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The Roles of Delay and Probability Discounting in Texting while Driving: Toward the Development of a Translational Scientific Program

Yusuke Hayashi,
Pennsylvania State University, Hazleton

Heather J. Fessler,
Pennsylvania State University, Hazleton

Jonathan E. Friedel,
National Institute for Occupational Safety and Health

Anne M. Foreman, and
National Institute for Occupational Safety and Health

Oliver Wirth
National Institute for Occupational Safety and Health

Abstract

The overarching goal of the present study was to demonstrate the utility of use-inspired basic research in understanding the behavioral mechanism of texting while driving. A sample of 109 college students completed a survey to assess how frequently they send or read text messages while driving. Based on this information, participants were grouped by those who frequently text while driving and those who infrequently text while driving. In a novel discounting task that involved a hypothetical scenario in which participants receive a text message while driving, participants 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 (range: 30 sec to 3 hours) and probabilities of a motor vehicle crash (range: 10% to 0.03%). The groups were compared on the extent to which they discounted opportunities to reply to a text message while driving. The likelihood of waiting to reply to a text message decreased as a function of both the delay until the destination and the probability of a motor vehicle crash; these decreases were well described by a hyperboloid discounting function. Drivers who self-reported a higher frequency of texting while driving showed greater rates of both delay and probability discounting. Finally, 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

Correspondence concerning this article should be addressed to Yusuke Hayashi, Division of Social Sciences and Education, Pennsylvania State University, Hazleton, PA 18202. yuh26@psu.edu.

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underlying mechanisms of drivers' decision to text while driving. Implications of this finding in relation to developing a translational scientific research program on texting while driving are discussed.

Keywords

Texting while driving; delay discounting; probability discounting; impulsivity; translational science; college students

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 46 states and the District of Columbia (Governors Highway Safety Association, 2017), 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 of turning observations in the laboratory, clinic and community into interventions that improve the health of individuals and the public" (NCATS, 2015, p. 2). Translational science can offer critical insights into the nature of the public health problem of texting while driving, which eventually leads to interventions that can prevent and reduce the problem. Our overarching goal in this paper is to demonstrate the utility of *use-inspired basic research*, which is defined as "basic research that seeks to extend the frontiers of understanding but is also inspired by considerations of use" (Stokes, 1997, p. 74), to understand the behavioral mechanism underlying texting while driving. We believe it is critical to first establish a solid connection between knowledge generated from basic science in decision making and the public health challenge of texting while driving. This is the important initial step towards the development of effective prevention and intervention strategies, which are the terminal point of the *translational science spectrum* (NCATS, 2015).

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). Often, a major focus of behavioral economic research is to understand the nature of rational and irrational decision making (MacKillop et al., 2011). 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 this conceptualization. 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 (Madden & Bickel, 2010). Using a delay-discounting task with hypothetical monetary outcomes, they 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 a reinforcer or a punisher as a function of the likelihood of its occurrence (Green & Myerson, 2010), is also critical in impulsive decision making. Delay and probability discounting are consistently, although weakly, correlated (e.g., Jarmolowicz, Bickel, Carter, Franck, & Mueller, 2012) and are not represented by a single construct (Green & Myerson, 2013). 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* impulsivity (i.e., problematic gamblers valued unlikely outcomes to a greater degree than non-problematic gamblers). No significant correlation, however, was found between the degree of probability discounting and severity of gambling among the sample that mostly consisted of non-problem 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. The 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 and the delay to the destination.

The second purpose of the present study was to investigate whether drivers who frequently text while driving would show greater probability discounting of an opportunity to reply to a text message than those who infrequently text 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. Two groups of participants that differed in terms of a frequency of texting while driving were compared on the extent to which they discounted the opportunity to reply to a text message while driving as a function of the probability of a motor vehicle crash. 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, defined as “conceptualizing a single choice in terms of different but 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 the case with the decision-making process underlying texting while driving. In order for this use-inspired basic research to be useful, it is vital to fully appreciate the complexity of the processes involved in texting while driving and to select a realistic choice model. As Reynolds and Schiffbauer stated, “future attempts to predict safe or unsafe behaviors will be enhanced by the use of a multifactor choice model that includes multiple modes of discounting” (p. 241).

