Behavioural Processes 100 (2013) 192–196

Contents lists available at ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Short report

Parabolic discounting of monetary rewards by physical effort

Matthias N. Hartmann[a,b,*], Oliver M. Hager[a,b], Philippe N. Tobler[b], Stefan Kaiser[a]

[a] Department of Psychiatry, Psychotherapy and Psychosomatics, Psychiatric Hospital, University of Zurich, Lenggstrasse 31, 8032 Zurich, Switzerland
[b] Laboratory for Social and Neural Systems Research, Department of Economics, University of Zurich, Blümlisalpstrasse 10, 8006 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form 9 September 2013
Accepted 25 September 2013

Keywords:
Effort discounting
Effort-based decision making
Reward
Discounting
Decision-making

ABSTRACT

When humans and other animals make decisions in their natural environments prospective rewards have to be weighed against costs. It is well established that increasing costs lead to devaluation or *discounting* of reward. While our knowledge about discount functions for time and probability costs is quite advanced, little is known about how physical effort discounts reward. In the present study we compared three different models in a binary choice task in which human participants had to squeeze a handgrip to earn monetary rewards: a linear, a hyperbolic, and a parabolic model. On the group as well as the individual level, the concave parabolic model explained most variance of the choice data, thus contrasting with the typical hyperbolic discounting of reward value by delay. Research on effort discounting is not only important to basic science but also holds the potential to quantify aberrant motivational states in neuropsychiatric disorders.

1. Introduction

Every day, humans and other animals are faced with decisions about possible courses of actions that entail expected costs and benefits. The quality of this decision-making process is essential for the wellbeing of the individual and the survival of the species (Stephens and Krebs, 1986). In various neuropsychiatric disorders that are accompanied by aberrant motivational states, such cost–benefit decision-making seems to be critically impaired (Rahman et al., 2001). Consequently, understanding the psychological dynamics of weighing a reward against associated costs is of interest to basic behavioral science and also holds significant clinical implications.

We define rewards and costs as attributes of the expected outcome that lead to an increase or decrease in decision utility respectively (Kahneman et al., 1997). In this view, animals would generally strive to minimize expected effort. This idea was already stated in Hull's (1943) *law of less work*, according to which an organism will choose the low effort option when it faces two options that solely differ in amount of metabolic energy demands or work. In this context, the value of a given reward diminishes as a function of increasing cost, which has also been termed as *discounting* of the reward (Rachlin, 2006).

Several theoretical valuation models have been proposed that integrate benefits and costs. Discounting by delay and probability costs has been proposed to follow an exponential (*discounted utility model*; Samuelson, 1937) or hyperbolic model (Mazur, 1987). In a majority of empirical studies, the latter descriptive model has proven to provide a superior fit compared to the prescriptive exponential model derived from standard economic theory (Kirby, 1997; Myerson and Green, 1995; Rachlin et al., 1991).

Despite considerable knowledge about the neurobiology of effort-based decision-making and behavior from animal (e.g., Floresco et al., 2008) and human studies (e.g., Burke et al., 2013), only few studies have investigated the functional form of physical effort discounting. Phillips et al. (2007) proposed that effort costs would increase linearly, while others (Mitchell, 1999, 2003, 2004; Prévost et al., 2010; Sugiwaka and Okouchi, 2004) fitted hyperbolic models to their data. Contrary to the domain of delay discounting where exponential and hyperbolic functions are often compared, in the domain of effort discounting studies usually selected one type of model without testing whether others would provide a better fit. Here we compare three simple models (see below) in terms of their ability to explain effort discounting. Physical effort was operationalized as varying percentages of the subject-specific maximum voluntary contraction (MVC) on a hand dynamometer. Participants repeatedly chose between a *no effort/low reward* and a *high effort/high reward* option. In the latter, both physical effort (% MVC) and monetary reward magnitude were independently manipulated.

Based on reports that perceived effort in constant-force tasks increases as a power function of the target force (*Stevens' power law*; Stevens, 1957), we hypothesized that physical effort would

Abbreviations: MVC, maximum voluntary contraction; N, Newton; CHF, Swiss Francs; s, seconds; ms, milliseconds; SV, subjective value.

* Corresponding author at: Psychiatric Hospital, University of Zurich, Lenggstrasse 31, 8032 Zurich, Switzerland. Tel.: +41 44 384 28 17.
E-mail addresses: matthias.hartmann@uzh.ch (M.N. Hartmann), oliver.hager@uzh.ch (O.M. Hager), phil.tobler@econ.uzh.ch (P.N. Tobler), stefan.kaiser@puk.zh.ch (S. Kaiser).

