Contemporary Methods in Delayed Discounting: Applications for Suicidology with Simulation

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Abstract

Objective: This brief report presents an approach for integrating recently-developed methods in behavioral economics into suicidology research. At present, existing applications of delay discounting in suicidology have focused predominantly on hypothetical choices related to monetary value as a proxy to "risky" choices linked to unsafe or suicidal behavior. In this report, we outline a more targeted approach that directly indexes choices related to treatment in suicide prevention initiatives and also incorporates the strengths afforded by multilevel modeling. This more targeted approach precludes the need for multi-step comparisons (improving power), avoids compressing choice variability across delays into individual values (improving precision), and better accommodates decision-making and the upper and lower extremes (improving reliability). We present this approach within the context of a hypothetical decision-making task with simulated participants. This simulated study illustrates how this approach can be used to evaluate how individuals make temporally-delayed decisions related to treatment for suicidal behavior (i.e., temporarily limiting their access to firearms while undergoing treatment). The results of this simulated study are provided to illustrate how more advanced behavioral decision-making models can be used to supplement existing research methods in suicidology.

Keywords: discounting, behavioral economics, suicidal behavior, behavioral therapy

Introduction

Discounting, or delayed discounting, has been a construct of interest for various disciplines of the behavioral and social sciences (Amlung et al., 2019; Bickel et al., 2019; Vanderveldt, Oliveira, & Green, 2016). Discounting broadly refers to the phenomena whereby desired goods or events (i.e., rewards) lose relative value as they become more delayed. More often implicated in "implusive" patterns of decision-making, this framework has been applied to account for instances where individuals prefer smaller-immediate rewards over larger-delayed delayed ones. This framework has been used extensively across disciplines and among a range of decision-making contexts, such as food choice and obesity (Amlung, Petker, Jackson, Balodis, & MacKillop, 2016), unsafe sexual practices (Berry et al., 2018), adherence to medical treatments (Stoianova, Tampke, Lansing, & Stanger, 2018), and as an underlying (i.e., transdiagnostic) process observed across various psychiatric disorders (Amlung et al., 2019).

Although often incorporated in research on substance abuse and "risky" patterns of behavior (Amlung, Vedelago, Acker, Balodis, & MacKillop, 2017), the discounting framework has utility for quantifying risk for suicidal thoughts and behaviors (STBs) as well. That is, elevated rates of discounting have been linked to a variety of health conditions and psychiatric disorders related to suicide, such as borderline personality disorder and substance use disorders (Amlung et al., 2019). With respect to STBs specifically, Dombrovski et al. (2011) found that rates of discounting differentiated the levels of lethality (i.e., high vs. low) observed in attempts made by older adults. Specifically, individuals with higher rates of discounting (i.e., impulsivity) were observed to demonstrate less-lethal attempts (i.e., less planned) compared to attempters with relatively lower rates of discounting. Additionally, individual rates of discounting has also been linked to higher frequencies of suicide attempts (Mathias et al., 2011), family histories of suicidal behavior (Bridge et al., 2015), levels of risk for STBs in substance-dependent populations (Liu, Vassileva, Gonzalez, & Martin, 2012), and patterns of intertemporal choice immediately preceding and following a suicidal attempt (Cáceda et al., 2014). As such, the discounting framework has identified this phenomenon as a factor relevant to STBs. For a broad review of this topic in suicidology, such a review is provided in Dombrovski and Hallquist (2017).

Current Discounting Methodologies in Suicidology

A brief review of the discounting methods used in existing research on STBs revealed that the range of discounting methods and analyses has been limited in suicidology. Specifically, the tools used to evaluate this phenomenon in suicide-related research has been limited to the Delay Discounting Questionnaire task (DDQ; Richards et al. 1999), the Monetary Choice Questionnaire (MCQ; Kirby, Petry, & Bickel, 1999, and the Two Choice Impulsivity Paradigm (TCIP; Dougherty, Marsh, & Mathias, 2003). Shared among these tools, each evaluates how respondents come to make choices between smaller, sooner rewards (SSR) and larger, later rewards (LLR)—exclusively with monetary outcomes. For instance, a question posed here would likely take the form of the following: "Would you rather have $10 in 2 days (LLR) or $2 now (SSR)"?

