PSYCHOLOGY & NEUROSCIENCE

Psychology & Neuroscience, 2012, 5, 2, 135 - 146
DOI: 10.3922/j.psns.2012.2.03

Delay discounting: concepts and measures

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Abstract

Delay discounting, one element which underlies decision-making, can be defined as the depreciation of the value of a reward related to the time that it takes to be released. High rates of delay discounting are found in subjects who are willing to forgo greater rewards available only after some length of time and who show a preference for smaller rewards that are available immediately. Widely used as a measure of impulsiveness, delay discounting can be evaluated using experimental tasks. The present review evaluated tasks of delay discounting, their features, measures of evaluation and anomalies, and some variables that can affect delay discounting results and applications in the study of individual and intra-individual differences.

Keywords: delay discounting; decision making; impulsiveness; experimental tasks.

Received 26 June 2012; received in revised form 27 August 2012; accepted 30 August 2012. Available online 28 December 2012.

Decision-making and delay discounting

The study of decision-making[1] has brought together different areas of knowledge to deepen the understanding of various phenomena including drug dependence. Studies that combine psychology, economics, and neuroscience add elements of each of these areas to the investigated phenomenon. Studies developed specifically within the areas of psychology and economics consider the manner in which gains, losses, and probabilities associated with time are combined to generate the decision that will determine the choice.

In recent studies, attention has been devoted to the degree to which the immediacy of the release of rewards is an important factor in determining decision-making. The study of such a process allowed the development of a delay discounting paradigm that considers the manner in which the delay in the release of a reward or consequence can determine a choice. The present article examines the delay discounting paradigm and its suppositions, consequences, origins, and applications.

Economists were the first to be interested in intertemporal choices. A theoretical model, the Discounted Utility Model, replete with underlying psychological suppositions, was created in the first half of the 20th century to explain these choices. This model proposed that a subject's intertemporal preference is processed based on consumption profiles, preserving some attributions such as continuity, transitivity, and completeness that can be represented as a function of intertemporal utility. The model presupposes that the discounting rate must be applied to all choices, whereas the great majority of studies have failed to establish any stable measure. Nonetheless, although the Discounted Utility Model has some weaknesses, the model continues to serve as a reference, with its implicit psychological suppositions revealed in the anomalies that accompany the phenomenon.

Building on the economic model, there is currently interest in the role of individual characteristics in constructing a consumer profile, which can be much more realistic than mathematical parameters. The area of psychology then enters and gains force, allowing the description of variables that occur in a competitive manner in delay discounting for different reasons (Frederick, Loewenstein, & O'Donoghue, 2002).

Delay discounting can be defined as the cognitive process that allows the individual to compare values between the immediate and delayed consumption of a determined commodity (Loewenstein, 1988). Such a concept plays an important role in studies related to self-control and impulsiveness in decision-making. Definitions of delay discounting can be found in different

[1]Decision-making refers to a cognitive process that involves the evaluation of incentives, goals, and outcomes of alternative actions (PsycInfo posting note 39807, 1967).

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forms. Some definitions focus on the magnitude such as the depreciation in the value of a reward[2] related to the time that it takes to be released (Tesch & Sanfey, 2008) or the depreciation of the subjective value of a consequence when it is delayed (Baker, Johnson, & Bickel, 2003). Other definitions focus on the individual, such as the tendency to prefer smaller and more immediate rewards to larger, perhaps more advantageous, rewards that are released later (Mar & Robbins, 2007) or the choice of a reward or consequence of lower value that is released immediately over the alternative (supposing that the value of the greater and late reward is devalued; Carroll, Anker, & Perry, 2009). Thus, high rates of delay discounting are found in subjects who are willing to forgo greater rewards that are available after some time and who show a preference for small, immediately available rewards (Tesch & Sanfey, 2008). Some authors refer to the tendencies of subjects to conceptualize delay discounting. Importantly, however, although individuals may differ with regard to delay discounting in the form or degree to which the delayed results depreciate, delay discounting must be considered as a behavioral tendency that can change under different environmental or pharmacological conditions rather than as a fixed trait (Dallery & Raiff, 2007).

The process that underlies delay discounting implies that when a choice is made there is an automatic attribution of values for both the choice of the immediate value and the choice of the delayed value. These values are subjective[3] and increase or decrease according to the nature of the choice for the subject (i.e., what is chosen, the magnitude of what is chosen, the probability, whether the situation is one of gain or loss, the context, and conceptions), indicating the degree of self-control (Tesch & Sanfey, 2008). The option with the present value that is considered higher by the subject at the moment at which the decision is made is the one that will be chosen. The present value of the choice is then equivalent to the depreciated (i.e., discounted) objective value as a function of the delay in its receipt or appearance (Odum, Madden, Badger, & Bickel, 2000). Thus, the behavior of individuals who discount the value of delayed consequences at high rates is directed (i.e., biased) toward immediate consequences and overcomes the priority for larger and later consequences (Epstein, Richards, Saad, Paluch, Roemmich, & Lerman, 2003). All of these aspects can explain why the logic used by individuals does not always favor the apparently most advantageous choice.

The process of delay discounting has several suppositions including the fact that, according to normative or rational theories, people plan their acts by considering future consequences and that there is a weakening of the effects of the consequences in the case of a delay or lateness in their release (Critchfield & Kollins, 2001). In other words, the subjective value of a commodity diminishes according to the delay in its release (Reynolds & Schiffbauer, 2004). Moreover, the increase in the delay of a determined event decreases the preference for it, reducing the value that the event has for the organism (Coelho, Hanna, & Todorov, 2003).

