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THE ROLES OF DELAY AND PROBABILITY DISCOUNTING IN TEXTING WHILE DRIVING: TOWARD THE DEVELOPMENT OF A TRANSLATIONAL SCIENTIFIC PROGRAM

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A sample of 109 college students completed a survey to assess how frequently they send or read text messages while driving. In a novel discounting task with a hypothetical scenario in which participants receive a text message while driving, they rated the likelihood of replying to a text message immediately versus waiting to reply until arriving at a destination. The scenario presented several delays to a destination and probabilities of a motor vehicle crash. The likelihood of waiting to reply decreased as a function of both the delay until the destination and the probability of a motor vehicle crash. Self-reported higher frequencies of texting while driving were associated with greater rates of both delay and probability discounting. The degree of delay discounting was altered as a function of the probability of a motor vehicle crash and vice versa. These results suggest that both delay and probability discounting are important underlying mechanisms of drivers' decision to text while driving.

Key words: texting while driving, delay discounting, probability discounting, impulsivity, translational science, college students

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Texting while driving has been recognized as a major public health issue, with an estimated 6-16% of motor vehicle crashes in the United States stemming from texting and driving in 2013 (National Safety Council, 2015). According to the National Highway Traffic Safety Administration (NHTSA), 3,477 people were killed and an estimated 391,000 people were injured in motor vehicle crashes caused by distracted driving in 2015 in the United States (NHTSA, 2017a). Despite its dangers, 31.2% of people aged 18-64 reported that they have texted while driving in the past 30 days (Centers for Disease Control and Prevention, 2013). Texting and driving is particularly prevalent in young drivers, with more than 90% of college students reporting that they have texted while driving (Atchley, Atwood, & Boulton, 2011). Legislation has been put into place to ban texting while driving for all drivers in 47 states and the District of Columbia (Governors Highway Safety Association, 2018), yet evidence of the effectiveness of laws restricting cellphone use is mixed (e.g., Ehsani, Bingham, Ionides, & Childers, 2014; Ferdinand et al., 2015; see Delgado, Wanner, & McDonald, 2016, for review). Educational campaigns, such as *U Drive. U Text. U Pay.* (NHTSA, 2017b), bring information on the dangers of texting and driving to our televisions, radios, and the internet. Nevertheless, there is no evidence that these campaigns reduce cellphone use while driving (Delgado et al., 2016).

We propose that the public health challenge of texting while driving demands *translational science*, which is defined as "the field of investigation focused on understanding the scientific and operational principles underlying each step of the translational process" (National Center for Advancing Translational Sciences [NCATS], 2015, p. 2). Translation in this context refers to the process by which observations in the laboratory, clinic, and community are used for interventions that improve the health of individuals and the public (NCATS, 2015). Our overarching goal in this paper is to demonstrate the utility of *use-inspired basic research*—basic research that enhances our understanding of nature but is also inspired by considerations of use (Stokes, 1997)—to understand the behavioral mechanism underlying texting while driving. We believe it is critical to

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first establish a solid connection between knowledge generated from basic science in decision making and the public health challenge of texting while driving to develop effective prevention and intervention strategies.

Among the theoretical frameworks that serve the aforementioned goal, we believe a behavioral economic approach is particularly useful. Behavioral economics is a diverse field, but in this paper, we use the definition of behavioral economics provided by Bickel, Johnson, Koffarnus, MacKillop, and Murphy (2014). That definition is "the application of economic concepts and approaches to the molar study of individuals' choices and decisions" (p. 643). One of the areas that the behavioral economic literature has focused on is lack of self-control or impulsive decision making (Bickel & Marsch, 2001). One hallmark of texting while driving is that drivers continue to send and read text messages while driving despite knowing the dangers associated with the behavior (Atchley et al., 2011). It is this impulsive nature of texting while driving that makes the behavioral economic approach appropriate for studying this topic. From a behavioral economic perspective, texting while driving may be conceptualized as an impulsive choice of an immediate reinforcer (i.e., an immediate short text message) conjoined with a probabilistic punisher (i.e., a motor vehicle crash that may or may not happen) over a delayed reinforcer without a probabilistic punisher.

Previous studies support the behavioral economic conceptualization that texting while driving can be characterized as an impulsive choice. Hayashi, Russo, and Wirth (2015) investigated the relation between texting while driving and delay discounting—the process by which the decision maker subjectively devalues future events, either positive or negative (Madden & Bickel, 2010). Using a delay-discounting task with hypothetical monetary outcomes, Hayashi et al. (2015) compared the degree of delay discounting between drivers who self-reported a high frequency text while driving and those who self-reported a low frequency. They found that the degree of delay discounting was greater for drivers who frequently text while driving, suggesting that impulsive decision making is involved in texting while driving. This is consistent with numerous previous studies showing that delay discounting plays a critical role in impulsivity-related problems, such as substance dependence and abuse (e.g., MacKillop et al., 2011), pathological gambling (e.g., Petry & Madden, 2010), internet addiction (e.g., Saville, Gisbert, Kopp, & Telesco, 2010), risky sexual behavior (e.g., Johnson, Johnson, Herrmann, & Sweeney, 2015), and criminal behavior (Arantes, Berg, Lawlor, & Grace, 2013).