Measuring Delayed Choices in Suicidology

Although the tools noted above have been used effectively to evaluate relationships between discounting and STBs (Dombrovski & Hallquist, 2017), these methods could be made both more sensitive and more robust by incorporated methods used in other domains, e.g. more robust modeling, more targeted questions (Young, 2017, 2018). With regard to the sensitivity to choices and STBs, the tools often used in suicidology have focused largely on choices related to monetary outcomes (e.g., $1 now or $10 in a week). While this manner of decision-making captures sensitivity to delays, the discounting framework can be applied to more directly evaluate choices relevant to STBs. For example, Swift and Callahan (2010) used a discounting framework but instead used symptom relief as the valued reward rather than some amount in dollars. Similarly, others have also customized this framework to target more specific contexts as well, with applications ranging from "green" initiatives and environmental sustainability (Arbuthnott, 2010), preventative medicine (Chapman & Coups, 1999), adherence to medical regimens (Bruce et al., 2018), and choice of behavioral treatments for children (Call, Reavis, McCracken, Gillespie, & Scheithauer, 2015). However, no established tools have been made specifically to target STBs using this framework.

Analyzing Delayed Choices in Suicidology

As noted earlier, the discounting methodology evaluates choices that differ across magnitudes (i.e., *larger* and later vs. *smaller* and sooner) and delays (Odum, 2011). Most often, discounting tasks are designed to identify a point of *indifference* (i.e., ordinate) for several accompanying delays (i.e., abscissa). Put simply, an *indifference point* refers to a delay and value combination (i.e., x/y coordinate) where the participant is *indifferent* to the relative superiority of the more delayed choices. That is, the participant would subjectively value both the SSR and LLR equally—differences in value and delays considered.

The process of determining indifference points involves reducing a series of participant choices at individual delays into a single, empirical value. The result of which is a series of coordinates that are then fitting to any number of discounting models (Doyle, 2013). Although this approach has been refined over time (Franck, Koffarnus, House, & Bickel, 2015; Frye, Galizio, Friedel, DeHart, & Odum, 2016; Gilroy, Franck, & Hantula, 2017), the reduction of a great many individual choices to several empirical coordinates presents with several limitations, e.g. loss of precision (Young, 2018).

Modern Behavioral Decision-Making Models

More modern methods for analyzing discounting have extended the methods noted above in several ways. First, multi-level (i.e., mixed or random effects) modeling has been recommended as a tool that better accommodates the range and variability of participant decision-making (Young, 2017). Regarding the range and variability of choices, multi-level modeling fares well in this situation because choices evaluated at the individual-level are informed by responding at the overall group-level (i.e., population-level estimate). That is, the hierarchical structure here has an added benefit of drawing more extreme values towards the overall mean—better accommodating potentially outlying values. Similarly, this approach supports a more streamlined analysis because the process of (1) fitting parameters to a model and (2) comparing parameters can be reduced to a single step (i.e., an interaction specified in the model) and this improves overall power and precision (Young, 2017).

Second, recent extensions of the discounting framework have avoided the reduction of various individual choices into singular points of indifference (Young, 2018). That is, the methodology has shifted from fitting models to empirical indifference points (i.e., reducing choices to a single value) to directly fitting models to individual choice (i.e., predicting the probability of LLR choices). Using a logistic framework, more research methods have avoided the need to calculate/evaluate indifference points altogether (Wileyto, Audrain-Mcgovern, Epstein, & Lerman, 2004; Young, 2018) and this has enhanced the analysis of delayed choices in several ways. The specific model presented in Young (2018), is shown below[1]:

[1] We note here that the $+\ 1$ added to the LL_{Delay} term is only necessary in cases where LL_{Delay} could take a zero value.

$$P(LLR) = \beta_{Magnitude} * \ln\left(\frac{LLR_{Magnitude}}{SSR_{Magnitude}}\right) - \beta_{Delay} * \ln\left(LLR_{Delay} + 1\right)$$

In this model, a participant's probability of choosing the LLR is jointly predicted by the relative differences in reward magnitude ($\beta_{Magnitude}$, i.e., the relative benefit of the larger response) as well as the relative differences in delay (β_{Delay}, i.e., the relative difference in time with respect to the later response). Whereas earlier discounting models focused predominantly on sensitivity to delays as a single parameter (*k*; i.e., magnitude and delay simultaneously), this method of modeling evaluates individuals are affected by relative differences in delays (i.e., sooner vs. later), relative differences in magnitude (i.e., smaller vs. larger), or some interaction of the two. In addition to parsing out the relative effects of delay and magnitude, directly evaluating the individual choices will always be the richer data set compared to indifference points (Young, 2018).

Modern Discounting Methods for Research in Suicidology

In this report, we illustrate the usage of the more modern discounting methods outlined above in a simulated study with theoretical importance to the suicidology literature. We present this hypothetical study as both a tutorial and potential template in hopes that it serves to support the use of more robust discounting methods in suicidology. Included here in this report is a decision-making task customized to a pertinent question in suicidology and applies multi-level logistic modeling to evaluate the effects of delays and reward magnitudes on choice. Specifically, this study focuses on choices related to the temporary removal of a firearm from the home for participants determined to be at risk for STBs.

The exploratory hypothesis presented here is not without rationale, as firearms account for half of the annual suicide deaths in the United States and firearm safety discussions are commonly encouraged in clinical interventions (Barber & Miller, 2014). While work in suicidology has explored firearm ownership (Goldberg et al., 2019) and its link to suicide risk (Houtsma, Butterworth, & Anestis, 2018), no research has evaluated decision-making related to the voluntary, temporary removal of firearms from the home (i.e., secured by friends or family). For instance, it is possible that those high risk for suicide may be particularly sensitive to the delays associated with the voluntary, temporary removal of firearms from the home (e.g., one week versus three months) (β_{Delay}). Alternatively, it is also possible that some may be less sensitive to delays and more sensitive to the relative benefits of temporarily removing their firearms from the home (removal is related to a 90% decrease in likelihood for suicide compared to a 45% decrease) ($\beta_{Magnitude}$). In this study, we simulate a hypothetical comparison of decision-making associated with two groups. Specifically, Group 1 was a hypothetical sample of individuals demonstrating STBs who owned firearms primary for protection and Group 2 was a hypothetical sample of individuals demonstrating STBs who owned firearms for sport (e.g., hunting or shooting sports). As such, the following hypothetical research questions were tested:

RQ1: To what degree do differences in risk reduction (i.e., relative benefits associated with choices) predict choices to agree to temporarily remove firearms from the home?

RQ2: To what degree do delays associated with the agreement to remove firearms predict choices to temporarily remove them from the home?

Methods

Simulated Participants

A total of 100 simulated decision-makers were generated across two groups using the R Statistical Program (R Core Team, 2017). Simulated series were generated using seed values to illustrate the differential influence of magnitude ($\beta_{Magnitude}$) and delay weights (β_{Delay}) on the probability of making a larger, delayed choice. To illustrate the effects of delays specifically, the seeded values for $\beta_{Magnitude}$ for Group 1 (*n* = 50) and Group 2 (*n* = 50) had a value of 2 and the seeded values for β_{Delay} were -2 and -1 for Group 1 and 2, respectively. The difference between the β_{Delay} values indicated that that one group would be 100% more sensitive to delays than the other. The $\beta_{Magnitude}$ weights here represented sensitivity to the relative difference in treatment outcomes related to the SSR/LLR choice (i.e., degree of safety). Both the β_{Delay} and $\beta_{Magnitude}$ weights were used to jointly determine the logit odds at each delay and magnitude ratio for simulated participants. These values were subsequently back-transformed into Binomial probability and used to simulate the probability of Waiting (1; LLR) or Not Waiting (0; SSR) using the *rbinom* package in R (R Core Team, 2017).[2]