Consistent with this analysis, a choice can be determined by the extent to which the delayed consequences are discounted. If a future event is severely discounted, its impact on current behavior will then be less; therefore, an impulsive choice will be made (Baker et al., 2003; Odum et al., 2000). Delay discounting appears to be a phenomenon associated with a continuum of self-control (Shamosh & Gray, 2008) or self-regulation (Epstein et al., 2003). These are important measures (Shamosh & Gray, 2008) used sometimes as synonyms of impulsiveness (Bickel & Marsch, 2001; Rachlin, Brown, & Cross, 2000), a construct that has been strongly related to several other measures (Mitchell, 1999).

Studies of discounting have been crucial for understanding how decision-making, which involves time and risk factors, interferes in many daily situations such as financial investments and life choices related to health that involve the present and the future (Du, Green, & Myerson, 2002). Attaining long-term objectives requires the ability and motivation for future prospects to modulate the desire for immediate gratification. Thus, waiting for a reward can imply mental effort, and it is expected that such effort increases proportionally to the size of the reward (Thaler, 1981). Choosing larger and future rewards over immediate and smaller rewards is associated with various positive results throughout life including better academic performance, healthy social relationships (Hirsh, Morisano, & Peterson, 2008), lower rates of psychopathology and criminal behavior (Shamosh & Gray, 2008), and more adaptive social functioning (Hirsh, Morisano, & Peterson, 2008; Shamosh & Gray, 2008).

Clearly, the benefits that arise from late gratification result primarily from a stable environment. As indicated by Hirsh et al. (2008), investing in the future only makes sense when the future is relatively predictable. Therefore, the study of delay discounting involves several procedures that describe the variables that may lead to a choice. The environment, optimism, a history of personal experiences of deprivation or excess, financial insecurity, an inflationary macroeconomic climate, the period of development, and personal

[2]The term *reward* is the one most found in descriptions of studies of delay discounting for appetitive commodities that are used for the participants. However, *reinforcement*, *result*, *event*, and *outcome* are also used, showing that the procedures can be applied to a range of situations and that the nature of the choice is not always positive for the subject. In the present study, such terms will be alternately applied and used as equivalent terms related to the task of measuring delay discounting, which will be described later.

[3]*Subjective value* is the expression used to refer to the reward deemed by the subject to be equivalent in value to the reward declared by the experimenter (Rachlin, Raineri, & Cross, 1991). Also known as a *utility*, it can vary nonlinearly with the size of the commodity (i.e., reinforcer; Rachlin, 1995).

features (e.g., impatience or impulsiveness) contribute to the determination of a subject's choices, which can have consequences over time.

In humans, the degree of delay discounting can be estimated by exposing subjects to real or hypothetical contingencies of reinforcement in which the size of the reinforcement and delay are systematically varied in choice situations (Robles & Vargas, 2008). If delay discounting refers to the weakening of a consequence because of a delay in its occurrence, then an experiment that investigates the effects of this delay is called a delay discounting procedure (Critchfield & Kollins, 2001). In these studies, the degree of delay discounting is estimated by presenting the subject with a series of hypothetical choices between various amounts of a reinforcer (e.g., money, health, and drugs) that are to be received immediately or in a larger amount that is available after some time (Reynolds & Schiffbauer, 2004; Robles & Vargas, 2008). Studying delay discounting using experimental tasks allows one to learn more about various behavioral problems and their treatment (Myerson, Green, & Warusawitharana, 2001). Delay discounting has been a strong phenomenon consistently observed in the laboratory (Robles & Vargas, 2008). It extends to other species, regardless of the reward type or measure and evaluation procedure (Robles & Vargas, 2007).

Delay discounting tasks

In a typical delay discounting task with human participants, the subject is presented with a series of choices in which he/she must indicate preference (generally hypothetical) in a form to receive a given quantity of money, for example, between "R$1.00 now" or "R$10.00 in a year's time." Clearly, the tasks have some suppositions that the participant can consider including the fact that the results will occur with certainty, will be able to be consumed instantaneously, and will not be evaluated in the context of other possibilities (Read, 2003). Throughout several series of attempts, the lesser and immediate alternative is increased systematically (a feature called Fixed Delayed Reward [FDR]), the greater and delayed alternative is decreased systematically (Fixed Immediate Reward [FIR]),[4] or the delays or amounts are adjusted to the choices of the subject. At some point, most subjects change their choice, eventually choosing the immediate value instead of the delayed value (or the opposite), representing the present value of the greater and delayed alternative (Lawyer, 2008; Odum & Rainaud, 2003). This change of choice point is known as the indifference point when the immediate quantity and delayed quantity are equivalent in terms of subjective value (Reynolds & Schiffbauer, 2004). From a series of indifference points identified in the different delays, which can be transformed into parameters, a curve with subjective values can be generated for each participant, and a discounting rate can be calculated (Tesch & Sanfey, 2008).

Tasks that have evaluated delay discounting until the 1990s often presented the choice alternatives on pairs of cards that were systematically replaced by the researcher (Green, Myerson, Lichtman, Rosen, & Fry, 1996; Green, Myerson, & Ostaszewski, 1999), with one card offering the lesser and immediate alternative and the other card offering the greater and delayed alternative. Although tasks presented on cards can still be found in the 2000s (Odum & Rainaud, 2003; Ohmura, Takahashi, Kitamura, & Wehr, 2006), they are usually presented today on personal computers (Gonçalves, 2005; Myerson, Green, Hanson, Holt, & Estle, 2003; Robles & Vargas, 2007) with the lesser and immediate alternative and the greater and delayed alternative arranged side by side on the computer screen to be selected by the participant using the cursor of a computer mouse. Computer presentation also allows precise values to be extracted for measures of interest to the objectives of the studies, such as the duration of the task or reaction time of the choice (Reynolds & Schiffbauer, 2004; Robles & Vargas, 2007). Furthermore, the use of programmed adjustment procedures optimizes the task and guarantees the reliability of the indifference points.