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 hours). 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 delay discounting and the degree of 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 based 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, a horizontal line labeled from 0 to 100 in increments of 10 with the descriptive anchors *definitely reply now* on the left side and *definitely wait* on the right side, was located immediately below the instruction. 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).

Group Assignment and Data Analysis

Based on the mean ratings of (a) typing and reading while driving at any speed (see above for details) and then (b) typing and reading while stopped at a red light, the participants were stratified into two groups: the TWD group (upper half of scores, $n = 42$) and the Non-TWD group (lower half of scores, $n = 42$). In this process, four participants reported the exact same mean ratings across both scales, so one participant was assigned to the Non-TWD group so that the group sizes were equal. The participant who was assigned to the Non-TWD group was determined by computer-generated random numbers.

For demographic measures, gender was analyzed with a chi-squared test. Other continuous variables were analyzed with the Mann-Whitney U test because the data were not normally distributed. For years driving, five participants provided invalid information (e.g., an 18-year-old participant had driven with a valid driver's license for 15 years) and their data were excluded when calculating the median and conducting a correlational analysis (described below). For the delay and probability discounting assessment, Equation 1 was fitted to group data using least squares nonlinear regression performed with the Solver function in Microsoft Excel 2016. To compare the degree of delay and probability discounting across groups as well as across the values of odds against crashes and delay to the destination, the area under the curve (AUC), a descriptive, non-theoretical measure of discounting, was calculated according to the method described by Myerson, Green, and Warusawitharana (2001). The comparison of the AUC values across groups was performed with the Mann-Whitney U test because the data were not normally distributed. The comparison of the AUC values across values of odds against crashes and delay to the destination was performed with the Friedman test. Post-hoc pairwise comparisons were conducted using the Dunn-Bonferroni test (Dunn, 1964) with Bonferroni corrections for multiple comparisons. 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 summary discounting measures

(AUC of delay discounting averaged across all values of odds against crashes and AUC of probability discounting averaged across all values of delay to the destination) 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 discounting 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

Table 1 shows the demographic characteristics and frequencies of texting while driving. No significant differences among groups were found for gender, $\chi^2(1) = 1.25$, $p = 0.246$; age, $U = 782.50$, $p = .342$; years of higher education, $U = 698.50$, $p = .085$; or years driving, $U = 883.00$, $p = .307$.

Figure 1 shows the median likelihood of waiting to reply to a text message in the TWD group (left panels) and the Non-TWD group (right panels). The top panels show delay discounting at each odds and the bottom panels show probability discounting at each delay. The curved lines represent the fits of the hyperboloid discounting functions (Equation 1). Note that each of the five curves in the top panels shows delay discounting at a different odds of a car crash, and each of the five curves in the bottom panels shows probability discounting at a different delay to arriving at the destination.

For both groups, the likelihood of waiting decreased as a function of delay to the destination and odds against crashes, suggesting that the value of the opportunity to reply to a text message as a social reinforcer is subject to delay and probability discounting. With respect to the goodness of the fits of the equation, the R^2 values are generally high (ranged from 0.82 to 1.00). Second, the rates of delay discounting were a direct function of odds against crashes: the larger odds against crashes, the greater delay discounting. The rates of probability discounting were also a direct function of delay to the destination: the larger delay to the destination, the greater probability discounting. Finally, the rates of both delay and probability discounting were much greater in the TWD group at each level of odds against crashes and delay to the destination, respectively.

To further analyze the difference between groups as well as to examine the effects of the interaction of delay and probability on discounting, AUC was calculated based on the data obtained from each participant. Figure 2 shows median AUC of delay discounting (top panel) and probability discounting (bottom panel) as a function of delay to the destination and odds against crash, respectively. First, consistent with Figure 1, the degree of delay discounting at all values of odds against crashes was greater (i.e., the AUC values were smaller) for the TWD group than for the Non-TWD group. Particularly, the difference between groups was greater at higher values of odds against crashes (e.g., odds against crash of 2999). The Mann-Whitney U tests revealed statistically significant differences between groups at all values of odds against crashes (*ps* $< .05$. See Table 2). A similar pattern of differences was observed with probability discounting, with the exception that the difference between groups was smaller at smaller values of delay to the destination (e.g., 0.5 min delay to the destination). The Mann-Whitney U tests revealed statistically significant differences between groups at all values of delay to the destination (*ps* $< .05$. See Table 2).