In a subsequent study, Hayashi, Miller, Foreman, and Wirth (2016) directly assessed whether texting while driving is characterized as an impulsive choice. They developed a novel delay-discounting task with a hypothetical scenario in which, after receiving a text message while driving, participants rated their likelihood of replying to the text message immediately versus waiting to reply for a specific period of time. The participants also completed a delay-discounting task with hypothetical money, similar to the one in Hayashi et al. (2015). The researchers found that the decrease in the likelihood of waiting as a function of delay is well described by a hyperbolic delay-discounting function (see Atchley & Warden, 2012; Reed, Becirevic, Atchley, Kaplan, & Liese, 2016, for similar findings in general texting scenarios). More importantly, the researchers found that participants who frequently text while driving discounted the opportunity to reply to a text message at greater rates, although, contrary to the finding in Hayashi et al. (2015), no significant relation was found between the rates of discounting of hypothetical money and the frequency of texting while driving. This discrepant finding with hypothetical money across studies illustrates the complexity of the problem of texting while driving and indicates further investigation will be beneficial.

When it comes to impulsive decision making, delay is not the only variable that plays an important role. Probability discounting, defined as changes in subjective value of an outcome as a function of the likelihood of its occurrence (Green & Myerson, 2010), is also critical in impulsive decision making. As with delay discounting, probability discounting occurs with both a reinforcer and a punisher (or loss of a reinforcer). When the value of a punisher is discounted as a function of its probability, for example, a *decrease* in the probability to receive a punisher (or an *increase* in the odds against receiving a punisher) *decreases* the subjective aversiveness of the punisher. A comparison between probability discounting of gain and loss showed that degree of discounting is generally greater with gain than with loss (e.g., Estle, Green, Myerson, & Holt, 2006).

Delay and probability discounting are only weakly correlated (e.g., Jarmolowicz, Bickel, Carter, Franck, & Mueller, 2012) and are not represented by a single construct (Green & Myerson, 2013). Although some similarities have been reported (e.g., both delay and probability discounting of loss is insensitive to the amount of the outcomes to be discounted; Green, Myerson, Oliveira, & Chang, 2014), it is likely that delay and probability discounting represent separate behavioral processes.

Previous research on probability discounting and impulsivity-related problems has shown mixed results. With respect to probability discounting and the relation to drug addiction, no consistent difference in the degree of probability discounting for hypothetical money has been shown between drug-dependent samples and matched controls (e.g., Mitchell, 1999; Yi, Chase, & Bickel, 2007). In the area of gambling, participants who have problematic gambling discounted hypothetical money *less* steeply than matched controls (Holt, Green, & Myerson, 2003; Madden, Petry, & Johnson, 2009), indicating *greater* risk taking (i.e., problematic gamblers valued unlikely outcomes to a greater degree than nonproblematic gamblers). No significant correlation, however, was found between the degree of probability discounting and severity of gambling among the sample that mostly consisted of nonproblem-gambling college students (Shead, Callan, & Hodgins, 2008). Rasmussen, Lawyer, and Reilly (2010) found that individuals with high percent body fat discounted hypothetical probabilistic food outcomes *more* steeply than those with low percent body fat, which is contrary to the notion that impulsive individuals discount probabilistic outcomes *less* steeply. Finally, with respect to risky sexual behavior, Johnson et al. (2015) found that individuals diagnosed with cocaine-use disorder and matched controls did not differ significantly in degree of probability discounting of hypothetical sexual outcomes.

Texting while driving is considered risky because it is associated with a probabilistic, negative consequence (Ben-Zur & Zeidner, 2009)—injury or death of oneself or others. Beyond the delay to engaging in texting behavior, one important variable that would influence a decision to text while driving is the probability of a motor vehicle crash due to texting while driving. Nonetheless, no previous research has examined probability discounting as a potential mechanism that underlies texting while driving. To fill this gap in the literature, the first purpose of the present study was to determine whether decision making concerning texting while driving could be well characterized using the probability-discounting paradigm. Participants were presented with a hypothetical scenario in which, after receiving a text message while driving, they were asked to rate the likelihood of replying to a text message immediately versus waiting to reply until arriving at a destination. A key point is that whereas typical studies of probability discounting employ hypothetical monetary outcomes, the present study employed the outcomes associated with texting while driving (i.e., opportunities to reply as a social reinforcer). The texting scenario presented several probabilities of occurrence of a motor vehicle crash that ranged from 10% to 0.03% and several delays to a destination. It was hypothesized that the subjective value of opportunities to reply to a text message received while driving would be discounted as a function of the probability of a motor vehicle crash.

The second purpose of the present study was to investigate whether the rate of probability discounting of an opportunity to reply to a text message would be associated with the frequency of texting while driving. A previous study demonstrated that drivers who reported a high frequency of texting while driving show greater delay discounting (Hayashi et al., 2015, 2016), but it is unknown whether such drivers will show greater probability discounting as well. It was hypothesized that greater probability discounting would be associated with a greater frequency of texting while driving

Given the complexity of texting while driving, it seems unlikely that either delay or probability discounting alone would account for all of the decision-making processes underlying the behavior. Rather, it seems more likely that multiple modes of discounting are involved. This multiple-discounting-modes approach, which conceptualizes a single choice in terms of multiple (and concurrent) discounting processes (Reynolds & Schiffbauer, 2004), would be particularly useful in conceptualizing more fully the processes involved in complex choices about safety and health in general and texting while driving in particular. The multiple-discounting modes can take a form of either a choice leading to a single outcome with multiple dimensions (e.g., delayed and probabilistic reinforcer; Vanderveldt, Green, & Myerson, 2015) or a choice leading to multiple outcomes (e.g., immediate reinforcer and delayed punisher; Sy, Green, Gratz, & Ervin, 2016). As Green and Myerson (2004) stated, choices that produce combinations of positive and negative consequences often involve probabilistic outcomes, and this would probably be the case with the decision-making process underlying texting while driving. In order for this use-inspired basic research to have utility, it is vital to fully appreciate the complexity of the processes involved in texting while driving and to select a realistic choice model. Consistent with Reynolds and Schiffbauer (2004), we believe a multifactor choice model that includes multiple modes of discounting can improve our prediction and potentially control of safe or unsafe behaviors.