Usually, the pairs of alternatives for the choice are presented to the subjects in ascending or descending order. Robles & Vargas (2007) investigated whether the order of presentation of the values (i.e., ascending, descending, and random) affects the delay discounting results. They found similar results in the ascending and descending presentations. However, the degree of delay discounting was significantly greater when the choice alternatives were presented in random order. The ascending and descending presentations generated more consistent results among the subjects who became familiar with the task more easily and showed a shorter reaction time compared with subjects who performed the task with alternatives presented in a random order. The authors suggested that the random presentation of the alternatives more closely approximates the choices faced in daily life. To control for the effect of the order, some studies have distributed the application of the procedure according to a balanced system in which some of the subjects perform the experiment in ascending order, and others perform the experiment in descending order (Gonçalves, 2005; Robles & Vargas, 2007).

Another important feature to be considered in a delay discounting task in addition to the order of presentation of the alternatives concerns the arrangement of the amounts and delays of the alternatives. Typical studies offer the choice alternatives in series with determined delays and amounts of money. Such studies usually present five (Patak & Reynolds, 2007), seven (Johnson, Bickel, & Baker, 2007; Myerson et al., 2003), or eight

[4]FDR and FIR are considered theoretically equivalent, although some studies indicate that there are differences when the two forms of presentation and amounts and delays are compared, choices with FIR being discounted in higher rates than FDR. However, all that can be said so far is that FIR is usually employed predominantly in studies with nonhuman animals (Tesch & Sanfey, 2008).

delays (Gonçalves, 2005; Myerson & Green, 1995) that can begin with 6 h (Robles & Vargas, 2008) or 1 day (Johnson et al., 2007) and reach 25 years (Gonçalves, 2005; Johnson et al., 2007; Robles & Vargas, 2008). The amounts can start at $1 (Green et al., 1996) or $10 (Johnson et al., 2007) and end at $100 (Odum & Rainaud, 2003), $1,000 (Robles & Vargas, 2008), or $10,000 (Green et al., 1996), with a total of 25 (Odum & Rainaud, 2003), 27 (Bickel, Odum, & Madden, 1999; Ohmura et al., 2006), or 30 amounts (Gonçalves, 2005), depending on the objectives of the study.

However, the amounts and delays do not always have fixed values in delay discounting tasks. Reynolds & Schiffbauer (2004) used a procedure with amounts and delays that were quite different from those used by most researchers to check the effect of sleep deprivation and tiredness on probability and delay discounting.[5] These authors presented an adjustable value of $0.30, which was delayed between 0 and 60 s with a probability of 35% chance of receiving them.

The large quantity of alternatives presented to the research subject is one of the possible problems of tasks that use fixed amounts and delays because they require more of the experimenter's and participant's time in the study. Finding tasks that present participants with 200 (Robles & Vargas, 2008) or 240 (Gonçalves, 2005) pairs of alternatives is possible, regardless of the identification of the indifference point. The final number of pairs of alternatives is not usually presented by the researchers in such studies. The reader, if interested, must calculate the number of pairs from the description of the number of amounts and delays.

To optimize delay discounting tasks, scholars in this field have studied the use of abbreviated tasks, with the choices of amounts in the next delay presented to the subject as soon as an indifference point is defined (i.e., as soon as he/she changes his choice from immediate to delayed or the opposite). Consequently, in the abbreviated task, similar to the use of an amount-adjustment procedure, the total number of pairs of alternatives depends on the choices of the subject (Robles & Vargas, 2008). The use of an abbreviated task can become problematic if a participant is more anxious to finish the task and perceives this feature of the experiment. This was not a concern of Field, Santarcangelo, Sumnall, Goudie, & Cole (2006) who presented the task on self-managing cards. The abbreviated procedure implies a reduction of the absolute amount, what may affect some of the expected effects and an aspect that was not mentioned by Robles & Vargas (2008). Nevertheless, based on a comparison among subjects, these authors concluded that there were no significant differences between the complete and abbreviated methods. Other differences observed in their study were attributable more to the order of presentation of the values in the pairs of alternatives (i.e., ascending, descending, or random). Therefore, abbreviated tasks can be both an advantage and disadvantage. The size, duration, and pace of the task should match the requirements imposed by the aim of the study and its participants. For example, self-managing cards might be suitable for testing delay discounting in elderly subjects. An abbreviated computerized task may be more suitable for adolescents.

The adjustment of amounts and delays throughout the task is another feature that can vary among delay discounting studies. The researchers present different justifications for the use of adjustments of the amounts in delay discounting procedures, such as optimization of the time or intention of making the tasks more sensitive to discounting. The adjustment procedure consists of manipulating the amount from the previous choices of the research subjects. A simplified example of the adjusting amount procedure can be found in the study by Myerson et al. (2003). If the participant chooses the immediate reward, then the amount of the alternative of the immediate reward in the following choice will diminish. If the participant chooses the greater and delayed amount, then the amount of the immediate reward in the following choice will be increased. The first value that is adjusted corresponds to half of the difference between the immediate and delayed rewards, and the size of the adjustments of the immediate amount diminishes with successive choices. This procedure was tested but was not significantly different from the complete task.

