Published in final edited form as:

Am J Drug Alcohol Abuse. 2017 May ; 43(3): 234–236. doi:10.1080/00952990.2016.1257634.

Quantifying Impatience Using Models of Delay Discounting in Substance Use Disorders

Suzanne H. Mitchell, Ph.D.

Dept.s of Behavioral Neuroscience and Psychiatry, Oregon Health & Science University, Portland
OR

When offered a choice between \$95 available immediately or \$100 available in one month, most people will select the \$95 immediately because the required one-month wait reduces the subjective value of the \$100. This devaluation as a function of the delay is known as “delay discounting” (also intertemporal choice or temporal discounting). Researchers are interested in delay discounting because numerous studies have reported discounting behavior (i.e., tendency to choose the smaller, sooner monetary reward rather than the larger, later one) is more pronounced in groups of individuals who engage in behaviors associated with ill health. Thus, obese individuals show more discounting than healthy-weight individuals [e.g., 1]. People who do not perform preventative health activities, like scheduling regular dental appointments, discount more than those who do (e.g., [2], and those who have been diagnosed with some psychopathology discount more than those who have not. These psychopathologies include substance use disorders [see 3 for a meta-analysis] and neurodevelopmental disorders like Attention Deficit Hyperactivity Disorder (ADHD) [4] and schizophrenia [5].

To obtain the precise assessment of the degree to which individuals discount value due to delay, we can reduce the amount of money offered immediately until preference switches away from the immediate reward. Extending the example given at the outset where \$95 immediately was preferred over \$100 in one month: if this was done in \$5 steps, perhaps at \$70 immediately versus \$100 in one month, a person might switch their preference to the delayed reward. Traditionally the midpoint between the smallest immediate amount preferred (\$75) and the largest immediate amount rejected (\$70) is defined as the indifference point. A similar adjustment strategy can be used to identify indifference points associated with other delays, e.g., six months, one year, etc. As might be expected, as the delay lengthens, the indifference point drops, indicating that the value of the delayed reward is declining. This decline is nonlinear and how best to describe this decline mathematically is the major focus of the article by Hofmeyr et al. “Mixture Models of Delay Discounting and Smoking Behavior” in this issue of *The American Journal of Drug and Alcohol Abuse* [ref].

The primary motivation for identifying the appropriate mathematical model is to provide parameter value(s) that can be used to identify between-group differences, such as those described earlier between groups with and without a psychopathology. Such sensitivity might also enable researchers to detect manipulations that alter delay discounting within an individual. This is of interest because researchers and clinicians hope that manipulations that

reduce preference for the immediate reward, and thereby reduce discounting, will be accompanied by reductions in the severity of psychopathologies, such as substance use disorders. This hope is grounded in the assumption that, mechanistically, the neurobehavioral processes that underlie delay discounting somehow contribute to the development and/or maintenance of psychopathology; although the neurobiological mechanism underlying this link is yet to be specified. Recently, studies demonstrating that discounting in human subjects can be altered, at least for a short time, have been published [e.g., 6, 7]. However, studies demonstrating a subsequent, associated changes in psychopathology are as-yet unavailable, but are the focus of current research efforts.

To evaluate different mathematical models to describe discounting, Hofmeyr et al. examined delay discounting in current, never and former cigarette smokers. Previous research has indicated greater discounting (lower indifference points) in current smokers than the other groups [8], making these useful groups for comparing different models. Hofmeyr et al. fit three established models to the choice data generated by individuals in each group. While these models have been described before, they had not been compared for these three groups. For illustration, Figure 1 shows the fit of these three models to a set of indifference points for subject 23 from Study 1 in [9]. While these models are very similar, their implications and interpretations are very different, as discussed below.

The first model fit by Hofmeyr et al. was an exponential-decay model (Figure 1: solid line). Under this type of model, value declines as an exponential function of the length of delay, that is, at a rate proportion to its current value, just as the amount of radiation emitted from carbon-14 decreases over time and can be used in carbon dating. The application of an exponential-decay model was originally suggested by economists [10], who have applied this type of model successfully to a variety of other phenomena, such as the value of commodities. Their interest in parsimony has been a driving force in attempts to apply this model to delay discounting, as well as the ability of the model to fit short delay data. The second type of model examined was the hyperbolic model (Figure 1: dotted line), developed and widely-used by psychologists [e.g., 11]. It generally fits discounting data at the longer delays more closely than the exponential model. Further, it has the ability to describe “time-inconsistent” choices, which are readily observed in discounting studies. That is, the economically rational choice is to prefer a larger reward over a smaller reward when both rewards have the same delivery delay, no matter what that delay is, e.g., preferring \$100 over \$95 when both are available immediately or both are available after one month. According to economic theory, which uses an exponential-decay function to describe how value is discounted as a function of delay, it is also rational to prefer a large reward over a small reward, even when the delays are different, for example, preferring \$100 over \$95 when \$95 is available in one month and \$100 is available in one month plus one day. However, research has shown that this preference can reverse when the delay associated with delivery of the smaller reward is very short relative to the larger reward, e.g., preferring \$95 tomorrow over \$100 in two days. The third assessed model is the quasi-hyperbolic function [12], which combines both exponential and hyperbolic elements (Figure 1: dashed line). This model has been used infrequently in studies examining discounting within the context of psychopathology, but more widely by researchers examining the neural correlates of the delay discounting process in healthy volunteers. It describes a mechanistic model in which

discounting is the product of two processes: an impatient or “hot” process, which biases preference towards the smaller but sooner reward and a patient or “cool” process that directs preference to the more economically-rational, larger reward [13, 14]. This two-process perspective may assist in data description and in classification of neural correlates of the behavior as hot- or cool-focused, while not providing as good a level of fit as the other models. However, few studies have attempted to use this model to differentiate groups according to their psychopathology in an experimental context [see 9 for an exception]. Further, how the brain regions might interact functionally to determine choices in individuals or groups remains to be delineated.