Based on the conceptualization of the multiple modes of discounting, the third purpose of the present study was to investigate if the effects of delay to a destination and probability of a motor vehicle crash depend on the level of the other dimension or if the effects of delay and probability are independent. Previous research using delayed and probabilistic hypothetical money has shown that the probability affects rates of delay discounting, but the delay does not affect rates of probability discounting (Cox & Dallery, 2016; Vanderveldt et al., 2015; Weatherly, Petros, Jónsdóttir, Derenne, & Miller, 2015). Nevertheless, it is unknown whether similar results would be obtained in choices that involve both a delayed reinforcer and a probabilistic punisher, as in the case of texting while driving. To address this issue, participants were presented with a hypothetical scenario in which, after receiving a text message while driving, they were asked to rate the likelihood of replying to a text message immediately versus waiting to reply until arriving at a destination. Similar to the previous study by Hayashi et al. (2016), the scenario presented several delays to a destination (range: 30 sec to 3 hr). Unlike the previous study, however, the scenario also presented several probabilities of motor vehicle crashes, as mentioned above. That is, the scenario presented situations that differed in both delay to a destination and the probability of a crash such that effects of these variables on decision making associated with texting while driving could be simultaneously investigated. Because this is an exploratory investigation, we had no a priori hypothesis.

Method

Participants

One hundred nine undergraduate students enrolled in introductory psychology courses at Pennsylvania State University, Hazleton, participated. They were offered course credit for participation. Students who reported that they did not have a valid driving license (n = 24) or a smartphone/mobile phone capable of sending and receiving text messages (n = 1) on the demographic survey (described below) were excluded from the study (i.e., their data were not analyzed). The retained sample was composed of 33 males and 51 females. Their median age, years of higher education, and years driving were 19.0 (Interquartile range [*IQR*] = 1.0; ranging from 18 to 26), 1.0 (*IQR* = 1.0; ranging from 0.5 to 5.0), and 2.3 (*IQR* = 2.3; ranging from 0.1 to 9.0). The Institutional Review Board at the Pennsylvania State University approved the study protocol.

Procedure

All surveys were hosted online by Qualtrics (Provo, UT). Participants received an email through the Qualtrics website that contained a link to the online survey. After agreeing to participate, they completed a demographic questionnaire and a delay- and probability-discounting task with a hypothetical scenario of texting while driving.

Demographic questionnaire. The questionnaire had questions for age, gender, years of higher education (one semester counted as 0.5 year), years and months of driving, whether they have a valid driver's license, and whether they have a smartphone/mobile phone capable of sending and receiving text messages. The questionnaire also included questions on the frequency of texting while driving (hereafter TWD). The participants answered four questions that employed a 5-point Likert scale ranging from 1 (*never*), 2 (*seldom/occasionally*), 3 (*sometimes*), 4 (*often/usually*), to 5 (*always*). The first question was "How often do you type something on your cell phone (e.g. text messages, emails, social media posts, etc.) while you are driving at any speed?" followed by "How often do you type something on your cell phone (e.g. text messages, emails, social media posts, etc.) while you are stopped at a red light?" The other two questions followed similar suit, but instead of asking how often they "type" on their phone, they asked how often they "read" on their phone in both situations.

Delay and probability discounting task. We used a novel discounting task that was designed to simultaneously assess the degree of delay and probability discounting. The task was created by combining two separate discounting tasks. The delay-discounting component of the task was adapted from Hayashi et al. (2016), and the probability-discounting component was adapted from the sexual probability discounting task developed by Johnson et al. (2015) but was altered to assess the likelihood of replying to a text message while driving. Using visual analog scales (VAS), participants rated their likelihood of replying to a text message immediately versus waiting to reply for a certain period of time. The task presented the following hypothetical scenario:

> Imagine that your significant other (or your best friend) has just sent a text message saying "text me asap" while you are driving at 40 mph. You will arrive at the destination in [delay]. Given the current road conditions, there is a [probability] chance of having a car accident if you reply to the message. Please rate how likely you are to reply now versus waiting until you arrive at the destination.