Second, the comparison of delay discounting across values of odds against crashes indicates that, for both groups, the degree of delay discounting increased (i.e., the AUC values decreased) as odds against crashes increased. Particularly, the change was greater for the TWD group: The decrease in the AUC value from the first to the fifth odds against crashes was 0.54 and 0.19 for the TWD and the Non-TWD groups, respectively. The Friedman test revealed a statistically significant difference for both groups: $\chi^2(4) = 72.05$, $p < .001$ for the TWD group and $\chi^2(4) = 17.05$, $p = .002$ for the Non-TWD group. The results of the post-hoc comparisons are shown on Table 3. A similar pattern of changes was observed with probability discounting. First, the degree of probability discounting increased (i.e., the AUC values decreased) as delay to the destination increased. Second, the change was greater for the TWD group: The decrease in the AUC value from the first to the fifth delay to the destination was 0.87 and 0.31 for the TWD and the Non-TWD groups, respectively. The Friedman test revealed a statistically significant difference for both groups: $\chi^2(4) = 55.34$, $p < .001$ for the TWD group and $\chi^2(4) = 24.02$, $p < .001$ for the Non-TWD group (see Table 3 for the results of the post-hoc comparisons).

Table 4 shows Spearman correlation coefficients (Spearman's rho) of the demographic characteristics, frequencies of texting while driving, and the discounting measures. Consistent with the data in Figure 1, both discounting measures were significantly correlated with frequencies of texting while driving. 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 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 the hyperboloid discounting function, suggesting that both delay and probability discounting are an important underlying mechanism of driver's decision to text while driving. Drivers who self-reported a higher frequency of texting while driving showed 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) greatly reduced the likelihood of waiting in drivers who frequently text while driving, particularly when the probability of a crash was lower (i.e., odds against a crash was greater). 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 in both groups of drivers. Rates of both delay and probability discounting were greater for the group of drivers who frequently text while driving than drivers who infrequently text while driving, demonstrating that the assessment of discounting can successfully differentiate two groups (i.e., concurrent validity). Taken together, 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 reinforcer showed that rates of delay discounting were affected by the probability but not vice versa (e.g., Vanderveldt et al., 2015). On the other hand, the present study, which involved a delayed reinforcer and a probabilistic punisher, 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 versus punishers) and types of scenarios or contexts (e.g., hypothetical versus real; pecuniary versus nonpecuniary). A delayed reinforcer and a probabilistic punisher were employed in the present study, whereas a delayed and probabilistic reinforcer was employed in the previous studies. And 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.

At any rate, the present finding that there was an interaction of delay and probability on the decision to text while driving suggest that, to better understand the underlying behavioral mechanism of texting while driving, both delay to a destination and probability of a motor vehicle crash need to be taken into consideration. When the probability of a crash is lower (e.g., 0.03% or odds against a crash is 2999), drivers are more likely to make an impulsive choice (e.g., choosing an immediate opportunity to text at the risk of a crash), as shown by the greater degree of delay discounting at larger odds against a crash (the upper panel of Figure 2). Similarly, when the delay to a destination is larger (e.g., 180 min), drivers are more likely to underestimate the risk of a motor vehicle crash, as shown by the greater degree of probability discounting at larger delays (the lower panel of Figure 2). These patterns of discounting are observed in both groups of drivers (as shown by the significant difference in AUC of delay discounting across odds against a crash and AUC of probability discounting across delays to the destination). Nevertheless, the difference was more robust in the group of drivers who frequently text while driving. For delay discounting, the effect size (r) for the comparison between the odds against crash of 9 and 2999 was 1.12 and 0.42 for the TWD and Non-TWD groups, respectively (see Table 3). For probability discounting, the effect size for the comparison between the delays of 0.5 and 180 min was 0.88 and 0.43 for the TWD and Non-TWD groups, respectively. Taken together, these findings indicate that both delay and probability discounting play a critical role in texting while driving, which strongly supports the utility of the multiple-discounting-modes approach (Reynolds & Schiffbauer, 2004).

Toward Translational Science of Texting while Driving

We propose that the entire translational science endeavor aimed at addressing the public health challenge of texting while driving should take the form of a spectrum, which represents each stage of research along the path from basic science to interventions to improve public health (NCATS, 2015). This spectrum is not linear or unidirectional. That is, each stage of the spectrum builds upon and informs the others. The primary role of the present use-inspired basic study (or pre-clinical study in NCATS's term) is to connect basic science to the problem of texting while driving by "apply[ing] fundamental discoveries in the laboratory … to further understand the basis of [the problem] and find ways to treat it" (NCATS, 2015, p. 2). 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. One limitation of the present study is the use of self-reported data on frequencies of texting while driving. 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.

