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The Role of Numeracy and Impulsivity in Intertemporal Choice and Decision Making

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Abstract

A growing body of research has indicated a relationship between numeracy and decision making and that lower numerate people display more disadvantageous decisions. In the domain of intertemporal choice, researchers have long been using impulsivity to address choice preference. To further illuminate the psychological mechanisms of making intertemporal choices, the present study examined the role of impulsivity and numeracy in intertemporal choice, in the presence of each other. The study adopted both subjective and numeracy scales. These scales correlated with each other and with intertemporal choice preference. Moreover, it was found that after controlling for impulsivity, the object numeracy was significantly associated with choice preference, with higher numerate participants showing a stronger preference toward the later larger gains over the sooner smaller gains. Thus, the study indicated that intertemporal choice preference could be attributed to both impulsivity and numeracy.

Keywords: Subjective numeracy, objective numeracy, intertemporal choice, impulsivity

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Theoretical Framework

Intertemporal choice and impulsivity

Intertemporal choice deals with the trade-off between reinforcers (usually money) and time. It is common in everyday life. For example, employees may need to make a choice between two types of pensions: either receive a smaller immediate lump sum payment, or receive a larger amount that will be paid in small installments over a decade. Moreover, intertemporal choice has been found to be related to a number of important life consequences. Specifically, a stronger tendency of choosing a sooner smaller gain (as denoted by SS in the following text) over a later larger gain (as denoted by LL in the following text) is associated with worse academic performance (Kirby et al., 2005), poorer creditworthiness (Meier & Sprenger, 2012), lower income (Reimers et al., 2009), and a greater likelihood of substance abuse (Cheng et al., 2012) and unprotected sexual behavior (Johnson & Bruner, 2012).

In intertemporal choice, displaying *excessive* preference for SS over LL is considered myopic and impulsive (de Wit, 2008; Perry & Carroll, 2008). Consistent with this notion, some studies have revealed a positive relationship between preference of choosing SS and scores from the Barratt Impulsiveness Scale (BIS) in both clinical and non-clinical populations (Mitchell et al., 2005; Mobini et al., 2007). In another study, administering Tolcapone (a type of brain penetrant catechol-*O*-methyltransferase inhibitor, can increase dopamine in frontal cortex) to healthy participants could increase their preference for LL. However, the effect of Tolcapone was weaker in participants who displayed greater impulsivity with BIS (Kayser et al., 2012). Additionally, research has found that clinical populations being considered with greater impulsivity, such as substance abusers (Cheng et al., 2012, Cheng & González-Vallejo, 2014), patients with gambling disorder (Steward et al., 2017) or attention-deficit/hyperactivity disorder (Beauchaine et al., 2017), exhibit a stronger preference for SS over LL. Therefore, researchers have long been using impulsivity as a critical and robust factor to address intertemporal choice preference (de Wit, 2008; Grant & Chamberlain, 2014; Mackillop et al., 2016; Perry & Carroll, 2008).

Numeracy and decision making

Numeracy indicates the cognitive ability and tendency to understand, process, and utilize numerical information (Malloy-Weir et al., 2016; Peters & Bjalkebring, 2015; Peters et al., 2006). Numeracy is important to everyday life because low numeracy has been found to be related to disadvantaged lifestyles. For example, Benjamin et al. (2013) and Cutler & Lleras-Muney (2010) analyzed the data from the 1979 National Longitudinal Survey of Youth (NLSY) and found that lower numeracy was correlated with greater obesity and smoking, as well as less asset accumulation. In college students, numeracy was positively associated with academic performance (Peters & Levin, 2008). Patel (2017) found numeracy positively correlated with open-minded thinking and thebelief in evolution and negatively correlated with conspiracy beliefs.

In the domain of judgement and decision making, it is not uncommon to deal with numerical information when making decisions. Thus, the ability to process and utilize numerical information may correlate with decision outcome. Accordingly, Sinayev & Peters (2015) raised the numeracy hypothesis contending that lower numeracy was associated with more biased and disadvantageous decisions. This hypothesis received some support from past research. For example, in gamble choices, lower numerate people searched less information and in less depth, and they were less likely to follow the axiom of expected value (Jasper et al. 2017). Additionally, Peters & Bjalkebring (2015) showed low participants tended to display excessive risk-aversion in gamble choices. In medication-related decisions, lower numerate people were less likely to adopt the best possible solution because they could not appropriately utilize and comprehend numerical information, such as survival rate and treatment effectiveness (Reyna et al., 2009). In consumer choices, it was found lower numerate participants used less numerical information when comparing deals and were less likely to select a better deal (Graffeo et al., 2015). Martins & Szrek (2019) asked participants to select hypothetical mobile service plans and discovered lower numerate people were more likely to overpaid for their mobile services.