The VAS was located immediately below the instruction. It was a horizontal line labeled from 0 to 100 in increments of 10 with descriptive anchors of *definitely reply now* (far left) and *definitely wait* (far right). The participants were instructed to click on the slider bar and drag it to the point on the line that indicated their likelihood of waiting until destination to reply to the text message. The two parameters that varied across trials were delay to the destination: 30 sec, 3 min, 15 min, 1 hour, and 3 hours, and probability of having a car accident: 10% (1 in 10), 1% (1 in 100), 0.3% (1 in 300), 0.1% (1 in 1000), and 0.03% (1 in 3000). The entire task consisted of five blocks of five trials (total 25 trials). The delay values varied in an ascending order across *blocks*. Within each block, the delay value remained constant, but the probability values varied in a descending order across *trials*. On the first trial of the first block, for example, the delay and the probability were 30 sec and 10% (1 in 10), respectively, and on the second trial, the values were 30 sec and 1% (1 in 100). Based on a previous finding that there was no order effect (Vanderveldt et al., 2015), all participants experienced the same order of trials with delays and probabilities.

Data Analysis

For the delay and probability discounting assessment, the hyperboloid discounting function (Rachlin, 2006) was fitted to the data using least squares nonlinear regression performed with the Solver function in Microsoft Excel 2016:

$$V = \frac{A}{1 + rX^s} \tag{1}$$

where V refers to the subjective value of opportunities to reply as expressed by the likelihood of waiting to reply to a text message; A refers to the undiscounted value of opportunities to reply when there is no delay to the destination, or odds against crash is zero (also expressed by the likelihood of waiting to reply which was set to 100 in the present study); X refers to delay to the destination or odds against crash; r is a parameter that reflects the rate of discounting (hereafter, k and h will be used for delay and probability discounting, respectively); and s is a parameter that reflects the sensitivity to delay or odds against, which is consistent with the psychophysical scaling of Stevens' (1957) power law. We chose Rachlin's (2006) model because (a) the sensitivity parameter can provide potentially useful quantitative information on how discounting rates change at larger values of delay and odds against, and (b) Young (2017) observed that Myerson and Green's (1995) model was over-parameterized with the k and s parameters being highly correlated (r = -.87).

Note that what is discounted as a function of delay or odds against is the value of the opportunities to reply to a text message, which is expressed by the likelihood measure. This arrangement is consistent with previous studies using VAS (e.g., Johnson et al., 2015; Kaplan, Reed, & McKerchar, 2014), which is similar to expressing the value of a reinforcer by the indifference point (Rachlin, Raineri, & Cross, 1991). Also note that the present task involved both delay and probability discounting but the data for each type of discounting were fitted to Equation (1) separately, with the other dimension (either delay or probability) representing multiple conditions (e.g., the rate of delay discounting at the odds of 9, 99, 299, 999, and 2999 was calculated separately).[1]

To compare the degree of delay and probability discounting across the values of odds against crashes and delay to the destination, the area under the curve (AUC), a descriptive, nontheoretical measure of discounting, was calculated according to the method described by Myerson, Green, and Warusawitharana (2001).[2] The comparison of the AUC values for delay and probability discounting across values of odds against crashes and delay to the destination, respectively, was performed with the Friedman test because the data were not normally distributed. Finally, for correlational analyses among the demographic data, two measures of frequencies of texting while driving (mean frequencies of typing and reading while driving at any speed and typing and reading while stopped at a red light), and two AUC measures (averaged across all values of odds against crashes for delay discounting and across all values of delay to the destination for probability discounting) were performed by calculating Spearman correlation coefficients. In addition, partial correlation analyses among the two measures of frequencies of texting while driving and the two AUC measures were performed by calculating Spearman correlation coefficients while controlling for all four demographic variables (age, gender, years of higher education, and years driving). This analysis was conducted because some demographic variables were significantly correlated with the discounting measures. All statistical analyses were performed with SPSS Version 24. The statistical significance level was set at .05.

Results

Figure 1 shows the median likelihood of waiting to reply to a text message for delay discounting at each odds (left panel) and probability discounting at each delay (right panel). The curved lines represent the fits of the hyperboloid discounting functions (Eq. (1)). With respect to the goodness of the fits of the equation, the R^2 values are generally high (ranging from 0.87 to 0.99). Note that each of the five curves in the left panel shows delay discounting at a different odds of a motor vehicle crash, and each of the five curves in the right panel shows probability discounting at a different delay to arriving at the destination. The likelihood of waiting decreased as a function of delay to the destination and odds against crashes,[3] suggesting that the value of the opportunity to reply to a text message as a social reinforcer is subject to delay and probability discounting. The rates of delay discounting varied systematically as a function of odds against crashes: The larger odds against crashes, the greater delay discounting. The rates of probability discounting also varied systematically as a function of delay to the destination: The larger delay to the destination, the greater probability discounting.

[1]Another approach would be to fit the present data to a discounting equation that involves both delay and probability (e.g., multiplicative model; Vanderveldt et al., 2015). Unlike similar previous studies that involved choices leading to a single outcome with multiple dimensions (e.g., delayed and probabilistic reinforcer; Vanderveldt et al., 2015), however, the present study involved choices leading to multiple outcomes (e.g., delayed reinforcer and probabilistic punisher). Because creating a novel discounting model that involves multiple outcomes is beyond the scope of this translational study and we do not necessarily need such a sophisticated model to answer our experimental question of whether delay and probability interact, we separately fitted delay and probability data to Equation (1).

[2]We also calculated AUC values for all 10 cases (5 delay discounting and 5 probability discounting) based on the log-based method described in Borges, Kuang, Milhorn, and Yi (2016). These $\text{AUC}_{\log d}$ were strongly correlated with the AUC values based on the method described in Myerson et al. (2001). Across the delays to the destination and the likelihood of a motor vehicle crash, the average Pearson correlation coefficient is 0.94 (SD = 0.06).