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, for example, 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 human’s 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 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

The primary goal of the present study was to demonstrate the utility of use-inspired basic research on texting while driving in the context of the translational science spectrum. To this end, a novel delay and probability discounting task was developed that provided a meaningful assessment of decision making underlying texting while driving. Although the validity and reliability of the assessment tool need to be further established, we believe the present study could set a path towards the translational scientific research program on the public health challenge of texting while driving, which contributes a novel perspective to the prevention and intervention strategies for texting while driving.

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 uncritical generalization across research areas should be refrained, there is growing evidence suggesting that excessive discounting is not exclusive to a particular impulsivity-related problem. Rather, excess discounting is considered as *trans-disease 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 allows 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, 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 trans-disease 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 center 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 trans-disease-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 trans-disease process in one problem may be utilized to understand and treat other problem. 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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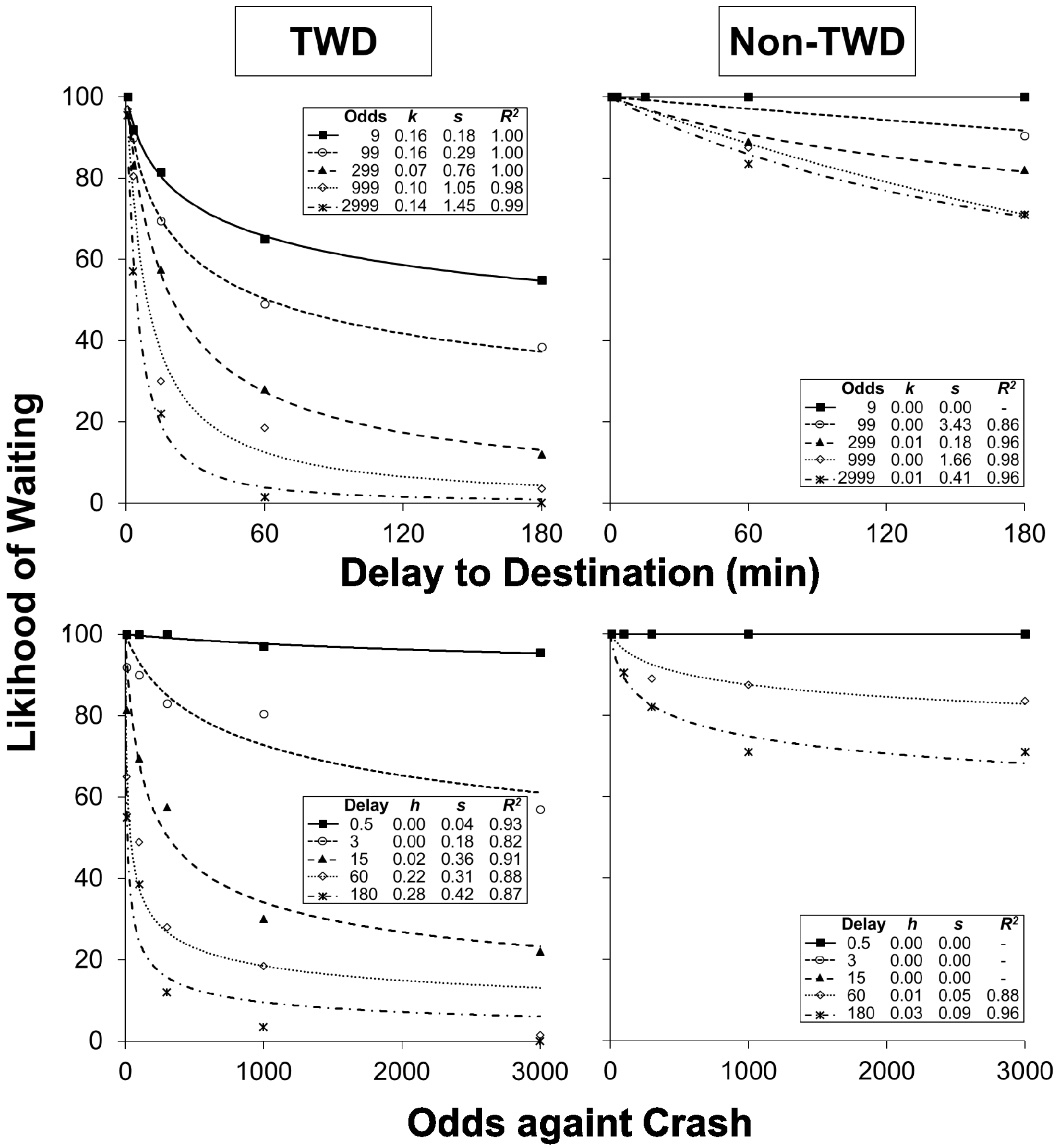

