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Non-Optimal Perceptual Decision in Human Navigation

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Abstract

We highlight that optimal cue combination does not represent a general principle of cue interaction during navigation, extending Rahnev & Denison's (R&D) summary of nonoptimal perceptual decisions to the navigation domain. However, we argue that the term 'suboptimality' does not capture the way visual and nonvisual cues interact in navigational decisions.

Main Text

We appreciate Rahnev & Denison's (R&D) brave target article for both its comprehensive summary of non-optimal perceptual decisions in various behaviours and its stringent critique of the conceptual shortcoming of optimality in characterizing human perception. Nonetheless, R&D's description of non-optimal perceptual decisions as *suboptimal* suggests that they are still trapped by the "optimality doctrine", rather than abandoning it. Taking studies of cue combination in navigation as an example, we argue (i) that perceptual decisions in navigation are not optimal in the sense of Bayesian theory, and (ii) that suboptimality does not capture the nature of cue interaction in navigation.

Within the framework of the "Bayesian brain" (e.g., Knill & Pouget, 2004), researchers have argued that perceptual decisions in navigation are statistically optimal (Cheng, Shettleworth, Huttenlocher, & Rieser, 2007; Nardini, Jones, Bedford, & Braddick, 2008). According to this view, when independent sources of spatial information (e.g., visual landmarks and idiothetic information about self-motion) are available for judging one's location or orientation, they are combined based on the reliability of each source. The greater the reliability of a source, the more heavily it is weighted in determining the navigator's decision. Under certain circumstances, the relative weighting of visual and self-motion cues in human navigational decisions conforms nicely to the prediction of Bayesian integration (e.g., Chen, McNamara, Kelly, & Wolbers, 2017; Nardini et al., 2008; Zhao & Warren, 2015b; see also Xu, Regier, & Newcombe, 2017, for cue integration in spatial reorientation).

However, optimal cue combination does not represent a general principle of cue interaction in navigational decisions. For instance, it has difficulty accounting for the competition among spatial cues in determining the direction of locomotion. Although visual and self-motion cues may be optimally integrated to reduce the variability of spatial judgments (e.g., Chen et al., 2017; Naridni et al., 2008), these cues often compete to determine the direction in which a navigator should go (Tcheang, Bülthoff, & Burgess, 2011; Zhao et al., 2015b). Visual cues often "veto" self-motion cues when they provide conflicting estimates of orientation or location; when such conflict becomes substantially large, the dominance reverts to self-motion cues (Foo, Warren, Duchon, & Tarr, 2005; Zhao et al., 2015b; see Cheng et al., 2007, for a review). This competition between visual and self-motion information occurs in both human and nonhuman animal navigation, and manifests in terms of both behavioural and neurophysiological responses (e.g., Etienne & Jeffery, 2004; Yoder, Clark, & Taube, 2011). Such cue dominance in navigation indicates that spatial cues are not generally combined in a statistically optimal or even suboptimal fashion, posing a challenge to Bayesian optimality in navigation. Without additional assumptions, the reliability-based theories of optimal cue combination predict neither the dominance of less reliable cues nor the co-existence of cue combination and cue competition in the same spatial judgment (Zhao et al., 2015b).

Another challenge to optimal cue combination in navigation is that many factors irrelevant to cue reliability also modulate cue interactions. One such factor is feedback about performance. Distorted feedback can change the reliability of visual or self-motion cues and their combination during navigation (Chen et al., 2017). Therefore, in addition to cue reliability per se, subjective evaluation of cue reliability also contributes to the weighting of spatial cues in navigation. Another factor is related to previous experience. Exposure to a stable visual environment can completely "silence" the contribution of self-motion cues to navigation (Zhao & Warren, 2015a), whereas experience with an unstable visual world can reduce or "switch off" the reliance on visual cues (Chen et al., 2017; Zhao et al., 2015a). Such experience-dependent cue interaction is observed in both human and nonhuman animal navigation (e.g., Knight et al., 2014), but is rarely considered in formulating optimal cue combination in navigation. The last factor we want to highlight here is individual differences. Optimal cue combination is often demonstrated at the group level. However, whether spatial cues are combined and, if so, the optimality of integration can vary substantially between individuals (Chen et al., 2017; Cheng et al., 2007; Nardini et al., 2008; Zhao & Warren, 2015b).

As R&D mention, these challenges to Bayesian optimality might be addressed by adjusting assumptions about the likelihood, prior, cost function, decision rules (LPCD), and their combinations – although this renders Bayesian models unconstrained and unfalsifiable (Bowers & Davis, 2012; Jones & Love, 2011). But before determining which components of LPCD are responsible for nonoptimal decisions, a prior question is why they should be optimal in the first place. If perceptual decisions need not to be statistically optimal, then seeking the causes of suboptimality will not help us to build models of perception and cognition. We see little evidence to justify such necessity. For instance, optimal perceptual decisions assume that humans are rational decision makers, which is often not the case (Kahneman, Slovic, & Tversky, 1982). In navigation, when two spatial cues point in different directions, optimally integrating them would lead one to walk somewhere in between, guaranteeing that one gets lost. Ultimately, evolution does not necessarily produce optimal solutions, given the rates of natural selection and environmental change, pleiotropy and other structural constraints, the heterogeneity of populations, and the random effects of genetic drift.

Without establishing the necessity of optimal cue combination in navigation, referring to the over- or under-weighting of cues as “suboptimal” still buys into the optimality approach. It implies that spatial cues *should* interact in a Bayesian optimal manner, and if they do not, some aspects of LPCD need to be better-specified. This approach runs the risk of overlooking the cognitive and neural processes that actually underlie cue interactions (see also Jones & Love, 2011). In fact, decades of research has shown that navigational decisions in mind and brain are often captured by one of two cues rather than their optimal – or suboptimal – combination (Etienne & Jeffery, 2004; Yoder et al., 2011).

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