Psychology of Sport and Exercise 33 (2017) 150–160

Contents lists available at ScienceDirect

Psychology of Sport and Exercise

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

Fatigue increases the perception of future effort during decision making

Pierpaolo Iodice [a, *], Cinzia Calluso [b], Laura Barca [a], Maurizio Bertollo [c], Patrizio Ripari [d], Giovanni Pezzulo [a]

[a] Institute of Cognitive Sciences and Technologies, National Research Council, Via San Martino della Battaglia 44, 00185 Rome, Italy
[b] Department of Business and Management, LUISS Guido Carli University, Viale Romania 32, 00197, Rome, Italy
[c] BIND - Behavioral Imaging and Neural Dynamics Center, Dept. of Medicine and Aging Sciences, University "G. d'Annunzio" of Chieti-Pescara, Via dei Vestini 31, 66013, Chieti, Italy
[d] University Centre of Sports Medicine, Dept. of Clinical and Experimental Science, University G. d'Annunzio Chieti-Pescara, Via dei Vestini 31, 66013, Chieti, Italy

A R T I C L E I N F O

Article history:
Received 3 March 2017
Received in revised form
16 May 2017
Accepted 24 August 2017
Available online 4 September 2017

Keywords:
Effort-discounting
Decision-making
Fatigue
Perceived exertion
Exercise performance

A B S T R A C T

Objectives: When making a decision, humans and other animals consider both the value of the alternatives and their associated effort. Accordingly, several studies have shown that the value-functions of rewards decrease proportionally to the effort required to secure them (*effort-discounting*). Nevertheless, it is unclear whether and how the momentary physiological condition of the body (e.g., fatigue) influences cost-benefit computations and the evaluation of future prospects.
Design: Participants were asked to make a series of effort-based choices between two different effort-demanding monetary outcomes, which varied both in reward magnitudes (money) and effort (time to be spent cycling on a bicycle ergometer at submaximal performance of ~70% of Vo_{2max} after the experimental session). The tests were performed in two conditions: when participants were fatigued versus not fatigued.
Methods: Visual presentation of the choice alternatives and recordings of the subjects' responses were performed using the Mouse Tracker software, which allowed the recording of the kinematics of the mouse movements associated with the choice of 20 human subjects.
Results: Our findings show that fatigued participants increased their preference for less-costly offers, which indicates effort-discount (i.e., decrease of participants' value functions). Kinematic analysis of participants' choices revealed the dynamical signature of this preference shift: while non-fatigued participants had a strong initial bias for the higher-value, higher-effort choice offer, this bias lacked in fatigued participants.
Conclusions: Our results suggest that increased fatigue levels may "scale up" effort-costs, counteracting the (otherwise default) choice of higher-valued offers. These results are relevant for the ongoing debate on whether and why fatigue impairs athletes' ability to select actions optimally.

1. Introduction

"Orazio: Iddio ci vende tutti li beni per prezzo di fatica."

(God sells us all things at the price of labor)

— Leonardo da Vinci

Sentences such as "this book is not worth the effort" or "he makes no effort for me" suggest that there is an inverse relation between the subjective value of a reward and the amount of effort required to secure it - or, in other words, an *effort discounting* effect. The inverse relation between the subjective value and effort has been assessed by several studies in humans and other animals (Botvinick, Huffstetler, & McGuire, 2009; Cos, Bélanger, & Cisek, 2011; Klein-Flügge, Kennerley, Saraiva, Penny, & Bestmann, 2015; Marcos, Cos, Girard, & Verschure, 2015; Phillips, Walton, & Jhou,

* Corresponding author.
E-mail address: pierpaolo.iodice@istc.cnr.it (P. Iodice).

http://dx.doi.org/10.1016/j.psychsport.2017.08.013
1469-0292/

2007; Prévost, Pessiglione, Météreau, Cléry-Melin, & Dreher, 2010; Salamone, Correa, Farrar, & Mingote, 2007; Walton, Kennerley, Bannerman, Phillips, & Rushworth, 2006). The emerging view in psychology and neuroeconomics is that the subjective value of a (fixed) reward declines in proportion to the effort required to secure it (Phillips et al., 2007). More formally, according to the prospect theory (Kahneman & Tversky, 1979) and assuming a curvilinear *value function* (i.e., mapping from reward's magnitude and its subjective value), a common assumption is that a subject's value function "shifts" proportionally to the effort required to secure a reward (Kivetz, 2003), so that, for the same reward magnitude, the higher the effort, the lower the subjective value and, consequently, the probability that the corresponding offer will be selected.

There is one key aspect of these cost-benefit computations that has received less attention in psychology and neuroeconomics: whether and how the momentary physiological condition of the body (e.g., fatigue, fitness) influences effort discounting and the subjective value of rewards requiring some effort to be secured. This is a central question, for example, for physiologists and exercise professionals (Amann & Secher, 2010; Amann et al., 2013; Noakes, 2000; Shephard, 2009). In this perspective, it has been recently proposed that during exercise, humans continuously make effort-based decisions and fatigue may affect their ability to select the optimal choice (Pageaux, 2014) or to execute actions optimally (Iodice, Cesinaro, Romani, & Pezzulo, 2015; Royal et al., 2006) – yet, the underlying mechanisms remain largely unknown. One possible hint comes from the embodied cognition field, which assumes that the body's physiological state should be considered as part and parcel of cognition, as it exerts significant influence on perceptual and decision processes (Pezzulo et al., 2011, 2013). In this perspective, participants' should consider the physiological state of their body as a source of information during (for example) the perception and evaluation of choice offers. Processes that influence body physiology or skills (e.g., fatigue, wearing heavy loads) might produce apparent misperceptions (e.g., in distance or size perception (Witt & Proffitt, 2005) or suboptimal economic decisions that however make more sense if one considers both bodily and cognitive processes as part of perceptual or decision processes (Cos et al., 2011; Lepora & Pezzulo, 2015; Pezzulo, 2013; Witt & Proffitt, 2008) - and the necessity for the brain to anticipate bodily needs in order to maintain allostasis (Pezzulo, Rigoli, & Friston, 2015; Sterling, 2012).