Richards, Zhang, Mitchell, & de Wit (1999) reduced the number of attempts required to estimate the indifference points from an amount adjustment procedure (i.e., to at least 74 and at most 103), which was reproduced in later studies (Baker et al., 2003; Johnson et al., 2007). Starting with a fixed delayed amount, two upper limits (maximum and minimum) and two lower limits (maximum and minimum) were always established for the changes, which changed according to the previous choices of the subjects. In each attempt, the participant made a choice between the variable amount and standard amount. The variable amount corresponded to the amount randomly selected between the upper and lower limits, which changed according to the previous choice of the subjects. If the participant chose the standard and not the variable amount, then an increase in the variable amount occurred in the next choice. However, if the participant chose the variable amount, then this led to the reduction of the variable amount in the next attempt. When the difference between the maximum lower limit and minimum upper limit reached $0.50, the corresponding variable amount was taken as the estimate of the indifference point. Afterward, alternatives were presented that distracted the

[5]*Probability discounting* refers to a phenomenon in which people show a preference for results of greater size with minimum probability of occurrence. Although similar to delay discounting in which the uncertainty is incorporated in the delayed result (Patak & Reynolds, 2007) and can be combined with it (Yi, de la Piedad, & Bickel, 2006) and correlated with large samples (Ohmura et al., 2006), this phenomenon is not the objective of the present work.

participants from the adjustment procedures (Richards et al., 1999). This demonstrates that researchers are free to define the indifference points to be used, although they all remain conceptually close.

Reynolds, Richards, Horn, & Karraker (2004) investigated the differences between the delay discounting and probability discounting processes. They used adjustments of the immediate amount to restrict the number of alternatives until the indifference point was found. This was also the objective of the adjustment procedures used by Odum & Rainaud (2003) who intended to investigate the differences in the delay discounting process when different types of reinforcers were considered. Additionally, Field, Rush, Cole, & Goudie (2007) used the adjustment procedure to study delay discounting in association with environmental cues related to smoking. In a relevant study, Estle, Green, Myerson, & Holt (2006) used an amount adjustment procedure to determine how much they can affect the degree of gain and loss discounting. For these authors, amount adjustment procedures had the advantage of producing a quick convergence of the amount of the immediate reward, making it equivalent to the delayed reward in terms of subjective value (Estle, Green, Myerson, & Holt, 2007).

Although many studies use fixed delays and amounts, amount adjustment is also useful to test its effect on the degree to which it is discounted because the magnitude of the amount affects one of the most common anomalies in the study of delay discounting (i.e., the magnitude effect[6]; Estle et al., 2006). Nevertheless, what has been concluded is that the magnitude has smaller and less reliable effects on discounting processes (Estle et al., 2006). Moreover, the adjustments have little effect on the processes that underlie delay discounting (Green, Myerson, Shah, Estle, & Holt, 2007). Studies that use adjustments of the amounts of reinforcers usually have human subjects, whereas research with animals has also used delay adjustments. The application of delay adjustments contributes to the research, especially when mapping discounting functions, although differences have not been found in discounting functions or the degree of discounting related to the delay adjustment procedure (Green et al., 2007).

Regardless of the need for adjustments, an alternative to computerized delay discounting tasks is the Kirby Delay-Discounting Questionnaire or Monetary-choice Questionnaire, which has been used in a smaller number of studies (Epstein et al., 2003; Hirsh et al., 2008; Jaroni, Wright, Lerman, & Epstein, 2004; Kirby, Petry, & Bickel, 1999; Reynolds, Leraas, Collins, & Melanko, 2009). Some studies used this for comparisons with computerized tasks (Epstein et al., 2003; Jaroni et al., 2004). This instrument is composed of 27 questions that present immediate values and fixed delays (between $11 and $80), limited magnitudes compared with other studies, delays between 7 and 186 days (i.e., time intervals that are also less than those used in most studies with computerized tasks), and value alternatives arranged in random order.

One of the advantages of this instrument is that for each alternative chosen by the participant, if it corresponds to an indifference point, then the parameter to be applied to the discounting function will be provided by the instrument itself, thus dispensing with value conversion procedures. However, for the 27 different values evaluated by the instrument, only 10 are supplied to be applied to the function (constants derived from the harmonic average of the choices of the sample that participated in the construction of the instrument), whereas a computerized task can provide continuous averages of the constant, so it is more sensitive to delay discounting.

When the discrepancies were evaluated between this instrument and a computerized task with similar values and delays, the degree of correspondence between measures indicated that both procedures measured similar choice processes. However, significant differences were found when the magnitudes were compared, with the Kirby Delay-Discounting Questionnaire revealing a greater degree of discounting, especially with small amounts, which may be attributable to the limited number of parameters offered by the instrument (Epstein et al., 2003), limiting its sensitivity.

Despite being quite simple, this instrument apparently has not been used extensively in delay discounting studies. Epstein et al. (2003) understood that the use of each measure will basically depend on the situation in which it is applied. For these authors, the Kirby Delay-Discounting Questionnaire is an efficient method for obtaining estimates of discounting, whereas a computerized task can provide a more sensitive measure of discounting with fewer estimate errors. One of the advantages of the questionnaire is that it enables the collection of delay discounting data from large samples within a short time and at a low cost, which is useful when the emphasis of the study is not on the individual but rather on obtaining an epidemiological profile of delay discounting. However, such an approach does not permit inferences about individual delay discounting and does not represent individual behavior.

Microeconomic experiments may have macroeconomic interpretations (Duffy, 2008). An epidemiological profile of delay discounting suggested by Epstein et al. (2003) extrapolates microeconomics and strongly suggests that delay discounting is also a macroeconomic process, an hypothesis supported by studies that involve inflation (Todorov, Coelho, & Hanna, 2003) and other cultural macroeconomic characteristics (Du et al., 2002). Individual characteristics such as loss aversion, hoarding, and procrastination help explain significant deviations from the real-world economy. Intertemporal consumption, saving, inflation, unemployment, economic growth, banking regulations,

[6]Anomalies (i.e., common effects that are observed when executing delay discounting procedures) will be discussed in another section.

monetary policy, and other phenomena can be used in macroeconomic experiments. Unlike microeconomic models and games, macroeconomic models are typically built on a history of specific macroeconomics and are not easily generalizable to non-macroeconomic settings. Because microeconomic experiments can have macroeconomic interpretations (Duffy, 2008), macroeconomics should be based on behavioral considerations (Akerloff, 2002).

