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Are perceptuo-motor decisions really more optimal than cognitive decisions? ☆

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ABSTRACT

Human high-level cognitive decisions appear sub-optimal (Kahneman, Slovic, & Tversky, 1982; Kahneman & Tversky, 1979). Paradoxically, perceptuo-motor decisions appear optimal, or nearly optimal (Trommershäuser, Maloney, & Landy, 2008). Here, we highlight limitations to the comparison of performance between and within domains. These limitations are illustrated by means of two perceptuo-motor decision-making experiments. The results indicate that participants did not optimize fundamental performance-related factors (precision and time usage), even though standard analyses may have classed participants as 'optimal'. Moreover, simulations and comparisons across our studies demonstrate that optimality depends on task difficulty. Thus, it seems that a standard model of perceptuo-motor decision-making fails to provide an absolute standard of performance. Importantly, this appears to be a limitation of optimal models of human behaviour in general. This, in conjunction with non-trivial evaluative- and methodological differences, suggests that verdicts favouring perceptuo-motor, or perceptual, systems over higher-level cognitive systems in terms of level of performance are premature.

1. Introduction

There appears to be a striking dissociation between human perceptuo-motor- and cognitive decision-making performance. Cognitive decision-making ability is widely viewed as distinctly less than optimal, because it conflicts with the normative prescriptions of decision theory that set out how 'rational' decision makers should behave (Birnbaum, 2008; Kahneman, Slovic, & Tversky, 1982; Kahneman & Tversky, 1979). Perceptuo-motor decision-making, on the other hand, appears well described by the same theory (for a review see Trommershäuser et al., 2008; see Whiteley & Sahani, 2008 for a similar conclusion in a perceptual domain). This apparent dissociation has been highlighted repeatedly. Trommershäuser, Landy and Maloney, for example, note that "...in marked contrast to the grossly sub-optimal performance of human subjects in traditional economic decision-making experiments, our subjects' performance was often indistinguishable from optimal." (2006, p. 987; see also e.g., Maloney, Trommershäuser, & Landy, 2007; Trommershäuser et al., 2008).

This performance dissociation is puzzling. Few reasons are evident for why perceptuo-motor decision-making should be optimal, while cognitive decision-making is sub-optimal (but see e.g., Chater & Oaksford, 2008; Evans & Over, 1996). Furthermore, little progress appears to have been made in explaining the difference.

There are at least three possible sources for the apparent dissociation: (1) competence may be modality dependent (2) performance may be task dependent and (3)

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differences may result from the way performance is evaluated. If competence were indeed modality dependent this would be a striking finding. However, as pointed out by Trommershäuser and colleagues (e.g., Maloney et al., 2007), experimental paradigms across the two fields differ along a number of methodological dimensions. Perceptuo-motor studies generally involve repeated decisions with outcome feedback and internalized probabilities. Cognitive decision tasks, on the other hand, generally involve one-shot decisions without feedback and exact probabilities stated on paper (see e.g., Birnbaum, 2008; Kahneman & Tversky, 1979, but see e.g., Hertwig, Barron, Weber, & Erev, 2004; Thaler, Tversky, Kahneman, & Schwartz, 1997). Thus, a less interesting explanation is that one, or more, of these methodological differences give rise to the apparent dissociation.

Not only are there methodological differences in tasks, performance is also evaluated differently in the two fields. Although both perceptuo-motor- and cognitive studies draw on normative theories to provide performance standards, adherence to these norms is assessed in different ways. Generally, the perceptual and perceptuo-motor literature asks how closely human performance matches that of an ideal agent (see e.g., Barlow, 1962; Geisler, 2003; Trommershäuser, Maloney, & Landy, 2003a, 2003b). Broadly, an ideal agent is a model that performs a given task maximally well. Constraints under which the system is assumed to operate are typically built into the model. The cognitive literature, on the other hand, typically asks if a system violates one or more of the axioms of decision theory (assumed fundamental principles of rational choice such as the transitivity of preferences, or independence of irrelevant alternatives, see e.g., Birnbaum, 2008; Hertwig et al., 2004; Kahneman & Tversky, 1979). Experiments are designed so that certain response patterns would constitute violations of these axioms, thereby indicating irrationality (i.e., sub-optimality). Thus, assessment of performance typically differs in two ways across cognitive and perceptual/perceptuo-motor studies: quantitative versus qualitative violations of normative theories and presence or absence[1] of system constraints.