Taken together, past studies have shown a close relationship between numeracy and a variety of decision making tasks. Following those studies, as discussed below, the present study aims

to further advance the knowledge of the relationship between numeracy and intertemporal choice.

Goals and hypotheses of the current study

Similar to other decision tasks, people deal with numerical values when making intertemporal choices. Hence, examining the relationship between intertemporal choice and numeracy could further test the generalizability of the numeracy hypothesis and illustrate the psychological mechanism of making intertemporal choice.

The present study has three specific goals and related hypotheses.

First, in line with the relationship between numeracy and disadvantaged decisions as described above, a few studies found numeracy was positively related to the tendency of selecting the later larger gains over the sooner smaller gains (Ghazal et al., 2014; Sinayev & Peters, 2015). The current study aims to replicate the correlation between numeracy and intertemporal choice given a methodological consideration. In Ghazal et al. (2014) and Sinayev & Peters (2015), only one trial was adopted to measure intertemporal choice (i.e., one-shot decision). Although such a method was straightforward and easy to perform, with one choice, the task might not have been reliable and, hence, might not have captured a stable choice preference. Thus, the present study employs a more standard intertemporal choice task with forty items.

> H_1: It was hypothesized that similar to previous research, a positive correlation will be found between numeracy and preference of later larger gains.

Second and more importantly, the study aims to test the role of numeracy and impulsivity in intertemporal choice, particularly when taking each other into account. Previous research tested their role in intertemporal choice separately. The present study tests whether numeracy can explain additional variability in intertemporal choice in the presence of impulsivity. In other words, the study aims to further illuminate the psychological mechanisms of intertemporal choice.

H_2: Based on the research showing the relationship between numeracy and decision making, it was suggested that numeracy is positively related to the selection of later larger gains when taking impulsivity into account.

The third goal pertains to the validity of the concept of numeracy and aims to test the relationship between intertemporal choice and numeracy more comprehensively. It is worth noting that most research on numeracy focuses on objective numeracy, and less is known about subjective numeracy (tendency and confidence in using numerical information, Peters & Bjalkebring, 2015). Conceptually, people with lower subjective numeracy are less likely to utilize numerical information.

H_3: Thus, although subjective numeracy and objective numeracy capture different psychometrics, it was predicted that their associations with intertemporal choice are similar.

Methods

Samples

The study was approved by the institute's IRB before data collection. A prior power analysis was performed to estimate the needed sample size. According to on G*Power 3.1.9, with desired power = .80, α = .05, a regression analysis (two-tailed) with four predictors (gender, impulsivity, subjective and objective numeracy) required 103 participants to meet a median effect size, r^2 = .13 (Cohen, 1988). For the present study, data collection occurred during the 2019 spring semester and stopped at the end of the semester. One hundred and sixteen college students, recruited from the university's Psych Pool, participated in the study for course credit. All participants were freshmen or sophomores. Six participants did not complete at least 50% of items and were removed from the analyses. Thus, all analyses were based on the remaining 110 participants (52 females, 48 males, and ten did not disclose their gender). This sample size exceeded the one estimated by the power analysis.

Materials & Procedures

All participants completed an online survey via Qualtrics in the following order: subjective numeracy scale, impulsivity scale, Rasch-based numeracy scale and the intertemporal choice task. There was no time restriction for completing any scale or task.

Impulsivity scale

The Barratt Impulsivity Scale-11 (BIS) was employed to measure impulsivity. The BIS is a popular self-reported measure of impulsivity (Patton et al.,1995), which contains 30 items, measuring three aspects of impulsivity: (1) non-planning impulsivity (e.g., I plan task carefully); (2) motor impulsivity (e.g., I do things without thinking); and (3) attention impulsivity (e.g., I concentrate easily). The total score for the BIS is 120, with a higher score representing greater impulsivity.

Numeracy scales

The Subjective Numeracy Scale (SNS, Fagerlin et al, 2007; Zikmund-Fisher et al, 2007) aims to measure the perceived ability to utilize numerical information and perform mathematical tasks (e.g., How good are you at working with fractions?). This scale has eight items, and scores range from 1 to 6 on each item, with a higher score indicating greater subjective numeracy.

The Rasch-based Numeracy Scale (RNS, Weller et al, 2013) contains eight items (e.g., 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?) with difficulty varying across different items. Each item was graded as either correct or incorrect. In Peters & Bjalkebring (2015), SNS was positively related to this scale, $r(109) = .46$. For the RNS, the score was computed as the correct answer rate, ranging from 0 to 1, with 1 indicating someone answered all items correctly.