Delay discounting is a topic of interest in various sciences, with different methods and objects that reveal considerable epistemological conflicts when observed in isolation. However, the delay discounting phenomenon can be observed in other contexts and with converging methodologies or even in studies with mixed methodologies or triangulation. This represents an important step toward a better understanding of the influence of the environment on delay discounting, regardless of the micro- or macroeconomic aspects. Considering that most methods used in studies of delay discounting converge on a mathematical model that allows comparisons of the results and other concepts such as probability discounting and devaluation of effort, the combination of population studies, case studies, and clinical groups to better understand this unique delay discounting phenomenon becomes not only possible but also desirable. There will be an increase in converging methodologies to understand the complex phenomenon of decision making in the coming years.

Evaluation of delay discounting tasks

Regardless of whether individuals or groups are used as subjects in delay discounting studies, they are generally evaluated using delay discounting tasks with the same consistency (Critchfield & Kollins, 2001). This phenomenon has been considered fundamental in the decision-making process, and several mathematical models have been proposed to identify its underlying mechanisms (Myerson et al., 2001). In an effort to better understand delay discounting on the basis of experimental studies and the identification of points of indifference, evaluating the suitability of a series of mathematical models that could explain the relationship between the value of a determined reinforcer and its delay became possible.

Generally speaking, all models used in delay discounting studies seek to evaluate the value of a determined reinforcer that relates its physical size to the length of time that separates the moment of choice and presentation of the reinforcer (Gonçalves, 2005). Thus, a consistent body of evidence was produced. The first theories about delay discounting supposed that the subjective value of the reward would diminish exponentially as a function of the delay, based on the supposition that subjective values should remain consistent throughout the delay values, which was called the exponential model. Nevertheless, other delay discounting studies concluded that hyperbolic functions would adjust better to the subjective value curves. Although the value of the reinforcer is also inversely proportional to the delay, the function presents descending negative acceleration and is not constant as in the exponential model (Gonçalves, 2005). This leads to the conclusion that intertemporal decisions can be inconsistent, depending on the time during which they are made (Tesch & Sanfey, 2008).

Each of the models presents underlying suppositions that have paramount importance. The exponential model arose from normative economic theories (Johnson et al., 2007) and allows one to suppose that each unit of additional delay involves a marginal increase in the degree of risk (i.e., the choice of the immediate event can be considered safe, whereas the choice of the delayed event implies the risk that the reward will never be delivered; Myerson et al., 2001). The hyperbolic model is also based on experimental research (Johnson & Bickel, 2002) and presumes that a choice between an immediate reward and delayed reward represents the choice between two reinforcement values. Each unit of delay results in a reduction of the subjective value of the delayed reward. The hyperbolic model has also been sufficient to explain reverse preference. This is a phenomenon that allows one to forecast that determined preferences when the results are remote can be inconsistent with later preferences when they are more immediately available, which may reveal an irrational and impulsive choice (Bickel & Marsch, 2001). Despite the success of the application of the hyperbolic model in the description of discounting, the requirement to convert the values for equation parameters can generate asymmetric distributions and heterogeneous variance (Myerson et al., 2001).

One evaluation measure that is an alternative or complement to mathematical delay discounting models is the calculation of the area under the curve, a theoretically neutral method easily applied to both individual and collective data. Such a proposal avoids problems created by the lack of theoretical agreement about discounting functions and some of the quantitative analysis problems that derive from the statistical properties of the parameters of the discounting functions (Myerson et al., 2001). Moreover, segments of the curve related to determined intervals of delay in the tasks can be compared using multivariate variance analysis to identify the effect. Univariate analyses can indicate which delay values are responsible for the differences (Gonçalves, 2005).

The importance of this method is that it allows the parametric statistical analysis of discounting data based on standardization of indifference points (Dallery & Raiff, 2007). It does not depend on adjustments to the functions, thus avoiding the loss of data that may not adapt to the functions or errors resulting from a deficient adjustment (Ohmura et al., 2006). Moreover, the calculation of the area under the curve allows the form of the function to be empirically determined, and the rate at which the delayed rewards are discounted can be

empirically derived (Bickel & Marsch, 2001). Steeper discounting is associated with a smaller area under the curve (Myerson et al., 2001).

Well-known authors in the study of delay discounting have used this measure in their studies (Dallery & Raiff, 2007; Field et al., 2006; Ohmura et al., 2006; Patak & Reynolds, 2007; Robles & Vargas, 2008), both as a measure to calculate main results and as a complement to the results of discounting functions that corroborate or refute the conformation of the results to discounting theories (Dallery & Raiff, 2007). Moreover, similar to the hyperbolic model, calculation of the area under the curve has been sufficient to describe the relationship between delay and appetitive and aversive stimuli (Gonçalves, 2005).

Nature of the stimuli: appetitive and aversive in delay discounting

Experiments that study delay discounting have usually been developed with appetitive hypothetical or real rewards (e.g., money, drugs for drug users, health, and other types of commodities) and more rarely exploit aversive consequences. When they do, aversive items are usually electric shocks or emission of an aversive sound (Monterosso & Ainslie, 2007), generally consequences outside the daily context of human subjects.