Given these non-trivial differences between cognitive- and perceptuo-motor studies, comparisons of human performance across the two domains need to be made with care. In this paper we highlight difficulties associated with such comparisons using two perceptuo-motor decision-making experiments. The experiments demonstrate that minor changes in task parameters, specifically changes that do not affect an optimal agent's performance, influence whether participants are actually viewed as optimal or sub-optimal. We follow up these empirical results by illustrating through simulations how specific changes in task parameters can cause participants hitherto classified as optimal to be classed as sub-optimal. Our experiments also suggest that people's perceptuo-motor decisions are sub-optimal in ways not captured by Trommershäuser et al.'s (2003a, 2003b) model. Together these results, we think, suggest that claims of greater optimality for perceptual systems over higher-level cognitive systems may be premature.

[1] Studies of higher-level decision making and judgment typically are not concerned with constraints when evaluating participant performance. Instead it is assumed that the experimental task is sufficiently easy that any system that adhered to the studied axioms would in principle be able to perform the necessary computations (Evans, 1993). This is not to say that constraints have gone unstudied. Kahneman and Tversky (1996), for example, have argued that when extensional cues are given to participants, performance improves. This effect is presumed to be due to extensional cues triggering a slow and effortful processing system that would otherwise not have been used (Kahneman & Frederick, 2002).

2. Perceptuo-motor decisions & decision performance assessment

The recent interest in comparing the relative optimality of cognitive and perceptuo-motor decisions stems from Trommershäuser et al.'s (2003a, 2003b) elegant perceptuo-motor decision paradigm. Their paradigm has made it possible to translate into perceptuo-motor tasks the kinds of decision problems given to participants in cognitive psychological studies. We begin with a brief introduction to Trommershäuser et al.'s paradigm.

Because the perceptuo-motor system is noisy, speeded pointing towards a target will result in a response distribution dispersed around a chosen aim point (cross, Panel A, Fig. 1). Trommershäuser et al. exploit this noisiness to create perceptuo-motor decisions that are mathematically equivalent to standard cognitive decisions (such as those of e.g., Kahneman & Tversky, 1979).

In Trommershäuser et al.'s (2003a, 2003b) paradigm, participants point towards stimulus configurations (Panel B, Fig. 1) under time pressure, with the goal of earning as many points as possible. Participants accrue points if they hit a reward region (full line, Panel B), lose points if they hit a penalty region (dashed line, Panel B), and incur both penalty and reward if they hit the intersection of both regions.

Different aim points (different symbols, Panel B) will result in different probabilities of hitting each region (*hit probabilities,* Panel C). Different hit probabilities, in turn, will result in different numbers of points earned. Given that there are many aim points, participants are in effect choosing between many different options of the form: reward with probability $p = X$, penalty with $p = Y$, both reward and penalty with $p = Z$. This is easily recognized as a traditional decision-making problem (see e.g., Kahneman & Tversky, 1979).

If participants are to maximize the number of points they earn, they have to find the aim point that will allow them to do so. Trommershäuser et al. (2003a) propose that people's behaviour in these tasks can be explained by a process model that assumes that people solve this optimization problem and make optimal decisions.

As noted in the introduction, the standard way of assessing performance in paradigms such as Trommershäuser et al.'s (2003a, 2003b) is to compare participants' performance to that of an ideal agent. An ideal agent is an agent that performs the task maximally well. Of course, we should not expect participants (even if optimal) to *precisely* match optimal performance (e.g., because our estimates of their behaviour are noisy). Instead, the typical question is whether people are statistically distinguishable from optimal. Next, we describe how this is determined.