Cognitive Psychology 96 (2017) 26–40

Contents lists available at ScienceDirect

Cognitive Psychology

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

From information processing to decisions: Formalizing and comparing psychologically plausible choice models

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ARTICLE INFO

Article history:
Accepted 27 May 2017
Available online 8 June 2017

Keywords:
Judgment and decision making
Take-the-best
Model selection
Minimum description length
Bayes factor

ABSTRACT

Decision strategies explain how people integrate multiple sources of information to make probabilistic inferences. In the past decade, increasingly sophisticated methods have been developed to determine which strategy explains decision behavior best. We extend these efforts to test psychologically more plausible models (i.e., strategies), including a new, probabilistic version of the take-the-best (TTB) heuristic that implements a rank order of error probabilities based on sequential processing. Within a coherent statistical framework, deterministic and probabilistic versions of TTB and other strategies can directly be compared using model selection by minimum description length or the Bayes factor. In an experiment with inferences from given information, only three of 104 participants were best described by the psychologically plausible, probabilistic version of TTB. Similar as in previous studies, most participants were classified as users of weighted-additive, a strategy that integrates all available information and approximates rational decisions.

1. Introduction

Every day, decision makers face situations in which judgments must be made based on uncertain information, that is, inferences must be drawn on the basis of observable information that may differ in terms of how well it actually predicts the to-be-judged criterion (Brunswik, 1955; Hammond, 1955). In such probabilistic inferences, psychological theories explain how information from multiple cues is integrated. For instance, when judging which of two cities is larger, one can rely on cues (e.g., whether it is a capital) that are probabilistically related to the criterion (i.e., population size) and thus indicate larger cities. Such judgments are made under uncertainty because the available cues typically only offer limited validity. Often, this is formalized by the cue validity v_i, the conditional probability that a binary cue i leads to correct decisions given that it discriminates between options (Gigerenzer & Goldstein, 1996).

In such situations, Franklin's Rule or the weighted-additive strategy (WADD; Lee & Cummins, 2004) assume that decision makers integrate all available cues weighted by their validity. This strategy is in line with Simon's (1976) notion of *substantive rationality*, because the decision maker maximizes her utility by combining all available information in an approximately optimal way (Lee & Cummins, 2004). In addition, heuristics were proposed as psychologically plausible shortcuts that aim at a reduction of cognitive effort (Shah & Oppenheimer, 2008). In line with Simon's (1976) principle of *procedural rationality*,

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http://dx.doi.org/10.1016/j.cogpsych.2017.05.003
0010-0285/

these heuristics often use only a subset of the available information to draw inferences, thereby adhering to the assumption that the cognitive system may only have limited capacity and that certain heuristics are particularly useful in certain environments. Most prominently, Take-the-best (TTB; Gigerenzer & Goldstein, 1996) predicts that cues are considered lexicographically from most to least valid. A decision is made once a cue discriminates between the choice options, thereby eliminating the cost of further information search. This strategy produces high accuracy in non-compensatory environments (Hogarth & Karelaia, 2007) in which the dispersion of cue validities is large and the most valid cues are substantially more valid than others (see also Bröder, 2003; Glöckner, Hilbig, & Jekel, 2014). In contrast, TTB fares relatively poorly in compensatory environments with little dispersion in cue validities in which case equal-weight (EQW; Dawes, 1979) offers an alternative manner of simplification: EQW favors the option with the larger number of positive cue values without considering their validity, thereby reducing the costs for information integration.

As strategies are typically thought to differ in how well they approximate rational solutions but also in how effortful they are, research focuses on the moderating conditions that determine the trade-off between effort and accuracy (Payne, Bettman, & Johnson, 1988, 1993), that is, under which circumstances strategies like WADD, TTB, or EQW describe decisions best. Such factors include the environmental structure (e.g., Rieskamp & Otto, 2006), time pressure (Hilbig, Erdfelder, & Pohl, 2012; Rieskamp & Hoffrage, 2008), monetary costs (Newell & Shanks, 2003), working memory load (Bröder, 2003), and the task format (Platzer, Bröder, & Heck, 2014). For instance, decisions are better described by effort-reducing heuristics such as TTB whenever cues have to be retrieved from memory and are not readily available on display (Bröder & Schiffer, 2003b; but see Glöckner et al., 2014).