Hypothetical Firearm Decision Task

A hypothetical firearm safety task was designed to evaluate the likelihood that a simulated participant at risk for suicide would voluntarily and temporarily limit their access to firearms in their home. Specifically, the options included here consisted of an immediate choice (i.e., SSR; do not limit access, little-to-no reduction of risk for suicide) and a delayed choice (i.e., LLR; limit access, significantly reduce risk for suicide). These choices were designed to be analogous to decisions presented to individuals found to be at risk for suicide and being offered a course of safety planning and/or means safety discussions. Specifically, the task was couched in the context of a clinician discussing if a patient would consider temporarily reducing their access to their firearms for some period (e.g., one week, one month, three months, etc.) while they undergo a course of therapy for about four months—the highest delay point simulated here.

[2] The full code necessary to replicate this simulation is provided under an open source license at https://www.github.com/miyamot0.

The task evaluated choices when both the relative benefits (i.e., magnitude ratio) and delays (i.e., weeks of therapy) were varied. The magnitude of each option was conceptualized as a reduction in risk (e.g., reduced risk of dying by suicide during treatment) and thus an improved treatment outcome. That is, the suboptimal Not Wait option (SSR) resulted in higher risk/less benefit while the optimal Wait option (LLR) resulted in lesser risk/greater benefit. Specifically, the relative magnitude ratios evaluated consisted of 1 (1:1, identical risk/benefit), 2 (2:1, the delayed option had 100% greater benefit), 4, and 8. Regarding delays, the delayed Not Wait choices included delays of 1, 2, 4, 8, and 16 weeks to represent both brief psychological interventions (e.g., suicide safety planning with a follow-up contact) and longer interventions (e.g., a potential course of brief cognitive behavioral therapy for suicide prevention; Rudd et al., 2015).

Analytical Plan

Simulated participant responding at the individual choice level was analyzed using a multi-level modeling approach (Young, 2018). Modeling was performed using the *glmer* method in the *lme4* package in the R Statistical Program (Bates, Mächler, Bolker, & Walker, 2014). Group membership was included as a predictor in the model and interactions between Group and Delay/Magnitude ratios. Individual intercepts were excluded because the estimate is predicted to be 0.5 when both Delay and Magnitude ratios were equal (i.e., ln(1/1) = 0; Young, 2018). Regarding random effect structure, individual slopes for $\beta_{Magnitude}$ and β_{Delay} were permitted to vary at the individual level, if indicated by likelihood ratio tests.

Results

RQ1: Reward Magnitude and Treatment Choice

The purpose of Research Question 1 was to determine to what degree differences in the magnitude of immediate/delayed choices –reduction in suicide risk - predicted choices to safely store firearms (i.e., LLR). The results from modeling are illustrated in Figure 1 and findings on individual factors are listed in Table 1.Wald Z-tests on the fitted multi-level logistic model indicated a significant fixed effect for Magnitude (β = 1.84988, Z = 15.947, p < .001). As such, the choice to wait (i.e., LLR) was more probable as the LL grew in relation to the SS, see the intercepts of the plots in Figure 1. This can be interpreted as the more a person's risk level was to be reduced by removing firearms (50% versus 75%), the more an individual agreed to the relocation of firearms. Additionally, there was not a significant interaction between Group and $\beta_{Magnitude}$ (β = 0.07928, Z = 0.495, p = .621). That is, the effect of reward magnitude on the choice to wait was not significantly different across hypothetical owners of firearms for protection (Group 1; $\beta_{Magnitude}$ = 1.85) and sport (Group 1; $\beta_{Magnitude}$ = 1.92).