[3]Recall that in case of probability discounting of a punisher, discounting means that the averseness of the punisher (e.g., motor vehicle crash) is devalued (decreased) as the *increase* in odds against receiving it (or the *decrease* in the probability of receiving it).

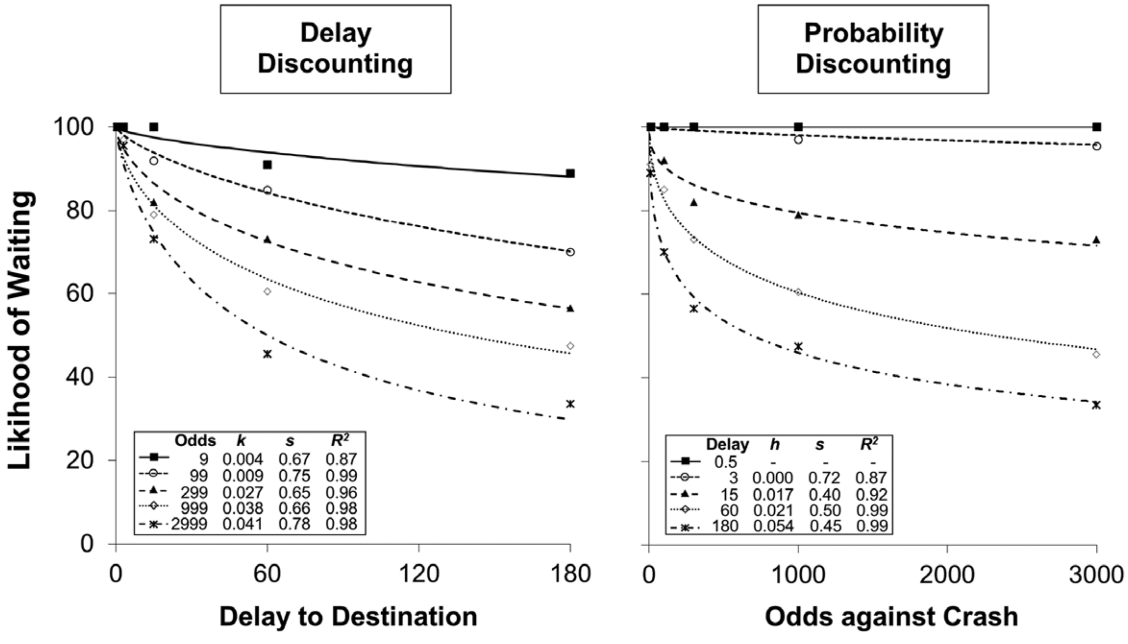

Fig. 1. Median likelihood of waiting to reply to a text message as a function of delay to the destination (left panel) and odds against crashes (right panel). The equation was not fitted to the data when no discounting was observed for probability discounting at the delay of 0.5 min.

Figure 2 shows box plots of AUC of individual participants for delay discounting (left panel) and probability discounting (right panel) as a function of delay to the destination and odds against crash, respectively. The comparison of delay discounting across values of odds against crashes indicates that the degree of delay discounting increased (i.e., the AUC values decreased) as odds against crashes increased. The Friedman test revealed a statistically significant difference: $\chi^2(4) = 68.40$, $p < .001$. A similar pattern of changes was observed with probability discounting: The degree of probability discounting increased as delay to the destination increased. The Friedman test revealed a statistically significant difference: $\chi^2(4) = 84.65$, $p < .001$.

Two correlational analyses were conducted to examine the relations between the frequencies of texting while driving and the delay and probability discounting rates. First, Figure 3 shows scatter plots depicting the relations between TWD frequencies and both AUC measures for delay and probability discounting. Note that rank-converted data are plotted because the data are not normally distributed and these plots are consistent with the Spearman's rho correlations (discussed below). AUC measures are averages of all odds (for delay discounting) or delays (for probability discounting). There are moderate negative correlations between the AUC measures and TWD frequencies, indicating that rates of delay and probability discounting were a direct function of TWD frequencies.

Second, Table 1 shows Spearman correlation coefficients (Spearman's rho) of the demographic characteristics, frequencies of texting while driving (while driving at any speed and while stopped at a red light separately), and the two AUC measures. Consistent with the data in Figure 3, both AUC measures were significantly correlated with both measures of frequencies of texting while driving (ps < .05). Controlling for all four demographic variables, the frequency of texting while driving at any speed was significantly negatively correlated with the mean AUC of delay discounting, $\rho(73) = -.57$, $p < .001$; and the mean AUC of probability discounting, $\rho(73) = -.53$, $p < .001$. Similarly, the frequency of texting while stopped at a red light was