Intertemporal choice task

In the present study, participants made selections between a sooner smaller gain (SS) and a later larger gain (LL). To challenge the ability to process numerical values (i.e., avoid a possible

ceiling effect), there were a few features of the intertemporal choice task. First, the sooner delay was never immediate. Second, all attributes, including sooner and later delays, and small and large magnitudes, varied irregularly across all choice pairs. The delays were presented in days and the magnitudes were presented in U.S. dollars ($). Third, to further increase numerical complexity, all magnitudes contained two decimal places (e.g., $45.96). Each participant completed forty choices in this task. Across all choice pairs, the mean values for the smaller and larger magnitudes, and sooner and later delays were $195.97, $345.75, 28.68 days, and 54.43 days respectively. This task was adopted in another study testing the relationship between intertemporal choice and an alternative form of cognitive reflection test (Cheng & Janssen, 2019). In the present study, the frequency of choosing the later larger gain (LL) was employed to index choice preference. This approach has been adopted in several recent studies (Cheng & González-Vallejo, 2016; Cheng et al., 2018; Cheng & Janssen, 2019; Dai & Busemeyer, 2014; Scholten et al., 2014).

Results

Performance on impulsivity and numeracy scales

Table 1 displays the means (standard deviations) and Cronbach's *α* for the impulsivity and numeracy scales. The descriptive statistics of BIS, SNS and RNS were similar to the findings in some previous studies (Patton et al, 1995; Peters & Bjalkebring, 2015; Weller et al, 2013). For the RNS, four participants (3.6%) answered all items incorrectly. None answered all items correctly (the best score was .875). Thus, no ceiling or floor effect was observed for the RNS. The RNS's Cronbach's *α* was a bit low. However, it was still comparable to the findings reported in Peters & Bjalkebring (2015), such that the relatively low reliability was consistent with the idea that "*having items distributed across difficulty levels sacrificing Cronbach's α*" (Peters & Bjalkebring, 2015).

Table 1

Means (standard deviations) and Cronbach's αs for the impulsivity and numeracy scales

Scale	*M* (SD)	Cronbach's α
Barratt Impulsivity Scale (BIS)	65.57 (10.45)	.83
Subjective Numeracy Scale (SNS)	3.96 (0.93)	.78
Rasch-based Numeracy Scale (RNS)	0.51 (0.23)	.68

Correlations between preference on intertemporal choice, numeracy and impulsivity

On average, out of 40 choices, participants selected LL over SS 22.01 times (*SD* = 10.89). Two participants always selected the LL option, and another one always selected the SS option. However, these participants showed reasonable responses in other scales (e.g., RNS score = .75; .625; and .50 respectively). Hence, their responses were kept in data analyses.

Table 2 shows the correlations between intertemporal choice preference (frequency of selecting LL), impulsivity, numeracy and gender. Similar to Peters & Bjalkebring (2015), the SNS was positively related to the RNS.

To analyze the effect of gender, females and males were coded as 1 and 2, respectively. As shown by the positive correlations between gender and objective and subjective numeracy scales in Table 2, males scored higher than did females on the SNS and RNS. Such findings were in line with some other studies regarding numeracy and gender (Primi et al., 2018; Thomson & Oppenheimer, 2016), However, there was no gender difference in impulsivity and choice preference.

As expected, the impulsivity scale was significantly associated with choice preference. Additionally, those who scored higher on the numeracy scales selected LL more frequently, indicating that numeracy was also related to intertemporal choice.

Table 2

Correlations between intertemporal choice preference, impulsivity and numeracy and gender

	Choice	BIS	SNS	RNS	Gender
Choice	--	-.35***	.23*	.42***	-.04
BIS			-.29**	-.31**	.08
SNS				.42***	.29**
RNS					.20*

Note. Choice: frequency of selecting LL.

***: $p < .001$; **: $p < .01$; *: $p < .05$

Although impulsivity and numeracy were both associated with intertemporal choice preference, the results based on correlations should be interpreted with caution for two reasons. First, Type I error might be inflated due to a series of correlations being conducted simultaneously. Second, as indicated in Table 2, impulsivity was negatively related to the numeracy scales. While such results were understandable (e.g., more impulsive persons were less likely to engage into numerical information processing), it was imperative to differentiate the effects of impulsivity and numeracy on intertemporal choice. Therefore, linear regressions were performed in the section below.