0376-6357/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.beproc.2013.09.014

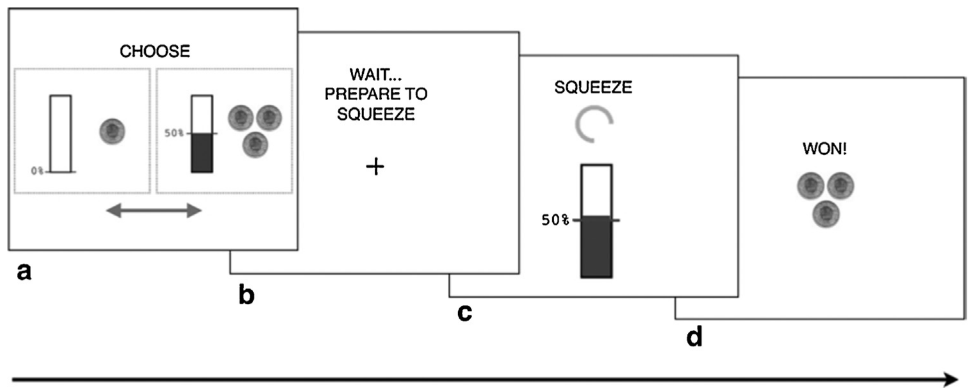

Fig. 1. Schematic of the sequence of task events. (a) Presentation of options (no time limit). (b) Fixation cross (4 s). (c) Effort exertion period (3.5 s). (d) Feedback period (3 s).

discount money as a power function. Stevens and Mack (1959) reported an exponent of 2 with ratio and magnitude production procedures on a hand dynamometer task. Thus we specifically hypothesized that we would observe parabolic (with an exponent of 2) rather than linear or hyperbolic discounting of monetary rewards by effort. These three functions crucially differ in their assumptions on how increasing force requirements impact choice: While a linear model predicts constant discounting over the whole force spectrum, the convex hyperbola predicts changes in low force to have stronger impact than changes in high force. In contrast, a concave parabolic model predicts the opposite. Consider the example of adding weight during a weight-lifting competition: The hyperbolic model predicts that adding 1 kg has a stronger impact on subjective experience at the beginning of the competition, when the lifters are well below their individual maximum. By contrast, the parabolic model predicts that the impact of adding 1 kg is larger toward the end of the competition, when lifters are close to their individual maximum and the linear model predicts the impact to be the same in both cases.

2. Materials and methods

2.1. Participants

This study's sample consisted of 24 participants (8 males) recruited from the hospital staff (Zurich University Hospital for Psychiatry). The average age of the participants was 28.63 years (*SD* = 9.11). The research ethics committee of the canton Zurich approved the study protocol and informed consent was given prior to the inclusion to the study.

2.2. Procedure

An isometric dynamometer (Zühlke Engineering and Sensory-Motor Systems Laboratory ETH Zurich; measuring range: 0–600 N) was used to assess participant's MVC and allow them to exert effort. Before detailed instructions to the task were given, participants were asked to grip the hand dynamometer with their dominant hand as hard as possible in two consecutive trials of 3.5 s. No visual feedback of applied grip force was given in these calibration trials. MVC was calculated taking the median force value of the period 1–3.5 s of these two maximum effort trials.

Participants were then presented with a series of choices between a *no effort/low reward* and a *high effort/high reward* option on a 19-in. computer screen and indicated their choice by button-press (see Fig. 1). The *no effort/low reward* option yielded a reward of 1 Swiss Franc (CHF; 1 CHF ≈1.07$), while the effortful option required 10/50/90/100% MVC and was rewarded with 1/1.5/2/2.5/3/5 CHF. The corresponding effort cost was implemented after each choice in a 3.5 s effort period with visual feedback. This effort period was also implemented if the *no effort/low reward option* was chosen. Thus, time costs were held constant in all options.

The criterion for success was the median force values achieved minus 5%. A relative margin was used to keep the risk of achieving the criterion independent of effort exerted. Moreover, to prevent exclusive choice of the *no effort/low reward* option due to risk aversion, participants were given the default reward of 1 CHF when failing to hold the required effort level in the *high effort/high reward* option. These measures were successful: the number of trials in which participants failed to reach criterion was low (1.21 trials out of 72 trials, 1.7%; *SD* = 1.82 trials) and not related to choice parameters ($p > 0.58$). Considering this, failed trials remained in the analysis as choices to exert effort. Incidentally, the small number of failed trials also indicates that participants behaved as instructed in the task. Participants could have always or in 50% of the trials chosen the effortful option even if they did not intend to actually exert effort because the monetary outcome would have been the same as that of the no effort option. However, such behavior would result in considerably higher failure rates, which were not observed in the present study.

Each decision pair was presented three times, resulting in a total of 72 trials, which were divided in three randomized blocks. Time for choice was not restricted. Response times were determined as the period from presentation of the two options to selection of one of them in milliseconds (ms). Participants were instructed to rest only during breaks between blocks. To control for effects of fatigue, we assessed an additional MVC measure (identical to the one described above) immediately after finishing the experiment. Participants were further instructed that, after completion of the task, five of the 72 trials would be randomly drawn and paid out.

2.3. Data analysis

To investigate group level effects of effort and reward on choice and response times, we applied repeated measures ANOVA with fraction of effortful choice and response times as the dependent variables and the factors effort and reward as independent variables. For each participant we then estimated indifference points in the different effort conditions (10/50/90/100% MVC). These indifference points were estimated by fitting a logistic function to the proportion of effortful choices, plotted as a function of the reward in the effortful option (1/1.5/2/2.5/3/5 CHF). The indifference point is therefore the amount at which the probability of choosing to exert effort was 0.5. In other words, we used choices to determine by a logistic fit the monetary amount for which participants would be indifferent between (i.e., choose equally often) the no effort and the high effort option (see Fig. 2).