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The feeling of effort during mental activity

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ABSTRACT

The feeling of effort is familiar to most, if not all, humans. Prior research shows that the feeling of effort shapes judgments (e.g., of agency) and decisions (e.g., to quit the current task) in various ways, but the proximal causes of the feeling of effort are not well understood. In this research, I address these proximal causes. In particular, I conducted two preregistered experiments in which participants performed a difficult vs. easy cognitive task, while I measured effort-related phenomenology (feeling of effort) and physiology (pupil dilation) on a moment-to-moment basis. In both experiments, difficult tasks increased the feeling of effort; however, this effect could not be explained by concurrent increases in physiological effort. To explain these findings, I suggest that the feeling of effort during mental activity stems from the decision to exert physiological effort, rather than from physiological effort itself.

1. Introduction

When people think hard, they tend to experience the *feeling of effort*. The feeling of effort is a basic state of consciousness, akin to hunger and pain, that is often thought to reflect the costs of ongoing actions (e.g., Hockey, 2013; Preston & Wegner, 2009). The feeling of effort shapes people's judgments and decisions in numerous ways (e.g., Reber & Greifeneder, 2017); accordingly, self-reports of effort have proven a valuable source of information for practitioners—e.g., for therapists, who wish to assess their patients' mental state (Radloff, 1977), and for education professionals, who wish to evaluate their teaching materials (Mattis, 2015). Yet, despite its everyday familiarity, and despite its long history as a topic of study (James, 1880), the proximal causes of the feeling of effort are not well understood, particularly when the feeling of effort emerges during mental activity (Shenhav et al., 2017). In this research, I examine these proximal causes of the feeling of effort. Thus, with this research, I aim to help clarify the origins of a familiar human experience. Relatedly, I aim to increase our ability to precisely interpret self-reports of effort: what does it mean when people say that some mental activity 'felt effortful'?

I will consider two possibilities. First, building on previous research on introspection, it can be expected that the feeling of effort arises from *physiological effort*—i.e., the investment of energetic resources (e.g., adenosine triphosphate [ATP], oxygen, glucose) in the service of goal-directed behavior (Gendolla, Wright, & Richter, 2011). Although it is unlikely that the brain consumes substantially more energetic resources during heavy (vs. light) cognitive activity (Kurzban, 2010), heavy (vs. light) cognitive activity still causes sympathetically-innervated organs, like the heart, to operate more vigorously (Gendolla et al., 2011; Richter, Gendolla, & Wright, 2016), suggesting that cognitive tasks can and do trigger physiological effort. Also, research suggests that people can readily detect such physiological changes via afferent pathways (Craig, 2002; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Damasio & Carvalho, 2013; Laird, 2007). In experiments, afferent pathways have indeed been shown to contribute to physiology-related conscious experiences, such as hunger (Stevenson, Mahmut, & Rooney, 2015) and pain (Almeida, Roizenblatt, & Tufik, 2004). So, one possibility is that the feeling of effort emerges from physiological effort, via body-to-brain feedback. This *feedback model* (Fig. 1a) is in

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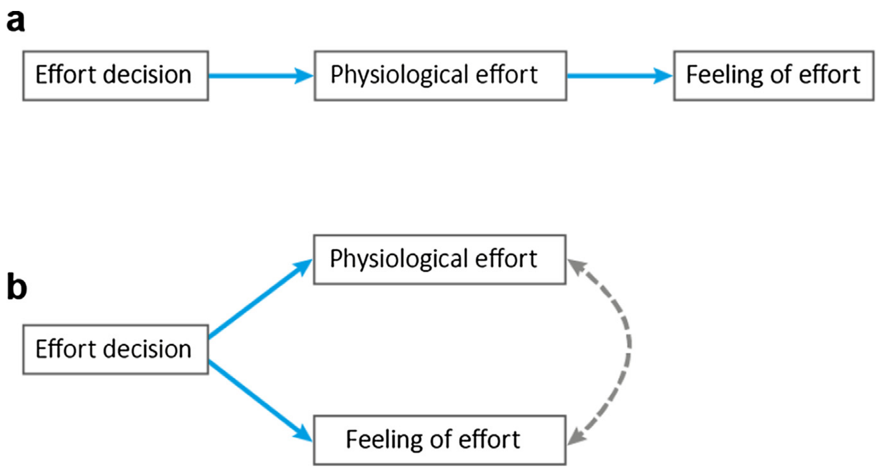

Fig. 1. Two models of the feeling of effort. (a) The feedback model; (b) the shared cause model. Solid, blue lines indicate causal pathways. The dashed, grey line indicates a spurious relationship.

line with the common-sense notion that the feeling of effort signals the current expenditure of energy.