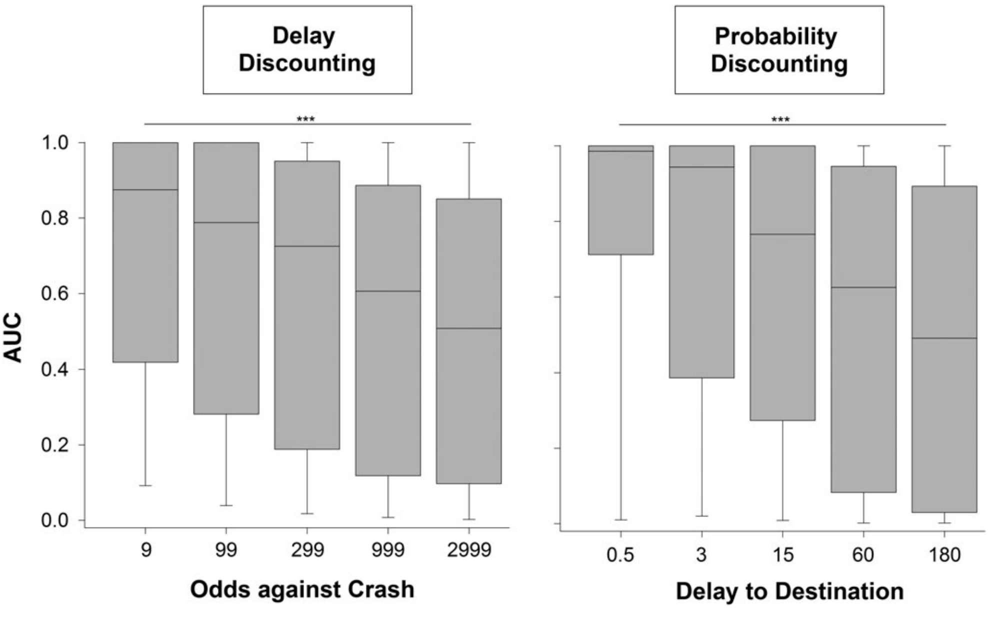

Fig. 2. Box plots of area under the curve (AUC) of individual participants for delay discounting (left panel) and probability discounting (right panel) as a function of delay to the destination and odds against crash, respectively. Each box represents the interquartile range (25th and 75th percentile) and the horizontal line within the box indicates the median value. Bottom and top bars of the whisker indicate the 10th and 90th percentiles, respectively. $^{***}p < .001$.

significantly negatively correlated with the mean AUC of delay discounting, $\rho(73) = -.42$, $p < .001$; and the mean AUC of probability discounting, $\rho(73) = -.41$, $p < .001$. Two other notable correlations are: between the mean AUC of delay discounting and that of probability discounting, $\rho(73) = .93$, $p < .001$; and between the frequency of texting while driving at any speed and that while stopped at a red light, $\rho(73) = .71$, $p < .001$.

Discussion

The overarching goal of the present study was to demonstrate the utility of use-inspired basic research in understanding the behavioral mechanism underlying texting while driving. To this end, we developed a novel delay and probability discounting task using a hypothetical scenario that presented several delays to the destination and probabilities of a motor vehicle crash. The participants rated their likelihood of immediately replying to a text message received while driving versus waiting to reply until arriving at the destination given a particular delay and probability. The likelihood of waiting decreased as a function of both delay to the destination and the probability of a motor vehicle crash. In addition, these decreases were well described by Rachlin's (2006) hyperboloid discounting function, suggesting that both delay and probability discounting are important underlying mechanisms of a driver's decision to text while driving. Self-reported higher frequencies of texting while driving were associated with greater rates of delay and probability discounting, further supporting the importance of the discounting processes in texting while driving. Finally, the delay to the destination and the probability of a motor vehicle crash interact on their effects on the decision to text while driving: Rates of delay discounting were altered as a function of the probability of a motor vehicle crash and rates of probability discounting were altered as a function of the delay to the destination.

Consistent with the previous study (Hayashi et al., 2016), the present results show that delay is a critical variable in drivers' decision to engage in texting while driving: Adding a relatively short delay (e.g., 15 min) could greatly reduce the likelihood of waiting,