Differentiating the role of impulsivity and numeracy in intertemporal choice

To examine the effects of impulsivity and numeracy on intertemporal choice in the presence of each other, two approaches were employed. The first approach focused on the relationship between the overall numeracy composite and intertemporal choice. This composite was obtained by averaging the standardized scores of the two numeracy scales (hence centered). A hierarchical linear regression was performed, with the frequency of selecting LL as the outcome variable. For predictors, gender (females = 1 and males = 2) and the BIS (mean centered) were entered into the first two blocks, respectively. The third block contained the overall numeracy composite. The fourth block further tested the interaction between the BIS and the overall

numeracy composite. The interaction aimed to examine whether numeracy could directly negate or reduce the effect of impulsivity.

Table 3 depicts the regression results. Consistent with the correlational results, gender was never related to choice preference. As shown in the second block, BIS added significantly to the model. Block 3 exhibited that the overall numeracy composite could explain significant additional variance of choice preference when taking impulsivity into account. By contrast, the interaction between the overall numeracy composite and impulsivity failed to add significantly to the model. Given the redundancy of the interaction (Aiken et al., 1991), the third block was adopted as the final model. Hence, it was found that both impulsivity and the overall numeracy composite were able to predict intertemporal choice preference, in the presence of each other.

Table 3
Hierarchical linear regression on intertemporal choice preference with impulsivity and overall numeracy composite

Block and Variables	*B(SE)*	R^2	R^2 change	*F* change	Tolerance
Block 1		.001	.001	0.13	
Gender	-0.81 (2.21)				1.0
Block 2		.12	.12	13.12***	
Gender	-0.18 (2.10)				.99
BIS	-0.36 (.10)***				.99
Block 3 (final model)		.18	.06	7.47**	
Gender	-2.24 (2.17)				.87
BIS	-0.24 (.11)*				.81
Overall Numeracy	3.78 (1.38)**				.75
Block 4		.18	.003	0.32	
Gender	-2.36 (2.18)				.86
BIS	-0.23 (0.11)*				.79
Overall Numeracy	3.77 (1.39)**				.75
BIS*Overall Numeracy	0.05 (0.10)				.96

Note. ***: $p < .001$; **: $p < .01$; *: $p < .05$.

The second approach focused on the effects of the specific numeracy scales. The present study employed two numeracy scales. In Table 2, although the two numeracy scales were significantly associated with each other, the correlation coefficient was at a moderate level *r(108)* = .42,

indicating that the scales captured different aspects of numeracy. Hence, their relationship with intertemporal choice might be different. Similar to the first approach, for each numeracy scale, a hierarchical linear regression was performed on the frequency of selecting LL. Gender (females = 1 and males = 2), the BIS (mean centered), the specific numeracy scale (mean centered), and the interaction between the BIS and that numeracy scale were sequentially entered into the four blocks, respectively. In all three regression models, none of the interaction term was significant or added significantly to the model. Therefore, these interaction terms were removed from the regression analyses.

Table 4

Hierarchical linear regression on intertemporal choice preference with impulsivity and specific numeracy scales

Block and Variables	*B*(*SE*)	R^2	R^2 change	*F* change	Tolerance
Block 1		.001	.001	.13	
Gender	-0.81 (2.21)				1.0
Block 2		.12	.12	13.12***	
Gender	-0.18 (2.10)				.99
BIS	-0.36 (.10)***				.99
Block 3 - SNS		.13	.01	1.57	
Gender	-1.13 (2.22)				.88
BIS	-0.31 (0.11)**				.85
SNS	1.60 (1.27)				.78
Block 3 - RNS		.21	.09	10.33**	
Gender	-1.77 (2.06)				.94
BIS	-0.25 (0.10)*				.88
RNS	15.62 (4.86)**				.85

Note. ***: $p < .001$; **: $p < .01$; *: $p < .05$.

Table 4 presents the regression analyses for the two numeracy scales. The first two blocks were the same across the two regression analyses. The third block varied (one for SNS and the other for RNS) based on the specific numeracy scale. It was found that impulsivity was consistently related to choice preference in all regressions. In the presence of impulsivity, the subjective numeracy scale (SNS) was not significant. In contrast, the Rasch-based numeracy

scale (RNS) was significant after controlling for impulsivity. Thus, unlike the zero-order correlation matrix, the effect of numeracy on choice preference varied between specific numeracy scales when taking impulsivity into account.

Discussion and Conclusion

The present study examined the relationship between numeracy and intertemporal choice. In line with some past studies (Ghazal et al, 2014; Sinayev & Peters, 2015), based on the zero-order correlations, the present study found that both numeracy scales were positively related to the preference toward LL over SS. Hence, the study replicated previous findings. Moreover, the study also supported the notion that lower numeracy was associated with more disadvantageous decisions, as proposed by the numeracy hypothesis (Sinayev & Peters, 2015).

