$, $p < .0001$, and, in a second analysis, to less DMU, $b = 0.04$, $t(74) = 3.10$, $p = .003$. When symbolic-number-mapping scores were introduced into the model predicting DMU, participants with more exact mappings exhibited more linear value functions, $b = 0.08$, $t(74) = 2.38$, $p = .02$, simple $r = .40$; at the same time, the influence of numeracy became nonsignificant, $b = 0.02$, $t(74) = 1.30$, $p = .20$ (Table 1). We then generated 10,000 samples and tested numeracy's indirect effect on DMU, employing bootstrapped 95% confidence intervals (CIs; with smaller samples, bootstrapping provides more power than Sobel tests do). Results indicated a significant indirect effect of numeracy on DMU through symbolic-number mappings, $b = 0.02$, CI [.001, .044]. Numeracy's effects on the value function appear to be due, at least in part, to more exact symbolic-number mappings. Table 2 presents correlations among all Study 1 variables.

A possible concern is that more numerate participants (who would also tend to have more exact symbolic-number mappings) may be more comfortable and expert with numeric responding such as that entailed by Study 1's WTD measure. This difference, then, could cause the greater linearity in their value functions. To address this possible concern, we replicated Study 1 using a nonnumeric response scale and found similar results (see Study 1a and Table S1 in the Supplemental Material).

Table 2. Correlations of Variables Used in Study 1

Variable	Value-function-exponent parameter	Symbolic-number-mapping score	Numeracy	Gender	Age	Income	Education
Value-function-exponent parameter	1.00						
Symbolic-number-mapping score	.40**	1.00					
Numeracy	.34**	.56***	1.00				
Gender	–.16	–.24*	–.21†	1.00			
Age	.01	.15	.09	.09	1.00		
Income	–.09	.02	.07	.31**	.09	1.00	
Education	.05	.17	.28*	–.01	.22†	.03	1.00

Note: Gender is coded as 1 = male and 2 = female.
†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .0001$.

The results of Study 1 supported H1. Specifically, participants with more exact symbolic-number mappings exhibited less DMU in response to riskless prospects than did those with less exact mappings. Moreover, in support of H2, the influence of symbolic-number-mapping scores on DMU mediated numeracy's effect on DMU.

Study 2

Because both of the tasks in Study 1 used nonlinearly spaced magnitudes, a tendency to convey only rank order in responses could explain the results from that study. In Study 2, we extended our tests of the same hypotheses using a more conventional assessment of value, a risky-choice paradigm, which precludes this alternative explanation.

Method

Mechanical-Turk participants (N = 99; 42.9% female, 57.1% male; mean age = 33.8 years, age range = 18–67 years) were recruited online and paid $0.50 for task completion. Participants were assigned a unique ID and completed their first task by clicking a link that brought them to Dynamic Experiments for Estimating Preferences (DEEP; Toubia, Johnson, Evgeniou, & Delquié, 2013). DEEP uses adaptive experimental designs for the estimation of prospect-theory parameters (Kahneman & Tversky, 1979) by tailoring questions that best discriminate participant-level parameters. For example, if a participant chose a guaranteed $40 over a 50% chance of $100, otherwise $0, the DEEP program then might present a choice between a guaranteed $40 and a 50% chance of $110, otherwise $0 (see https://vlab.decisionsciences.columbia.edu/deeprisk/demo).

After a short explanation of how gambles are played, participants were presented with two gambles and had to correctly answer four associated test questions before proceeding. The preference-parameter measurement task then included 16 adaptively tailored questions to assess risk preferences. The DEEP program uses a hierarchical Bayesian approach to efficiently estimate aggregate and individual-level parameters (Toubia et al., 2013). For each participant, the DEEP program provided all presented gambles, choices made, and the corresponding fitted prospect-theory parameters, including the value-function exponent representing DMU.

Participants then completed the symbolic-number-mapping and numeracy tasks used in Study 1. Table 3 presents correlations among all of the Study 2 variables.

Results and discussion

As in Study 1, we calculated symbolic-number-mapping scores and then predicted DEEP-generated value-function exponents with these scores, age, gender, income, and education in a multiple-regression model (see Table 1). Consistent with H1, results indicated that participants with more exact symbolic-number mappings exhibited more linear value functions, $b = 0.07$, $t(90) = 2.34$, $p = .02$, simple $r = .30$ (see Fig. 2); no other variable was significant, ps > .24.