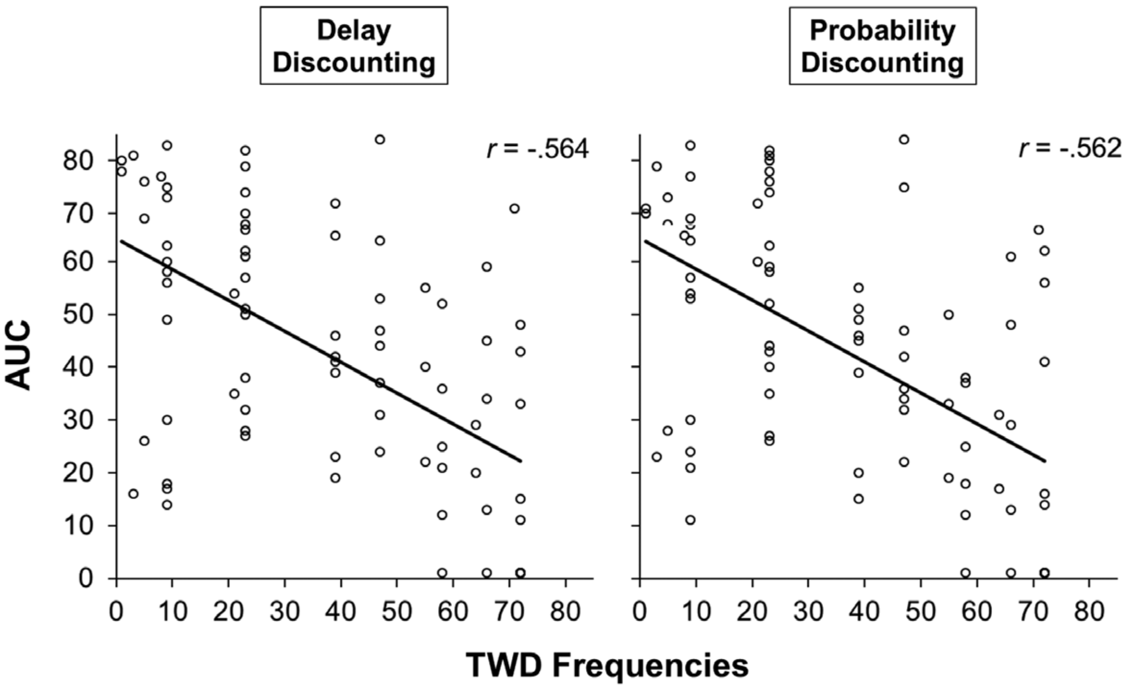

Fig. 3. Scatter plots showing the relations between AUC measures and TWD frequency. Note that rank-converted data are plotted ($N = 84$). AUC measures are averages of all odds (for delay discounting) or delays (for probability discounting).

particularly when the probability of a crash was lower (i.e., odds against a crash was greater).[4] More importantly, the present study extends the previous study by demonstrating that probability of a motor vehicle crash is also a critical variable in texting while driving: Decreases in the probability of a motor vehicle crash systematically reduced the likelihood of waiting. Taken together with the finding that rates of both delay and probability discounting were significantly associated with the frequencies of texting while driving, it appears that the novel delay and probability discounting task developed in the present study provided a meaningful assessment of texting while driving and that the multiple-discounting-modes approach (Reynolds & Schiffbauer, 2004) is useful in modeling the complex nature of texting while driving.

Previous studies involving a delayed and probabilistic monetary reinforcer showed that rates of delay discounting were affected by the probability but not vice versa (e.g., Vanderveldt et al., 2015). In contrast, the present study, which involved a delayed reinforcer and a probabilistic punisher involved in texting while driving, showed that rates of delay discounting were affected by the probability, and rates of probability discounting were affected by the delay. Taken together, these findings suggest that the effects of delay and probability on each other depend on other variables, such as the types of outcomes (e.g., reinforcers vs. punishers) and types of scenarios or contexts (e.g., pecuniary vs. nonpecuniary). A delayed reinforcer and a probabilistic punisher were employed in the present study, whereas a

[4]Although the participants reported they were less likely to reply to a text message during short trips and most drives are short trips (cf. the average driver takes approximately 3 trips per day at an average 9.75 miles per trip; U.S. Department of Transportation, 2009), this does not mean that these participants are at no risk of a motor vehicle crash due to texting while driving. As shown in Figure 1, the median likelihood of replying to a text message was 8 (cf. the likelihood of waiting: 92) even when the delay to the destination was as short as 15 min and the estimated probability of a crash was as high as 1%. Despite the probability of a crash for each text received is very small under this condition (0.0008%), the cumulative effect of these small probabilities at a societal level would be nonnegligible.

Table 1

Spearman correlation and partial correlation coefficients of demographic characteristics and discounting measures

	1	2	3	4	5	6	7	8
1. Age in years	-							
2. Gender (F = 0)	**.34**	-						
3. Years of higher education	**.64**	**.22**	-					
4. Years driving	**.55**	**.28**	.34	-				
5. TWD frequency (driving)	-.07	.10	-.17	.13	-			
6. TWD frequency (stopped)	-.06	.09	-.14	.10	**.73**	-		
					(.71)	-		
7. AUC (DD)	.10	.10	.20	**-.22**	**-.60**	**-.46**	-	
					(-.57)	**(-.42)**	-	
8. AUC (PD)	.13	-.03	**.26**	-.21	**-.58**	**-.45**	**.94**	-
					(-.53)	**(-.41)**	**(.93)**	-

Note. The numbers in parentheses are partial correlation coefficients with the demographics controlled for. The numbers in bold indicate significant correlations ($p < .05$). TWD = texting while driving. AUC = Area under the Curve. DD = delay discounting. PD = probability discounting.

delayed and probabilistic reinforcer was employed in the previous studies. Also, a hypothetical texting scenario was employed in the present study, whereas a hypothetical monetary scenario was employed in the previous studies. To better understand the relation between delay and probability, further study is needed to elucidate the variables responsible for the difference across studies.

Some limitations of the present study are noteworthy. First, the present study employed self-reported data on frequencies of texting while driving. It is possible that the accuracy of the self-report measure was influenced by the social desirability bias—the tendency to underreport socially inappropriate behavior (Nederhof, 1985). Another limitation is the use of hypothetical scenarios in that previous research on risk-taking have shown that individuals generally tend to take more risks with hypothetical outcomes (e.g., Irwin, McClelland, & Schulze, 1992). Therefore, it is ideal for future research to correlate the performance on the delay and probability discounting task to actual texting behavior. For example, observational data of texting while driving may be collected using an on-board camera (e.g., Klauer et al., 2014). Another approach is to develop a smartphone application that detects text messages sent while driving and automatically records them, although this technology cannot separate messages sent by a driver versus those sent by a passenger. If the performance on the delay and probability discounting task is shown to reliably predict frequencies of actual texting while driving (i.e., the task possesses predictive validity), the usefulness of the task would be greatly enhanced.