RQ2: Delays and Treatment Choice

Research Question 2 was designed to investigate the degree to which the delays associated with the choice to temporarily remove firearms from the home were influenced that decision. Results are illustrated in Figure 1 and findings are also listed in Table 1. Wald Z-tests on the fitted multi-level logistic model indicated a significant fixed effect for Delay overall (β = -1.84458, Z = -17.565, p < .001). That is, the choice to wait was increasingly less probable as the proposed delays grew, see the decreasing probabilities plotted in Figure 1. This can be interpreted as the more a person was asked to temporarily remove access to firearms (8 versus 4 weeks), the less an individual agreed to the relocation of firearms. Further, there was a significant interaction between Group and β_{Delay} (β = 0.94033, Z = -7.501, p < .001). That is, the effect of delays on the choice to temporarily remove firearms was significantly greater for hypothetical owners of firearms for protection (Group 1; $\beta_{Magnitude}$ = -1.84) than for hypothetical owners of firearms for sport (Group 2; $\beta_{Magnitude}$ = -0.91).

Discussion

The purpose of this brief report was to present and evaluate novel methods for evaluating choice behavior in the context of suicidology research. The simulated experiment serves as an example of how recent advances in the discounting framework could be incorporated into applied research on decision-making in suicidology. For instance, it is common in clinical practice with high-risk patients to assess for and discuss firearms ownership and storage practices (Chu et al., 2015). Specific techniques for having this discussion with patients are included in suicide-specific care interventions, such as suicide safety planning (Stanley & Brown, 2012), brief cognitive-behavioral therapy (BCBT; Rudd et al., 2015), motivational interviewing (Britton, Bryan, & Valenstein, 2016), and the Collaborative Assessment and Management of Suicidality (CAMS; Jobes, 2016). In these interventions, safety discussions are done collaboratively with a focus on negotiating safe practices for a brief period of time while suicide risk is elevated (or longer). With respect to CAMS, the first session finalizes with the collaborative creation of a treatment plan to reduce suicide drivers (Jobes, 2016; Tucker, Crowley, Davidson, & Gutierrez, 2015). In order to provide hope and realistic expectations for treatment success, the provider indicates how long they think it would take to reduce the patient's driver and thus gain relief. The provider is encouraged to ask the patient to "take suicide off the table" for the specified duration to increase internal motivation and further assess outpatient safety. Knowledge of an individual's sensitivity to delayed outcomes may aid in establishing this duration, rather than relying on clinical judgment and/or the predicted length of intervention.

In addition to evaluating factors underpinning choice (e.g., delays), discounting phenomena have also been targeted more directly using behavioral intervention. That is, individual sensitivity to delays has been found to decrease after specific forms of intervention. For example, practices such as Acceptance and Commitment Therapy (Morrison, Madden, Odum, Friedel, & Twohig, 2014) and Episodic Future Thinking have been found to reduce rates of discounting in clinical populations (Daniel, Said, Stanton, & Epstein, 2015; Stein, Tegge, Turner, & Bickel, 2018) and nonclinical populations (Bromberg, Lobatcheva, & Peters, 2017). Should individual discounting emerge as a factor relevant to subgroups of those demonstrating STBs, these treatment elements could serve as adjuncts that enhance the efficacy of existing treatment approaches (and overall sensitivity to delayed outcomes).

Although the specific approach presented here is novel to suicidology, it warrants noting that other applied researchers have successfully adapted discounting methods to evaluate treatment-related choice. For example, Swift and Callahan (2010) adapted this framework to evaluate choices related to treatment discontinuation. In this study, authors evaluated the extent to which patients would tolerate delays to symptom reduction throughout the course of treatment (e.g., "I would stop attending therapy if it took 12 weeks for me to feel better"). In keeping with this example, a suicide-specific replication of these efforts could help determine how long at-risk individuals perceive their likelihood of engaging in outpatient interventions to reduce suicide risk and have important implications for suicide-specific interventions.