Second, research from exercise physiology suggests an alternative possibility, namely, that the relationship between physiological effort and the feeling of effort is spurious, rather than causal (Marcora, 2009). This would work as follows: the *decision to exert* physiological effort directly causes the feeling of effort, independently of body-to-brain feedback. As a result, physiological effort and the feeling of effort correlate. Importantly, though, this correlation is not due to a causal relationship: it emerges only because both variables are affected by the same upstream decision-making process (Marcora, 2009; Naccache et al., 2005; Wegner, 2002). This *shared cause model* (Fig. 1b) predicts that feeling of effort should closely reflect decisions to exert extra effort—e.g., which occur when people face a difficult task—but not necessarily the actual expenditure of energy.

Here I report two experiments, in which participants carried out a working memory task, consisting of easy and difficult trials. Importantly, in both experiments, I measured physiological effort and the feeling of effort, concurrently, on a trial-by-trial basis. This novel design enabled me to examine predictions from the feedback and shared cause models in detail.

2. Experiment 1

In this research, non-controversially, I assume that task characteristics—mainly, task difficulty and time on task—are a primary driver of people's decisions to expend physiological effort (Gendolla et al., 2011; Richter et al., 2016). Accordingly, by varying task difficulty, I manipulated people's decisions to expend more vs. less effort. In addition, also non-controversially, I assume that physiological effort involves activity of the sympathetic branch of the autonomic nervous system. Via the paravertebral ganglia, this neural network boosts contractions of the heart, opens the bronchi in the lungs, and dilates the pupils of the eye, among a range of other, concurrent effects. Indeed, since the 1970s, pupil dilation has been considered a valid indicator of physiological effort during mental activity (Beatty & Lucero-Wagoner, 2000; Bijleveld, Custers, & Aarts, 2009; Kahneman, 1973; Laeng, Sirois, & Gredebäck, 2012)[1].

Given the above assumptions, the feedback model predicts that the effect of task difficulty (a proxy for effort decisions) on the feeling of effort is mediated by physiological effort. The shared cause model predicts that the association between physiological effort and the feeling of effort should weaken after controlling for task difficulty (Einhorn & Hogarth, 1986; and see Method). The most important goal of Experiment 1 was to provide an initial test of both these predictions.

In addition, as an exploratory analysis, I will examine the feedback model and the shared cause model in an alternative way. Specifically, research on *fatigue* suggests that people's effort decisions do not only depend on task difficulty—but that these decisions should also change over time. That is, with *time on task*, increasing amounts of effort are needed to uphold performance; thus, *time on task* may trigger decisions to exert more effort (Hockey, 2013). Based on this rationale, I will again test the feedback model and the shared cause model, but now with *time on task* as a proxy for effort decisions. In particular, to examine the feedback model, I will test whether the effect of time on task on the feeling of effort is mediated by physiological effort. To examine the shared cause model, I will test whether the association between physiological effort and the feeling of effort weakens after controlling for time on task.

[1] In more recent years, researchers have uncovered the brain mechanisms that trigger physiological effort. While not the main focus of the present work, substantial evidence points to a key role for the Locus Coeruleus (Joshi, Li, Kalwani, & Gold, 2016; Murphy, O'Connell, O'Sullivan, Robertson, & Balsters, 2014; Samuels & Szabadi, 2008), the neural node that lies at the origin of the brain's norepinephrine pathways. This node directly sends impulses into the spinal cord, activating the sympathetic nervous system (Samuels & Szabadi, 2008), enabling the investment of energetic resources.