Toward Translational Science of Texting while Driving

The primary role of the present use-inspired basic study (or preclinical study in NCATS's term) is to connect basic science to the problem of texting while driving by applying fundamental discoveries in basic research to further understand the basis of the problem and find ways to solve it (NCATS, 2015). It is important to note that this is only an initial step toward the development of the entire translational scientific program on texting while driving. Along with this view, there are some important steps that future research should address to achieve the endpoint of the spectrum of solving the public health challenge.

First, although the task developed in the present study appeared to properly simulate multiple behavioral processes in relation to texting while driving, it is critical for future research to further establish the validity and reliability of the delay and probability discounting task. To this end, it is important to assess the construct validity of the present discounting task by testing whether a variable that presumably affects texting while driving, such as speed of driving and experience of a motor vehicle crash or near miss, can actually affect the performance in this task.

Another important direction for future research is to assess the test–retest reliability of the task (cf. Johnson & Bruner, 2013). In order for the task to be useful for investigating the effects of a potential intervention, it is critical that the task can produce a reliable measure of discounting when the assessment is repeated. Finally, because the present sample exclusively consisted of college students, the generalizability of the present finding (i.e., external validity) needs to be assessed by recruiting a more diverse sample of drivers. For example, future studies should compare delay and probability discounting between younger and older drivers, and drivers who do and do not drive for work. This is particularly important because young drivers are more likely to underestimate the probability of traffic hazards (Deery, 1999).

Once the present delay and probability discounting task is shown to be valid and reliable, it can serve as a powerful research tool (cf. Sigurdsson, Taylor, & Wirth, 2013) that can reveal important variables that affect texting while driving. This is an important next step toward development of effective intervention strategies. The greatest advantage of developing a valid and reliable research tool is that we can utilize an experimental approach, in which a variable of interest is manipulated and its effects on choices related to texting while driving can be analyzed. For example, the effectiveness of the methods of narrative theory, which "harness humans' unique sensitivity to language and storytelling to influence decision making" (Bickel et al., 2017), in reducing texting while driving can be evaluated in a simulation study that uses hypothetical scenarios (see Quisenberry, Eddy, Patterson, Franck, & Bickel, 2015, for an example in risky sexual behavior). Conducting simulation studies at this stage in translation is often warranted due to practical concerns (e.g., time and cost). Once potentially important variables are identified, the research program can proceed to the next stage of translation, in which effectiveness and safety of an intervention can be tested.

As mentioned previously, the translational science spectrum is bi-directional. That is, translation can be done either from bench to bedside or bedside to bench (cf. McIlvane et al., 2011). As an example of a bedside-to-bench translation, the present finding that two outcomes (a delayed reinforcer and a probabilistic punisher) interact on their effects on the choice of engaging in texting while driving calls for more basic research on choice involving positive and negative outcomes. In a review paper on delay and probability discounting published more than 10 years ago, Green and Myerson (2004) claimed, "Another important topic for future research concerns outcomes that combine positive and negative attributes. Such combinations are exemplified by many everyday situations" (p. 788). Nevertheless, the empirical evidence in this important area is still sparse. To better understand such complex choices and to promote adaptive choices in our everyday situations, further basic research in this area is of great significance, which can generate another round of translation (McIlvane et al., 2011).

Conclusion: Toward General Understanding of Impulsive Behavior

We believe that the translational scientific research program on texting while driving has some important implications to other impulsivity-related problems. Although unique characteristics of texting while driving are not negligible, and we should refrain from uncritical generalization across research areas, there is growing evidence suggesting that excessive discounting is not exclusive to a particular impulsivity-related problem. Rather, excess discounting is considered as *transdisease process*—a general decision-making bias that underlies a range of impulsivity-related problems, such as drug addiction, pathological gambling, obesity, and other various risky and unhealthy behaviors (Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012). A similar argument was made regarding executive function—cognitive abilities for adaptive functioning that allow for goal-oriented, flexible, and autonomous behavior (Spinella, 2005). As with excessive discounting, impaired executive function has been shown to be associated with addictive disorders, such as substance abuse (Goldstein & Volkow, 2011), pathological gambling (Reid, McKittrick, Davtian, & Fong, 2012), and most notably, texting while driving (Hayashi, Foreman, Friedel, & Wirth, 2018; Hayashi, Rivera, Modico, Foreman, & Wirth, 2017). In this manner, both excessive discounting and impaired executive function occur across various impulsivity-related problems, suggesting that they may be transdisease processes. Support for this also comes from the shared neural mechanism. Self-controlled decisions, an opposite of impulsive decisions, are shown to be associated with relatively greater activity in executive control centers of the brain such as the lateral prefrontal cortex (e.g., McClure, Laibson, Loewenstein, & Cohen, 2004). Similarly, executive function depends on neural circuits involving regions in the prefrontal cortex (e.g., the lateral areas) and thus referred to as neurocognitive (Zelazo, Blair, & Willoughby, 2016).

An important implication from the transdisease-process perspective is that "empirical and theoretical advances from one disorder can shape the theoretical lens through which we view other related disorders" (Bickel, Jarmolowicz, Mueller, Gatchalian, & McClure, 2012). That is, advances in understanding one transdisease process in one problem may be utilized to understand and treat other problems. Indeed, some evidence shows that reducing impulsive decision making in one realm reduced impulsive decision making in another realm (Black & Rosen, 2011). In this sense, the translational scientific research program proposed in this study may be beneficial not only for the prevention and intervention strategies for texting while driving but also for other public health challenges associated with impulsive choice.

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