To investigate H2 (that more exact symbolic-number mappings would mediate numeracy's influence on DMU), we built a series of simple regressions. First, greater numeracy was related, in one analysis, to more exact symbolic-number mappings, $b = 0.20$, $t(97) = 5.53$, $p < .0001$, and, in a second analysis, to marginally less DMU, $b = 0.02$, $t(97) = 1.68$, $p < .10$. When symbolic-number-mapping scores were introduced into the model predicting DMU, participants with more exact mappings exhibited more linear value functions, $b = 0.07$, $t(97) = 2.56$, $p = .01$; at the same time, numeracy's influence decreased, $b = 0.00$, $t(97) = 0.25$, $p = .81$. We then generated 10,000 samples and tested numeracy's indirect effect on DMU, employing bootstrapped 95% CIs. Results

Table 3. Correlations of Variables Used in Study 2

Variable	Value-function-exponent parameter	Symbolic-number-mapping score	Numeracy	Gender	Age	Income	Education
Value-function-exponent parameter	1.00						
Symbolic-number-mapping score	.30**	1.00					
Numeracy	.17†	.49***	1.00				
Gender	−.22*	−.30**	−.32**	1.00			
Age	−.03	−.12	−.20*	.13	1.00		
Income	.02	.23*	.21*	.03	−.10	1.00	
Education	.03	.19†	.19†	−.06	−.06	.35**	1.00

Note: Gender is coded as 1 = male and 2 = female.
†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .0001$.

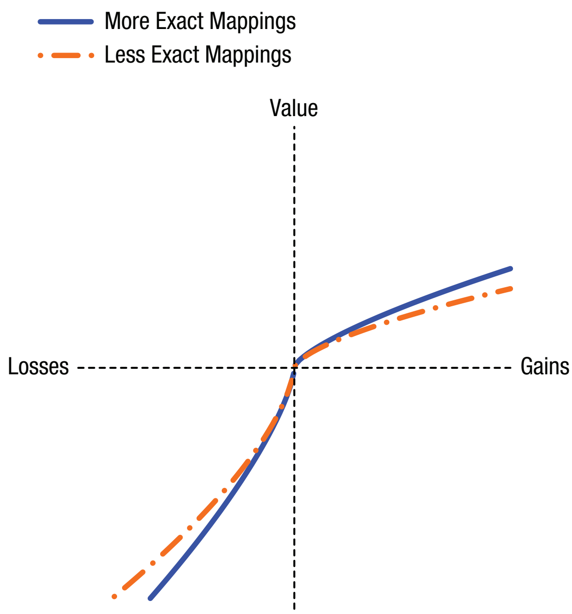

Fig. 2. Results from Study 2: relation between symbolic-number mappings and fitted value functions from the risky-choice task (generated from the Dynamic Experiments for Estimating Preferences, or DEEP, program) based on median-split symbolic-number mappings.

indicated a significant indirect effect of numeracy on DMU through symbolic-number mappings, $b = 0.014$, CI [.004, .030]. These results suggest that numeracy's effects on the value function in risky choices may be due, at least in part, to more exact symbolic-number mappings. For additional results with loss-aversion and probability-weighting parameters, see the Supplemental Material.

General Discussion

Across riskless and risky prospects and three different dependent measures (including Study 1a, as reported in the Supplemental Material), we demonstrated that individuals differ in their mappings of symbolic numbers, and value depends on these mappings. That is, the extent to which individuals value the prospect of $100 depends on how they map the symbolic number "100" to a mental magnitude. In Study 1, we tested this relation using an ecological riskless paradigm, and in Study 2, we used a conventional risky-choice paradigm (Toubia et al., 2013).[2]

Are the effects due to mental magnitudes or mapping?

A recent distinction within the numerical-cognition literature concerns whether mapping tasks (e.g., the current number-line task) also reflect mental-magnitude representations (Chesney & Matthew, 2013; Rips, 2013). Whereas conventional mental-magnitude-representation measures involve quick discrimination of nonsymbolic magnitudes (e.g., "Are there more blue or yellow dots?"; Halberda et al., 2008), the number-line task also requires the mapping of symbolic numbers to those mental magnitudes. Thus, valuations in the present studies may be determined by exactness in individuals' mental-magnitude representations, their mapping of symbolic number to mental magnitudes, or a combination of both processes.