An interesting study developed by Mischel, Grusec, & Master (1969) used a sequence of experiments to evaluate the effect of delay on appetitive and aversive stimuli in children and adults. The first phase of the study involved children who had to choose between receiving different rewards associated with a point in time (i.e., 1 day, 1 week, or 3 weeks). This procedure was repeated several times as well as choices of aversive condition. The results indicated that the immediate stimuli were considered, on average, to be more attractive than the delayed stimuli. Nevertheless, for the aversive stimuli, there was no preference for either the immediate or delayed stimuli, a result that was replicated when the experiment was applied to an adult population. In the second phase of the study, university students were invited to participate in a study that would involve the delivery of an electric shock. In one of three evaluation sessions, they had to choose the session in which they would receive the electric shock (i.e., in 1 day, 1 week, or 3 weeks). Participation until the end of the study would provide academic credits. After this choice, participants were informed of the real objectives of the experiment and that there was no need to receive the shock. The results of this phase of the study showed a preference for the immediate shock (~80%), implying that immediate aversive events are considered less aversive than if they are delayed. These results also allow us to infer that the delay itself can be considered aversive (Ainslie, 1975) or that the delay makes the aversive effect more powerful.

Yates & Watts (1975) performed a study that was similar to real life, involving aversive stimuli in an experimental group (i.e., paying one-third of the value received at the start of the experiment or paying two-thirds after some time) and appetitive stimuli in the control group (i.e., choosing between receiving a lesser amount more immediately or a greater amount with a longer delay). These authors found that the results of Mischel et al. (1969) could not be generalized. In their experiment, in situations that involve aversive stimuli and delays, there was a preference for the delayed stimulus with a greater magnitude.

Thaler (1981) and Gonçalves (2005) explored the receipt of a given amount (i.e., lesser and immediate or greater with a delay) as an appetitive condition and the payment of a given amount (i.e., lesser and immediate or greater with a delay) as an aversive condition to study the difference between delay discounting phenomena in appetitive and aversive situations, stimuli quite adapted to daily life. Differences were found in ways that delay affect appetitive and aversive situations. Discounting occurs in a more significant manner in appetitive situations, although without correlations between the situations, indicating that they can be affected by different variables (Gonçalves, 2005). This author used only hypothetical stimuli in both of the appetitive and aversive cases.

Real, potentially real, and hypothetical rewards

The use of hypothetical rewards in delay discounting tasks has been quite widely discussed, especially to question the ecological validity of the experiment (Johnson & Bickel, 2002). In most studies with human subjects, participants do not experience the delays; they choose their alternatives and do not receive real money (Tesch & Sanfey, 2008). The studies are designed with hypothetical rewards for two reasons. The first reason concerns the magnitudes studied. Researchers frequently work with a range of magnitudes. Some of the magnitudes can be considered rather high and are presented repeatedly throughout a series of choices, which would make the delivery of the total accumulated amount throughout the series of choices impractical for the majority of researchers. The second reason concerns the delivery of the value chosen, which will only occur after a time interval that ranges from very short to very long, such as 20 or 25 years, meaning that the delivery of the real value becomes very problematic (Johnson & Bickel, 2002).

To resolve such issues, some researchers use potentially real rewards (Lagorio & Madden, 2005) or chance payoff (Shamosh & Gray, 2008), which proposes the use of real reinforcers in delay discounting tasks with financial rewards that ensure the compatibility of the incentive (Ballard & Knutson, 2008). In these tasks, it is clear to the participant that one of the value alternatives chosen (immediate or delayed) in each series will be selected at random by a computerized system, and the money will be paid to the participant at the end of the interval of time that is also related to the alternative chosen, within coherent limits both in

terms of value (between $10 and $100) (Johnson et al., 2007) and time (1 day to 6 months) (Johnson & Bickel, 2002; Johnson et al., 2007). Although studies of delay discounting that use hypothetical reinforcers appear to generate data similar to studies that use potentially real rewards, the authors stress the care with which one should acknowledge possible differences between potentially real awards and real rewards (i.e., if the rewards were really administered; Madden et al., 2004). However, in previous studies that used potentially real rewards and delays, there were no direct or immediate consequences for the choices. The process that measures the probability of receiving a real reward that is selected at random among the choices remains unknown (Lane, Cherek, Pietras, & Tcheremissine, 2003).

Although it can be considered to be a weakness (Yi et al., 2006), Johnson & Bickel (2002) performed a review of the literature and concluded that choices made in response to hypothetical rewards can act as valid representatives of real choices in delay discounting research. In their study, they stated that care should be taken in research with hypothetical rewards. However, they pointed out that many research questions would remain without answers if the only option was the use of real rewards, similar to studies of financial values, gains in health, social reinforcers, and drugs such as cigarettes and heroin (Odum et al., 2000).

Lane et al. (2003) used a delay discounting evaluation procedure with rewards contingent on the choices, in addition to the same procedure that used hypothetical rewards and real rewards on a lesser scale. The objective of these authors was to determine whether the contingent reward reproduces the hyperbolic discounting typically observed in studies that use hypothetical rewards and to verify whether the addition of contingencies for each choice would reveal any differences between other studies. The results of this study showed a preference for the greater and delayed contingent reward. The delays were 5, 10, 20, 35, 60, and 90 s and were related to the contingent rewards (i.e., the contingent rewards acted as conditioned reinforcers) and exerted substantial control over the choices.

Another objection to the use of hypothetical rewards is based on the premise that there are no systematic differences for determined effects. There can be more pronounced differences for others such as the magnitude effect (Johnson & Bickel, 2002), which refers to the fact that large magnitudes are discounted at lesser rates than small magnitudes (Baker et al., 2003). However, this has not been proven to be a general rule and can be explained by the fact that studies with real rewards use smaller sizes than studies that use hypothetical rewards. Other effects expected in delay discounting tasks will be described in the next section.