Hofmeyr et al.’s comparisons of the mathematical models do not identify any one of the three mathematical models as significantly better relative to the others in terms of distinguishing between the different subject groups defined by smoking history. However, in a novel and intriguing analysis, the authors examine a “mixed model” approach to describe the decline in the value of delayed rewards. Unlike the quasi-hyperbolic approach which combines both exponential and hyperbolic functions within a single model, the mixed-model approach examines whether an exponential or hyperbolic function described specific data points; for example, a hyperbolic function might explain the indifference points associated with \$100 available at longer delays, such as in one month or in six months, but an exponential function may account better for the indifference point data for \$100 available at shorter delays, such as in a week. In addition to the identifying the parameters for each model that best describe the decline in value of the delayed alternative, the relative proportion of data accounted for better by each model can be calculated. This is potentially useful because it provides a characterization of an individual’s indifference points in terms of the contribution of the different mathematical formulations for different time periods. For example, an individual’s performance might be better characterized as exponential when short periods are examined but hyperbolic if only longer delays are the focus. Although this modeling approach is in its initial stages, Hofmeyr et al. provides a template for its use and show that it can be used to describe discounting data more accurately than any of the three traditional models.

It should be recognized, however, that these numerical values are only a first step and provide little concrete information about the neurobiological processes underlying differences between groups, because the link between model parameters and mechanistic elements of decision-making are as-yet unspecified. As we move forward in our attempts to understand the intriguing relationship between delay discounting and psychopathology, additional studies are needed to identify and to link the underlying neurobiological processes to the mathematical descriptors delay discounting. For example, dopaminergic system differences might contribute to the hyperbolic gradient observed for an individual, while other neurotransmitter systems might have a more exponential-based relationship to preferences in a delay discounting task. It is hoped that research delineating these relationships in general, and for specific individuals, will suggest better therapeutic target to ameliorate discounting behavior and any associated psychopathology.

Acknowledgments

Financial disclosures: none

Funding: NIAAA P60 010760

References

1. Jarmolowicz DP, et al., Robust relation between temporal discounting rates and body mass. *Appetite*, 2014 78: p. 63–7. [PubMed: 24650831]
2. Story GW, et al., Does temporal discounting explain unhealthy behavior? A systematic review and reinforcement learning perspective. *Frontiers in Behavioral Neuroscience*, 2014 8: p. 76. [PubMed: 24659960]
3. Mackillop J, et al., Delayed reward discounting and addictive behavior: A meta-analysis. *Psychopharmacology (Berl)*, 2011 216(3): p. 305–321. [PubMed: 21373791]
4. Scheres A, Sumiya M, and Thoeny AL, Studying the relation between temporal reward discounting tasks used in populations with ADHD: A factor analysis. *International Journal of Methods in Psychiatric Research*, 2010 19(3): p. 167–76. [PubMed: 20812292]
5. Wing VC, et al., Effects of cigarette smoking status on delay discounting in schizophrenia and healthy controls. *Addictive Behaviors*, 2012 37(1): p. 67–72. [PubMed: 21963152]
6. Bickel WK, et al., Remember the future: working memory training decreases delay discounting among stimulant addicts. *Biological Psychiatry*, 2011 69(3): p. 260–5. [PubMed: 20965498]
7. van der Wal AJ, et al., Do natural landscapes reduce future discounting in humans? *Proc Biol Sci*, 2013 280(1773): p. 20132295. [PubMed: 24197412]
8. Bickel WK, Odum AL, and Madden GJ, Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology*, 1999 146(4): p. 447–454. [PubMed: 10550495]
9. Mitchell SH and Wilson VB, Differences in delay discounting between smokers and nonsmokers remain when both rewards are delayed. *Psychopharmacology (Berl)*, 2012 219(2): p. 549–62. [PubMed: 21983917]
10. Samuelson PA, A note on utility. *Review of Economic Studies*, 1937 4(2): p. 155–161.
11. Mazur JE, An adjusting procedure for studying delayed reinforcement, in *The effect of delay and of intervening event on reinforcement value. Quantitative analyses of behavior*, Commons ML, et al., Editors. 1987, Lawrence Erlbaum Associates, Inc.: Hillsdale, NJ p. 55–73.
12. Laibson D, Golden Eggs and Hyperbolic Discounting. *The Quarterly Journal of Economics*, 1997 vol. 112(2): p. 443–77.
13. McClure SM, et al., Separate neural systems value immediate and delayed monetary rewards. *Science*, 2004 306(5695): p. 503–7. [PubMed: 15486304]
14. Bickel WK, et al., The behavioral economics and neuroeconomics of reinforcer pathologies: Implications for etiology and treatment of addiction. *Current Psychiatry Reports*, 2011 13(5): p. 406–15. [PubMed: 21732213]

Figure 1. Indifference points (filled circles) for choices between small, immediate rewards and \$100 available at various delays (0, 7, 30, 90, 180 and 365 days) are shown (data from Subject 23 in Study 1 of Mitchell & Wilson, 2012). Lines depict the best fitting exponential function (solid), hyperbolic line (dotted) and quasi-hyperbolic (dashed) for comparison.