Although we cannot definitively identify the process (or processes) at work on the basis of the current data, recent research examining responses to nonsymbolic and symbolic formats and their relations to mathematical competence provides some clues. To begin, children with more acute mental-magnitude representations (measured with a conventional nonsymbolic task) also mapped symbolic numbers more accurately to those magnitudes (Mazzocco, Feigenson, & Halberda, 2011). Mental-magnitude-acuity and symbolic-number-mapping scores both predicted better math performance (see also Mundy & Gilmore, 2009). These findings are consistent with prior theorizing that symbolic-number mappings build on nonsymbolic representations and that both are related to math performance (e.g., Verguts & Fias, 2004). Furthermore, Mazzocco et al. found that performance on highly symbolic math tasks (i.e., rank ordering the values of fractions and decimals) depended, in particular, on the accuracy of symbolic-number mappings. Experimental manipulations that trained better mapping among children also improved math performance (Booth & Siegler, 2008).

Among adults, the relation between mental-magnitude acuity and math performance is less clear. Some researchers have found the expected positive correlation (DeWind & Brannon, 2012; Halberda et al., 2008), whereas others have found little to no correlation (Castronovo & Göbel, 2012; Price, Palmer, Battista, & Ansari, 2012). But more exact mapping ability is more consistently related to adult numeracy (Castronovo & Göbel, 2012; Peters et al., 2008). These results (combined with the highly-symbolic-task results of Mazzocco et al., 2011) suggest that mapping ability is likely to have a greater influence than mental-magnitude acuity in many common (and often symbolic) judgment-and-decision paradigms, including the present riskless judgments and risky choices.

However, it seems likely that both components influence different judgments and decisions. We suspect that, when decision makers evaluate a monetary prospect (e.g., saving $30), representations of mental magnitudes inform them about the perceived bigness of $30 while mapping ability allows them to assess the approximate value of "30" dollars. Furthermore, mapping ability may matter more in valuing other symbolic-number-based prospects (e.g., a lottery ticket with 1:175,223,510 odds of winning the

Powerball grand prize), whereas mental magnitudes may play a larger role in the valuing of nonsymbolic-number-based prospects (e.g., choosing between different-sized clusters of grapes). Given the existence of domain-general comparison processes, mental-magnitude acuity also may be a better predictor of comparative judgments of weight, intensity, and time (DeWind & Brannon, 2012; Holloway & Ansari, 2008). The distinctions between and relations among different measures of mental magnitudes, mapping, and other forms of number and magnitude processing deserve more study.

This discussion highlights a number of potential directions for future research. Understanding lower-level cognitive processes and how they influence higher-level processes has been useful in other domains, such as reading and math (Holloway & Ansari, 2009); we believe it will also prove fruitful in understanding judgment and decision making.

Implications for risk aversion

Previous research has demonstrated a link between lower numeracy and greater risk aversion (Cokely & Kelley, 2009; Frederick, 2005; Weller et al., 2013). The current results, however, support this link as being due, in part, to symbolic-number mappings. The participants in Study 2 with less exact symbolic-number mappings (and generally lower numeracy) were more likely to choose certain prospects (e.g., guaranteed $40) over risky prospects (e.g., 50% chance of $100, otherwise $0), presumably because they perceived the difference between riskless and risky quantities as subjectively smaller than did participants with more exact mappings (and generally higher numeracy). What appears on the surface to be an aversion to risk may also be produced by differences in symbolic-number mapping.

Potential implications for intertemporal choice

The current research also may explain certain aspects of hyperbolic discounting in intertemporal choice (Peters et al., 2008; Zauberman, Kim, Malkoc, & Bettman, 2009). Choosing $100 today over $200 in 10 days indicates a high discount rate. However, if individuals have less exact mappings of symbolic numbers to mental magnitudes, they may simply be less sensitive to the difference in magnitude between "100" and "200." Thus, symbolic-number mapping may intrude on the valuation process.