Beyond discounting due to delays, this framework can be applied to odds or probability. For example, Bruce et al. (2018) leveraged a probability discounting approach to identify how the probability of negative side effects influenced adherence to a medication regimen in Multiple Sclerosis. Drawing from this example, probability discounting (i.e., decisions influenced by the probability of undesired effects) also has relevance to suicidology. For instance, this methodology could be used to evaluate why many of those experiencing suicidal thoughts do not use crisis services such as the suicide prevention lifeline. Jaroszewski, Morris, and Nock (2019) demonstrated that less than 30% of young adults and adolescents exhibiting indicators of a suicidal crisis wanted to interact with a crisis chat service. Reasons identified included concerns about police involvement and a discussion of suicidal thoughts would be too intense. Adapting the probabilistic discounting paradigm, one could jointly evaluate how individuals experiencing STBs make decisions when balancing the probability that treatment will produce benefits (e.g., suicidal thoughts are 85% as strong as they could be) and potential side effects (e.g., 50% chance of potential police involvement). Similar adaptions could also be made to understand tolerance of broken anonymity (e.g., 80% likelihood that your family and friends would find out you used the services). Although these adaptations may seem contrived, testing assumptions about suicide stigma and the role it plays in help-seeking is certainly necessary to understand clinical and public health interventions. Probabilistic discounting is one tool to aid in this line of study.

A final potential application for probabilistic discounting transcends its relevance to the decision making of those experiencing STBs. Gatekeeper prevention initiatives such as Question Persuade Refer (QPR; Mitchell et al., 2013) are commonly used in public health and community level suicide prevention efforts. In these interventions, lay individuals are provided skills to recognize suicide risk, discuss thoughts of suicide with others, and help individuals experiencing suicidal thoughts get to professional help. Despite widespread usage, empirical studies do not provide clear indication of their efficacy (Isaac et al., 2009). One way in which the efficacy of gatekeeping interventions can be diluted is if trained individuals do not apply their skills. It could be that some gatekeepers do not want to ask others about suicidal thoughts for a variety of reasons, including fear of being wrong (e.g., I would be hesitant to ask if I thought there was a 30% chance I was wrong), closeness of the identified individual (e.g., I would be hesitant to ask a good friend [stranger, coworker] if I thought there was a 10% chance I was wrong), and even mode of communication (e.g., "I would be 75% likely to ask a good friend [stranger, coworker] about thoughts of suicide over the phone [in person]). Further understanding a gatekeepers perceptions of when they would use their acquired skills could help delineate changes to trainings and protocols that could enhance likelihood gatekeeping conversations are enacted following training.

Limitations

Although the methods provided here are in keeping with recent advances within the discounting framework, several aspects of this approach warrant noting. First, the use of multilevel modeling and logistic methods significantly increase the overall complexity of the analysis (Young, 2018). Second, reports provided by respondents are purely hypothetical and it is unclear to what degree individual self-report regarding suicidal thinking and perceived risk corresponds to suicides and attempts. However, these limitations have not halted the application of the discounting framework across domains and across species (Vanderveldt et al., 2016). As such, we believe the extension of this approach to decisions related to suicide is both timely and warranted. Through further exploration of decision-making, including discounting processes, suicidologists can better understand why people die by suicide (Dombrovski & Hallquist, 2017) as well as design more effective prevention strategies (Bauer, Tucker, & Capron, 2019). However, continued work in this area will require numerous demonstrations to validate and refine these novel applications. It is our hope that the simulated study and discussion above not only provide a “tutorial” to apply the discounting methodology but also encourage creative adaptions to yet unstudied decisions that may influence suicide prevention (e.g., the decision to store a firearm safely).