Beyond the zero-order correlations, the present study examined the role of impulsivity and numeracy in intertemporal choice in the presence of each other. Consistent with past research (Kayser et al, 2012; Mitchell et al, 2005; Mobini et al, 2007), the study found that greater impulsivity, represented by the BIS, was negatively related to the preference of LL over SS. Furthermore, the study revealed that the overall numeracy composite (by combing the two numeracy scales) could explain significant additional variability in intertemporal choice in the presence of impulsivity. Specifically, for lower numerate people, they were more likely to select SS over LL. As discussed, researchers have long been using impulsivity to address intertemporal choice preference. The present study implied that in addition to impulsivity, numeracy was also a psychological mechanism of intertemporal choice.

Although the study did not test the dual-process theory directly (Evans, 2008), the findings were consistent with the dual-process theory at the apparent level. That is, Process 1, as reflected by impulsivity, is associated with the preference toward SS. By contrast, numeracy, as associated with Process 2, is related to the preference toward LL. The negative relationship between impulsivity and numeracy (e.g., a more impulsive person is more likely to use numerical information) also is consistent with the concept that the two processes compete with each other (Frederick, 2005). Future studies could further advance the knowledge of mapping numeracy into the dual-process theory.

The present study also tested the performance of two specific numeracy scales. It was found that the two numeracy scales were correlated with each other, suggesting good construct validity of the scales. The study also replicated the gender effect on numeracy as found in past research (Primi et al, 2018; Thomson & Oppenheimer, 2016). However, the results indicated the scales' relationship with intertemporal choice was not entirely the same. That is, even though both numeracy scales were associated with choice preference based on the zero-order correlations, only the RNS was still related to choice preference after controlling for impulsivity. The findings suggested when making intertemporal choices, the ability to utilize numerical information (objective numeracy as measured by the RNS) might be more independent of impulsivity than was the tendency to utilize numerical information (subjective numeracy). Hence, the study further advanced the differences between objective numeracy and subjective numeracy, despite their relationship (Peters, & Bjalkebring, 2015).

The present study replicated the role of impulsivity in intertemporal choice. Furthermore, the study found after controlling for impulsivity, the objective numeracy was negatively related to the short-sighted intertemporal choices. The study implied numeracy as a plausible psychological mechanism of making intertemporal choices, and provided support the numeracy hypothesis introduced in Sinayev & Peters (2015).

Practical implications

The present study generates two practical implications. First, as reviewed earlier, researchers have long used to impulsivity to explain intertemporal choice preference. This study shows that in the presence of impulsivity, numeracy also correlates with intertemporal choice preference. Thus, the present study suggests that when addressing individual behavioral differences in intertemporal choice, numeracy should also be considered. For example, studies have found substance abusers show more short-sighted intertemporal choice than matched healthy controls (e.g., Cheng et al, 2012; Cheng & González -Vallejo, 2014). It is thus of interest to know to what extent the differences in choice preference between substance abusers and matched healthy controls are related to numeracy. Put differently, future research may examine whether numeracy contributes to the short-sighted choices in substance abusers. In a similar vein, as for the relationship between intertemporal choice preference and unprotected sexual behavior

(Johnson & Bruner, 2012), researchers may further investigate the extent to which this relationship is associated with numeracy (e.g., underestimate the risk) on top of impulsivity. Therefore, the present study provides a new perspective from numeracy to address the individual differences in intertemporal choice.

The second implication deals with education. Although the study is correlational in its nature, the findings suggest that improving numeracy might help reduce the excessive preference toward SS and irrational behaviors as described above. Hence, the study highlights the importance of math education (Gravemeijer et al., 2017), particularly in countries with so called “math crisis” (Anderson, 2016). It is worth noting that future studies with more rigorous causal design (e.g., cohort design) are needed to test this implication.

Limits of the study

The present study is not free of limits. First, this study recruited college students to measure the relationship between numeracy and intertemporal choice. While college students are frequently used in psychological research, whether the findings can be generalized to other populations demands further studies. For example, it would be of interest to test whether the relationship between impulsivity, numeracy and intertemporal choice still exists in different generation cohorts. Additionally, like the studies cited above, the present study employed hypothetical choices. While some past studies found no difference between when using hypothetical options and when using real option in intertemporal choice (Johnson & Bickel, 2002; Locey et al., 2011), future studies may use real options to enhance the external validity of findings regarding the relationship between numeracy and intertemporal choice.

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