However, one recurring challenge in attempting to infer which decision strategies individuals use—or, more generally, which model may best account for the cognitive process of decision making—is that many models overlap in their choice predictions (Bröder & Newell, 2008; Glöckner, 2009; Jekel, Fiedler, & Glöckner, 2011). For instance, almost all decision strategies of substantive interest predict that an option is chosen if all cues favor it over alternative options, and therefore choices in such scenarios are not informative for testing competing explanations of the underlying judgment process. As a consequence of this overlap in choice predictions, decision strategies cannot be reliably teased apart based solely on counting how often individuals choose the option predicted by a strategy (Bröder & Schiffer, 2003a). Also, strategies may predict guessing (e.g. EQW would guess if the sum of cue values does not differ between options) and thus it cannot be determined whether any one choice was in line with this prediction. Taken together, as Newell (2005) emphasized, ‘it is essential to incorporate an error theory [...] to account for the stochastic deviation from the deterministic rules of heuristics’ (p. 12).

To overcome these limitations, Bröder and Schiffer (2003a) proposed classifying participants as users of one of the decision strategies by means of statistical model selection. Instead of merely counting how often decisions coincide with strategy predictions, this method selects the most likely strategy given a specific response pattern or vector across different constellations of cue values (see details in Section 2). Importantly, these cue patterns are carefully selected to differentiate between the decision strategies under scrutiny. To derive the likelihood of observable response patterns, statistical strategy classification rests on the critical assumption that each strategy is applied with a constant, small error probability (reflecting, for instance, attention fluctuations; Bröder & Schiffer, 2003a). Put differently, it is assumed that, in some trials, individuals using a particular strategy choose a strategy-inconsistent option due to unsystematic factors such as inattention or strategy execution errors. Thereby, systematic deviations from the predicted response pattern are penalized more strongly than unsystematic deviations arising from application errors.

1.1. Psychologically plausible models of strategy application errors

The strategy-classification method of Bröder and Schiffer (2003a) builds on the assumption that strategies are applied with unsystematic execution errors formalized by a constant error probability. However, concerning WADD, it is implausible that the weighted integration of cue values and validities results in a constant error probability. Empirically, decisions are often faster and more consistent (i.e., the predicted option is chosen more often) when cues provide coherent evidence compared to scenarios where cues provide contradictory information (e.g., Birnbaum & Jou, 1990; Brown & Tan, 2011; Glöckner & Betsch, 2012; Heck & Erdfelder, in press; Pohl & Hilbig, 2012). Importantly, psychological theories that assume a weighted integration of cue values and validities predict that more evidence for an option leads to smaller error probabilities. Many axiomatic decision theories (e.g., Luce’s choice rule; Luce, 1959) imply graded instead of constant error probabilities, assuming that differences on a unidimensional latent variable (utility, evidence) are mapped to choice probabilities by a monotonic link function (e.g., by a logistic or probit link function; Luce, 1979; Thurstone, 1927). On the other hand, process models implementing or approximating WADD describe the mechanism of how cue information is integrated, for instance, by an automatic parallel search for a coherent representation of the available information (Glöckner & Betsch, 2008a) or by sequential evidence accumulation (Busemeyer & Townsend, 1993; Diederich, 1997; Trueblood, Brown, & Heathcote, 2014). Irrespective of specific underlying mechanisms, process models usually predict how strongly an option is preferred, which in turn implies graded instead of constant error probabilities.

Overall, psychological theory implies that error probabilities of WADD must not be constant across different cue constellations, but depend on the amount of evidence in favor of the preferred choice option (i.e., on the evidence difference). Importantly, this psychologically plausible assumption should be reflected by the statistical model used for strategy classification. Addressing this issue, Hilbig and Moshagen (2014) proposed a probabilistic version of WADD (WADDprob) reflecting the assumption that larger differences in the evidence for the preferred option result in smaller error probabilities. Put