Recently, Zauberman and colleagues (2009) suggested that curvilinear time-discrimination functions can account for hyperbolic discounting. The authors measured time perceptions with a number-line task similar to ours; participants indicated the position of different time horizons (e.g., 3 months) on a line with anchors of *very short* and *very long*. Results indicated curvilinear time-discrimination functions that could account for hyperbolic discounting. On the basis of the current findings and those of Peters et al. (2008), we suggest that these curvilinear time-discrimination functions may have tapped into more fundamental symbolic-number-mapping phenomena, given that quantities of time and money are presented with symbolic quantities (e.g., 10 days, $5) and therefore may be subject to individuals' ability to represent magnitudes and map symbolic numbers onto them.

Normative implications

Just as greater numeracy generally appears to lead to better judgments and decisions but can also result in worse ones (see Study 4 in Peters et al., 2006), greater accuracy in symbolic-number mappings may do the same. For example, holding constant other influences, more linear value functions produced by more accurate mappings presumably would lead individuals to be more likely to value an extra apple equally whether they already had 100 apples or had none. This valuation seems normatively appropriate if apples can be stored indefinitely and individuals can eventually use the 101st apple, but could be inappropriate otherwise. It is also possible that more linear value functions may result in greater affective forecasting errors (Wilson & Gilbert, 2005). Specifically, Hsee and Zhang (2004) found that joint evaluation (evaluating two options side by side) produced more linear value functions than did separate evaluation (evaluating each option in the absence of any other). However, actual experiences of the options related more closely to the less linear value functions derived from separate evaluation. Thus, valuations made by individuals with less accurate mappings may resemble experienced valuation more closely than those made by individuals who map more accurately. Future research should delineate potential separable influences of these related number processes (i.e., mental-magnitude representations, mapping, and numeracy) on expected versus experienced valuation.

Conclusions

Our results suggest that the ability to map symbolic numbers is associated with the valuation of prospects in judgments and decisions. In addition, the influence of greater numeracy on judgments and decisions may be due, at least in part, to its link with more exact mappings (Halberda et al., 2008; Peters et al., 2008). The current results thus further the understanding of the psychological mechanisms underlying judgments and decisions and point toward potentially more effective interventions. In particular, the results add to the growing call for improved mathematics education, including training aimed at improving the accuracy of symbolic-number mappings. Effective training may require further understanding of the detailed mechanism (or mechanisms) underlying the current results. Although we believe that the present results are most likely due to symbolic-number mapping, given its causal link with improved numeracy (Booth & Siegler, 2008), accuracy on the number-line task may be influenced by mental magnitudes (Siegler & Opfer, 2003) and by symbol-to-magnitude mapping (Chesney & Matthew, 2013; Rips, 2013); subdivision strategies could also play a role (Barth & Paladino, 2011).

The current findings have theoretical implications for conceptualizations of DMU, risk aversion, intertemporal choice, predicted versus experienced utility, and possibly other judgment- and decision-related phenomena. To the extent that symbolic-number mappings are influenced by mental magnitudes, the current research also adds to dual-process debates in decision making. Some researchers view the dual processes as independent systems (Frederick, 2005); recent research, however, has suggested that the more intuitive process (mental-magnitude acuity) and the more deliberative one (numeracy) influence one another (Park & Brannon, 2013; Piazza et al., 2013), and both processes influence judgments and decisions (Peters, 2012; Peters et al., 2008). Thus, dual processes for evaluating numeric information in decisions appear to be separable but not independent. The present results further suggest the existence of an important trait underlying how individuals derive economic value and utility.

Although humans are capable of tremendous feats of intellect, our judgments and decisions reflect and build on an evolutionary past that allows us to represent approximate quantities. Choosing on the basis of inexact mappings of symbolic numbers to mental magnitudes is likely sufficient for most decisions (and may maximize decision quality in some cases), but may be inadequate for some more complex everyday judgments and decisions.

Author Contributions

D. R. Schley and E. Peters developed the research hypotheses and developed the studies. D. R. Schley collected the data. Both authors worked to analyze and interpret the data and prepare the manuscript. The final version of the manuscript was approved by D. R. Schley and E. Peters.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Notes

1. Results were similar in all studies when we fit regular- and cyclical-power functions (Barth & Paladino, 2011) to each participant's data and used the exponent as an individual-difference measure of symbolic-number mappings.
2. A possible concern regarding these studies was that responses were not incentivized. Previous research, however, has demonstrated that incentives produce little influence on responses in similar tasks, at least within a similar range of dollar values (i.e., \$5–\$100; Holt & Laury, 2002).

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