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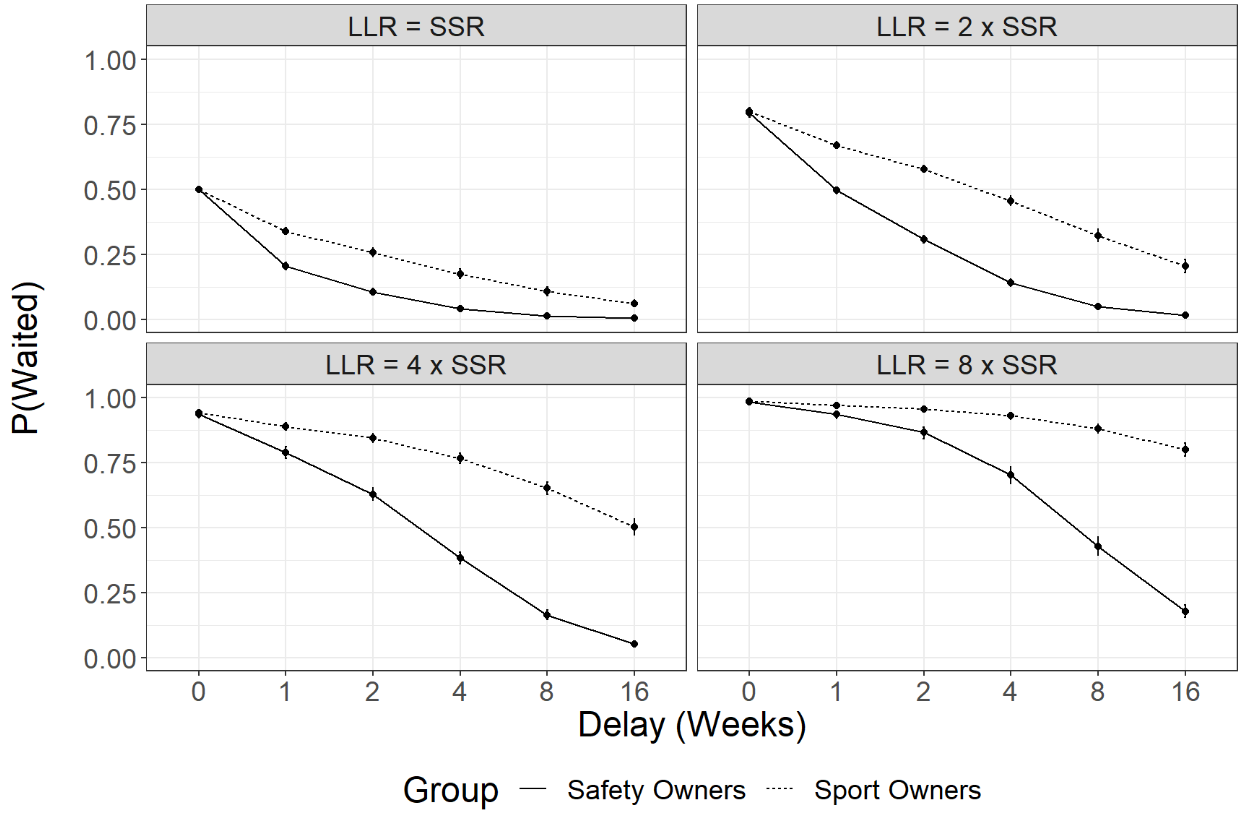
Table 1

Results of Wald Z-test

Factor	**β (SE)**	**Z**	***p***
Magnitude	1.84988 (0.11600)	15.947	< 2e-16 *
Delay	-1.84458 (0.10501)	-17.565	< 2e-16 *
Group x Magnitude	0.07928 (0.16030)	0.495	0.621
Group x Delay	0.94033 (0.12535)	7.501	6.32e-14 *

*: Significant at p < .001

Figure 1. Simulation Results



This figure depicts the predicted probability making a choice to wait (i.e., the more optimal choice) across the two groups. These results indicate that Group 2 was consistently less likely to wait when relative delays were larger and when the differences between choices were smaller.