Anomalies

Regardless of the object of discounting, some specific main effects can be expected when delay discounting is studied. For some authors, these effects are called anomalies because they are not in accordance with normative theory (Chapman & Elstein, 1995). Thus, an empirical result is described as an anomaly if it is difficult to rationalize or if implausible suppositions are required to explain it within a paradigm (Loewenstein & Thaler, 1989). According to Read (2003), conclusions about a set of possible anomalies imply that people do not apply a single discounting rate to all of their decisions. On the contrary, such a rate is highly domain-dependent. Even within one domain, it will depend on the context of the choice. Indeed, the domain effect indicates that delay discounting will depend on the commodity considered (e.g., money, health, food, or drugs; Baker et al., 2003; Chapman & Elstein, 1995).

Reference points also play a fundamental role in intertemporal choices and can determine anomalies as the framing effect and loss aversion. These effects were exhaustively researched by Kahneman & Tversky (1979) in their Prospect Theory. These authors sought to explain how choices made under risk conditions behave (Edwards, 1996), not within the paradigm of delay discounting. Decisions are made not because of the absolute values of the alternatives but rather because of a reference point that reflects the manner in which the alternatives are formulated or the manner in which they are interpreted by the subjects (Gonçalves, 2005). When considering the delay, one may refer to Loewenstein (1988) who proposed a model similar to Prospect Theory, the Reference Point Model. People evaluate the results of the act of choosing in terms of gains and losses or from a psychologically relevant point of view[7] instead of a final level of riches. This implies that a determined value will be perceived as less valuable in situations in which it is presented as a gain rather than a loss.

Other effects commonly reported in empirical studies of delay discounting are the magnitude effect, which implies that the discounting rate is greater for small amounts (i.e., an inverse relationship between the rates of discounting and magnitude of the alternative) and the sign effect (i.e., asymmetry of gains or losses; Kahneman & Tversky, 1979), which refers to the fact that gains are discounted at higher rates than losses (Baker et al., 2003; Chapman & Elstein, 1995; Read, 2003). In the empirical studies selected in the present review, anomalies are exposed to the extent at which they are produced by the experiments. Few authors have explored other types of effects involved in discounting behavior (Chapman & Elstein, 1995; Frederick et al., 2002; Read, 2003) such as sequence effects (i.e., the effect of the sequence in which the alternatives are presented to the research subjects) in which there is generally a preference for constant or ascending sequences (Chapman & Elstein, 1995; Frederick et al., 2002; Read, 2003). Direction effects may also be observed in which the discounting rate obtained by the

[7]For example, from the interpretation of the instructions of an experimenter in a determined task.

increase in the delay is greater than the discounting rate obtained by the reduction of the delay. Interval effects result from considering two points in time. Discounting largely depends on the extension of the interval between these points, with short intervals leading to greater discounting per time unit (Read, 2003).

Another anomaly or expected effect is dynamic inconsistency or reversion (Chapman & Elstein, 1995) in which people can reverse their preferences, showing that choice behavior will not always be consistent throughout time (Loewenstein & Thaler, 1989). Read (2003) defined this anomaly as temporal inconsistency, a synonym of impulsiveness. This involves the choice of the most useful or advantageous alternative at the first moment. When the nearest and most tempting alternative is available, the choice changes to it. A feature that accompanies this anomaly is precisely the large rate of discounting attributable to small delays and a lower rate of discounting that is attributable to large delays (Chapman & Elstein, 1995). A reversion of preference considered irrational fails to explain the determinants of a change in choice when it is known that the original preference can be reversed if a second choice is offered based on past experience (Rachlin, 2007). It is not possible to assume that everyone has rational beliefs and makes rational choices at all times (Kahneman, 2003).

These and other anomalies that may not have been described in the present review do not imply errors of judgment by the person making the choice. Indeed, as mentioned previously, they are anomalies only when considering normative models that are constructed without considering descriptive validity (Frederick et al., 2002; Rachlin, 2007). Anomalies are present in a large number of studies (Chapman & Elstein, 1995; Dallery & Raiff, 2007; Estle, Green et al., 2006; Johnson et al., 2007; Kirby et al., 1999), and their best function is to provide information about delay discounting, the variables for which this phenomenon is a function, the task itself, and the choice behavior of human and nonhuman subjects. Some studies have shown that the stability of the task is limited by factors identified throughout time, a demonstration that occurs as a type of bonus associated with the greatest choice and delay.

Stability of the procedure throughout time

With regard to procedural stability throughout time, an important aspect is predicting the occurrence of some psychological problems and treating them. For example, studies were found that identified stability of 1 week (Critchfield & Kollins, 2001), 2 months (Takahashi, Furukawa, Miyakawa, Maesato, & Higuchi, 2007), 10 weeks (Critchfield & Kollins, 2001), and 3 months (Ohmura et al., 2006). Yoon et al. (2007) did not have the objective of checking procedural stability throughout time but perceived stability of 1 year. Differences between such results may also be explained by the populations studied. Ohmura et al. (2006) studied participants who were smokers, and Takahashi et al. (2007) studied abstinent alcoholics. Critchfield & Kollins (2001) studied patients with attention deficit/hyperactivity disorder and opiate-dependent individuals, populations with a high degree of impulsive behavior. Their experiment presented stability of 1 week. The latter authors suggested that not only clinical populations with problems related to the control of impulses show less stability in delay discounting tasks. Populations of unstable domestic economies with high inflationary rates or low-income populations would also show greater delay discounting, thus restricting the stability of the task because it presupposes a stable environment.