Figure 1.

Likelihood of waiting to reply to a text message as a function of delay to the destination (upper panels) and odds against crashes (lower panels) for students who frequently text while driving (TWD) and students who don't frequently text while driving (Non-TWD). Group medians are plotted with the hyperboloid delay-discounting function. For some conditions there was no decrease in the likelihood of replying to a text and the model fit the data perfectly (i.e., $V = A$). In these cases, R^2 values could not be calculated because the total sum of squares was 0. Nevertheless, the obtained and predicted values matched perfectly with the parameters shown above.

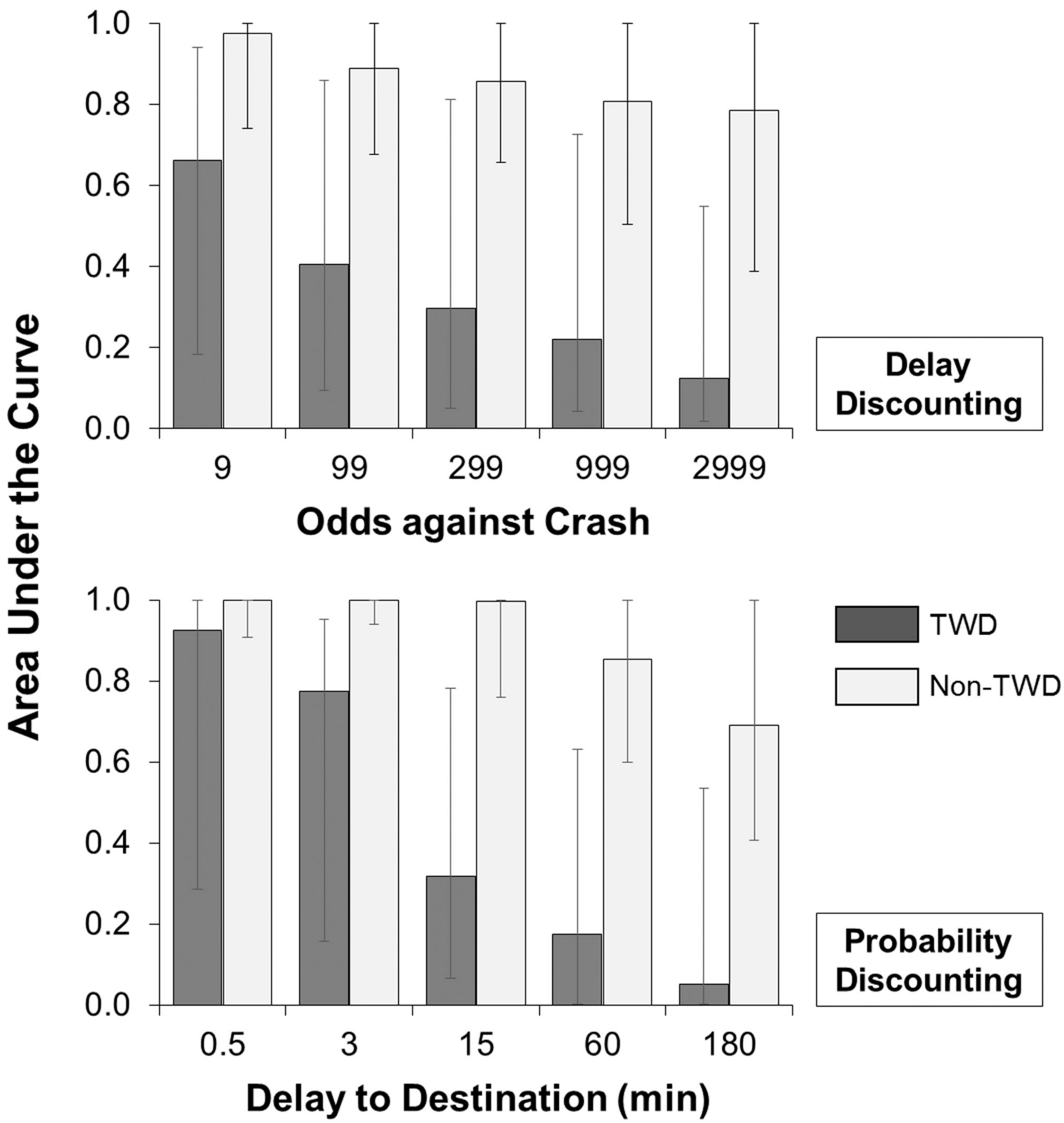

Figure 2.

Median area under the curve of delay discounting (top panel) and probability discounting (bottom panel) as a function of delay to the destination and odds against crash, respectively, for the TWD group (dark gray bars) and the Non-TWD group (light gray bars). Error bars represent 25th and 75th percentiles.

Table 1

Demographic Characteristics for Both Groups

Characteristics	TWD	Non-TWD
Gender		
Male	19	14
Female	23	28
Age in years	19.0 (1.0)	19.0 (1.0)
Years of higher education	0.5 (1.0)	1.0 (1.0)
Years driving	2.5 (1.8)	2.2 (1.9)
TWD frequency (driving)[a]	3.0 (1.0)	1.3 (1.0)
TWD frequency (stopped)[a]	3.8 (1.0)	2.0 (2.0)

Note. The numbers are medians (and interquartile ranges) except for Gender.

[a]Median differences depict the results of the stratification.

Table 2.

Comparisons of AUC of Delay and Probability Discounting across Two