To study how fatigue influences effort-based decisions, we designed an experiment in which participants made a series of decisions between two outcomes requiring or not requiring a certain effort to be secured (e.g., 15€ if one cycles for 20 min vs. 10€ without cycling). Importantly, they made these choices in two conditions: when they were fatigued versus not fatigued. This experiment permits to assess whether (and under which conditions) fatigue influences participants' choices and their evaluation of the costs and benefits of the two alternatives.

Specifically, this experiment permits to disambiguate between different possible ways fatigue might influence the subjective value of choices that require effort (in the future). If effort-based decisions are based on fixed representations of "effort costs" - akin to fixed "offer values" reported in orbitofrontal cortex (Padoa-Schioppa, 2011) - they should not be permeable to momentary changes in the participants' physiological state (e.g., participants' current fatigue state). As a consequence, we should observe no difference in the preferences or subjective values of participants when they are fatigued or not fatigued (i.e., no *fatigue discount*). Conversely, and in accordance with an embodied view, the cost-benefit computations underlying effort-based decisions might be more context-sensitive and consider jointly bodily and cognitive variables. In this latter case, participants' value functions should "shift" depending on their current physiological state (e.g., fatigue) - as the latter, in turn, might influence the evaluation of effort (e.g., scale it up) and the willingness to exert it (Wright & Stewart, 2012; Wright, 2014). This would entail that the subjective value of a (fixed) effort-demanding reward should be lower for *fatigued* than for *non-fatigued* participants, aka *fatigue discounting.*

2. Material and methods

2.1. Participants

Twenty students recruited from University of Chieti [20 men; $M_{age} = 22$, SD = 2 yr, M_{height} 177 SD = 7 cm, $M_{weight} = 71$, SD = 8 kg, $M_{peak\ power\ output}$ 250, SD = 44 W, $M_{maximal\ oxygen\ uptake} = 44$, SD = 8 $ml.kg^{-1}.min^{-1}$, $M_{minute\ ventilation} = 110$, SD = 29 l/min] participated in this study. Because previous studies in the effort discounting literature lack in reporting information about the power/effect size of their analyses, it was not possible to calculate the required sample size based on the information derived from the literature. Thus, the required sample size was calculated based on a power analysis [G*Power 3.1.9.2 (www.gpower.hlu.de/en.html)], based on a *desired* $\eta_p^2$of 0.14 (corresponding to a Cohen's f = 0.40, and to a Power (1 − β err. Prob.) = 0.95) for the F-tests, and on a desired ρ^2 of 0.25 for the correlation analysis, which are interpreted as an index of a large effect size (Cohen, 1988; Richardson, 2011). The results of these analyses indicated a required sample size ranging from 16 to 22 participants; we also observed 20 to be a critical number of participants, as both the effect size and observed power remain stable above this number. Informed consent was obtained from each participant and the study protocol conforms to the ethical guidelines of the Declaration of Helsinki (BMJ 1991; 302; 1194) as reflected in prior approval by the institution's human research committee (ISTC-CNR, Rome).

The eligibility criteria were aimed at identifying participants without endocrine, cardiovascular, pulmonary and orthopedic disorders, with a BMI in the range of normality ($18.5 < BMI < 25$ kg m^{-2}). Participants were enrolled only if they had a sedentary lifestyle (regular aerobic exercise less than three times/week and less than 20 min (min)/session, sedentary occupation).

The sample size was calculated starting from the following parameters: eta square between 0.5 and 0.71; alpha = 0.05; power = 0.99; number of groups/measures: depends on the specific analysis. For the analyses that have fewer levels (e.g., on k values) the estimated number of participants was 15. For the analyses involving an higher number of factors and/or levels, the estimated number of participants was 18. We found 20 participants to be a critical number of participants, as the estimated power remains stable above this number. Power analysis was performed using G*Power 3.1.9.2 (www.gpower.hhu.de/en.html).

2.2. Apparatus and stimuli

2.2.1. Incremental test

The participants performed a graded maximal exercise test on a cycle ergometer (Ergoselect 100, Ergoline GmbH, Bitz, Germany) consisting of 3 min at rest and 5 min of priming exercise at 50 W, followed by a continuous increase in the workload by 20 W/min until exhaustion. The accepted criteria for maximal effort were: respiratory exchange ratio >1.1, and heart rate >90% of the predicted maximum based on age (Howley, Bassett, & Welch, 1995). All exercise tests were performed under continuous ECG monitoring (ECGpro, CardioPart 12 Blue, Amedtec, Aue, Germany) and supervised by a specialist medical doctor in sports medicine. Breath-by-breath oxygen uptake (l/min), carbon dioxide output (l/min) and minute ventilation (l/min) during exercise were measured continuously at the mouth (Ergostik, Geratherm Respiratory GmbH, Bad Kissingen,