To illustrate the manner that the economy can affect rates of delay discounting, the research of Todorov in Brazil in the 1990s is described in Todorov et al. (2003). Todorov was concerned about how the Brazilian economy affected people at the beginning of the 1990s, leading them to make risky decisions. Todorov replicated the experiment of Rachlin et al. (1991). These authors investigated delay discounting and probability discounting in university students, concluding that the choice of immediate or certain amounts that were subjectively equivalent to USD$1,000, delayed or probable, decreased with the increase in the delay and decrease in the probability. In the replication study performed by Todorov using domestic currency with Brazilian students at the start of the 1990s, a time at which inflation was very high, delay discounting was much greater than delay discounting exhibited by American students. When the study was replicated using values in dollars, the delay discounting function was similar to the one obtained by Rachlin et al. (1991), confirming the interpretation that high rates of inflation may be responsible for high rates of discounting in the experiment conducted with domestic currency. In 1994, after economic reform that led to a decrease in inflation, Todorov replicated his experiment, finding results that were similar to those obtained with foreign currency (Todorov et al., 2003). Thus, in delay discounting experiments that use monetary values, the inflationary macroeconomic context needs to be considered because it is able to affect choices, which can be more or less impulsive in situations of delay and, consequently, the stability of the delay discounting task (Critchfield & Kollins, 2001).

Clearly, in addition to the macroeconomic context, cultural characteristics that define attitudes and the perception of risk can lead to differences in both delay and probability discounting. Du et al. (2002) studied differences in delay and probability discounting in American, Chinese, and Japanese undergraduate students. No differences were found among groups when probability discounting rates were compared, although other differences related to size occurred. In delay discounting, however, Japanese subjects exhibited less discounting and Chinese and American subjects had virtually equal discounting.

Other variables have already been identified in association with high levels of delay discounting. In addition to those already mentioned, it is possible to find a study that showed that age and income can affect the rates of delay discounting. Adults with a low income showed greater rates of delay discounting than adults and youths with a higher income. When the income was constant, the degree of delay discounting noticeably diminished between 20 and 30 years of age, showing a reduction of impulsiveness with age (Green et al., 1996). Prior to this study, Ainslie (1975) recalled the study of Walls & Smith (1970), which found that economically deprived children did not first choose the greater and delayed reward, as did children in more favorable economic situations. Economically deprived children did so when they underwent a series of experiences in which promises of later gratification were fulfilled (Walls & Smith, 1970).

Extroversion (i.e., interacting in a significant manner with cognitive skills; Hirsh et al., 2008) increases levels of stress that interfere with tolerance to the delay of gratification (Metcalfe & Mischel, 1999), sleep deprivation, and fatigue (Reynolds & Schiffbauer, 2004). It also increases the levels of testosterone (only in the discounting of monetary gains but not losses; Takahashi, Sakaguchi, Oki, Homma, & Hasegawa, 2006) and optimism (Berndsen & van der Pligt, 2001). These are examples of other, not necessarily pathological, conditions already studied in association with greater rates of delay discounting. Individuals with a higher intelligence quotient (IQ) tend to have lowers rates of delay discounting (Shamosh & Gray, 2008). Some cognitive distortions (e.g., requirement of immediate gratification, focus on the short term, and mental reading) have been associated with greater rates of delay discounting (Mobini, Grant, Kass, & Yeomans, 2007).

In addition to studies that have investigated the effects of some states on delay discounting (Reynolds & Schiffbauer, 2004), research on delay discounting has been developed in several different areas related to decision-making. As an example of this diversity, one study used a delay and probability discounting paradigm to examine decision-making related to hypothetical sexual stimuli, which sought to investigate both the possible reinforcing effect of these stimuli and sensitivity of the task to capture individual standards of choice for such stimuli (Lawyer, 2008). Another study showing an example of an adaptation of the delay discounting paradigm sought to identify the amount of money that one person is prepared to yield to another according to the social distance between them (Jones & Rachlin, 2006).

In addition to learning more about the phenomenon itself and its association with several psychopathologies such as the pathological game (Dixon, Jacobs, & Sanders, 2006), studies of delay discounting can contribute consistently and especially to increasing the understanding of the processes that generate drug dependence. Tobacco addiction has been especially studied (Baker et al., 2003; Dallery & Raiff, 2007; Epstein et al., 2003; Field et al., 2007; Jaroni et al., 2004; Johnson et al., 2007) as have other addictions in general (Bretteville-Jensen, 1999; Odum et al., 2000; Petry, 2002; Richards et al., 1999). The inability to tolerate the delay in gratification may be a factor in the production of many social problems (Tesch & Sanfey, 2008). Considering individual characteristics, it is more likely that addictions occur in people with a high preference for the present moment (Bretteville-Jensen, 1999) and therefore have higher levels of delay discounting.

Final considerations

Intertemporal choices are what we make when evaluating costs and benefits that occur at different time points. Thus, one is always making intertemporal choices. One of the most important areas in which discounting plays an important role is related to health. These choices involve evaluations of different delays from different perspectives, referred to as visceral influences (e.g., hunger, thirst, and sleep deprivation), mercadological influences, or private mental analyses. Therefore, delay discounting involves multiple variables. Incorporating them will help to better understand and explain it in terms of both individual and intraindividual differences, objectives for which delay discounting tasks are adjusted with accuracy and consistency. Macro- and microeconomic variables are difficult to disentangle, but convergent methodologies can provide a better understanding of decisions from personal health to economics than a single approach. Mathematical modeling of delay discounting provides a rare tool that can be tested and eventually applied to evaluate changes in choice behavior. Its application can be transcultural, longitudinal, comparative, economic, and psychological. The challenge is to overcome methodological limitations to better understand intertemporal choices.

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