	Delay Discounting				Probability Discounting		
Odds	***U***	***p***	***r***	**Delay**	***U***	***p***	***r***
9	508.50	.001	0.37	0.5	644.00	.025	0.24
99	462.50	< .001	0.41	3	455.50	< .001	0.43
299	407.00	< .001	0.47	15	337.50	< .001	0.54
999	381.50	< .001	0.49	60	342.50	< .001	0.53
2999	326.00	< .001	0.54	180	364.00	< .001	0.51

Table 3.

Post-Hoc Comparisons across Values of Odds against Crash and Delay to the Destination

		TWD			Non-TWD		
Discounting	**Comparison**	***Z***	***p***	***r***	***Z***	***p***	***r***
Delay	9 & 99	−2.00	.454	0.31	−0.28	1.000	0.04
	9 & 299	−3.83	.001	0.59	−0.55	1.000	0.09
	9 & 999	−5.38	< .001	0.83	−2.17	.297	0.34
	9 & 2999	−7.25	< .001	1.12	−2.70	.071	0.42
	99 & 299	−1.83	.674	0.28	−0.28	1.000	0.04
	99 & 999	−3.38	.007	0.52	−1.90	.577	0.29
	99 & 2999	−5.24	< .001	0.81	−2.42	.157	0.37
	299 & 999	−1.55	1.000	0.24	−1.62	1.000	0.25
	299 & 2999	−3.42	.006	0.53	−2.14	.324	0.33
	999 & 2999	−1.86	.624	0.29	−0.52	1.000	0.08
Probability	0.5 & 3	−0.90	1.000	0.14	−0.66	1.000	0.10
	0.5 & 15	−2.76	.058	0.43	−0.41	1.000	0.06
	0.5 & 60	−5.28	< .001	0.81	−1.79	.728	0.28
	0.5 & 180	−5.73	< .001	0.88	−2.76	.058	0.43
	3 & 15	−1.86	.624	0.29	−1.07	1.000	0.17
	3 & 60	−4.38	< .001	0.68	−2.45	.143	0.38
	3 & 180	−4.83	< .001	0.75	−3.42	.006	0.53
	15 & 60	−2.52	.118	0.39	−1.38	1.000	0.21
	15 & 180	−2.97	.030	0.46	−2.35	.190	0.36
	60 & 180	−0.45	1.000	0.07	−0.97	1.000	0.15

Note. *p* values have been adjusted by the Bonferroni correction.

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Table 4

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.