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Post choice information integration as a causal determinant of confidence: Novel data and a computational account

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ABSTRACT

Confidence judgments are pivotal in the performance of daily tasks and in many domains of scientific research including the behavioral sciences, psychology and neuroscience. Positive resolution i.e., the positive correlation between choice-correctness and choice-confidence is a critical property of confidence judgments, which justifies their ubiquity. In the current paper, we study the mechanism underlying confidence judgments and their resolution by investigating the source of the inputs for the confidence-calculation. We focus on the intriguing debate between two families of confidence theories. According to single stage theories, confidence is based on the same information that underlies the decision (or on some other aspect of the decision process), whereas according to dual stage theories, confidence is affected by novel information that is collected after the decision was made. In three experiments, we support the case for dual stage theories by showing that post-choice perceptual availability manipulations exert a causal effect on confidence-resolution in the decision followed by confidence paradigm. These finding establish the role of RT2, the duration of the post-choice information-integration stage, as a prime dependent variable that theories of confidence should account for. We then present a novel list of robust empirical patterns ('hurdles') involving RT2 to guide further theorizing about confidence judgments. Finally, we present a unified computational dual stage model for choice, confidence and their latencies namely, the

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collapsing confidence boundary model (CCB). According to CCB, a diffusion-process choice is followed by a second evidence-integration stage towards a stochastic collapsing confidence boundary. Despite its simplicity, CCB clears the entire list of hurdles.

1. Introduction

Decision confidence is a metacognitive judgment, which enjoys a unique, dual status in the cognitive sciences. First, confidence judgments and their properties attract wide interest in their own right. For example, confidence judgments have been used to measure the calibration of subjective probabilities (i.e., the degree of correspondence between inner beliefs and objective probabilities of an event's occurrence; Lichtenstein, Fischhoff, & Phillips, 1982) and their resolution (i.e., the degree to which inner beliefs discriminate between an event's occurrence and nonoccurrence; Baranski & Petrusic, 1994). Second, confidence judgments constitute an important means for studying additional cognitive processes in a variety of fields including decision making (Koriat, 2012), psychophysical judgments (Peirce, 1877; Peirce & Jastrow, 1884), memory (e.g. Squire, Wixted, & Clark, 2007) adaptive control (Vickers, 1979), conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001) and social interactions (Shea et al., 2014). Appropriately, the neural mechanism underlying confidence is a subject of recent investigations in neuroscience (Kepecs, Uchida, Zariwala, & Mainen, 2008; Kiani & Shadlen, 2009).

This extensive study of confidence is motivated by its fundamental role in daily life situations. For example, the operation of control mechanisms in goal-driven behavior relies on decision-confidence, which serves as an internal, subjective form of feedback signal that can help assess progress towards one's goals. Consider a student taking a multiple-questions exam: The confidence level the student feels in the correctness of her answer will determine whether she should spend more thought on that particular item or proceed to the next one. Self-reports of confidence also play a crucial role in social interactions, where they affect the reliability attributed to information reported by others (Shea et al., 2014). The ubiquity of confidence judgments, in both daily life and the cognitive sciences, attests to the significance of understanding the psychological mechanisms that underlie them.

The critical property of decision-confidence that enables and justifies this broad usage of confidence judgments is their *positive resolution* i.e., the positive correlation between confidence and decision correctness: the higher the confidence, the more likely the decider is to be correct in his or her decision. In the current paper we examine a fundamental attribute of the mechanism underlying confidence judgments and their positive resolution. Specifically, we focus on the source of information used to calculate confidence and ask when is this information collected. According to one influential family of theories, the *single information-collection stage theories* (henceforth, single-stage theories), confidence is based on *aspects of the decision process* such as its duration, a feeling of effort or simply a different calculation involving the *same* evidence that was used to determine the decision. Importantly, such theories maintain that even if confidence is calculated 'offline' i.e., after the decision has been made, its calculation is confined by the aspects of the process that led to the decision. An opposing family of theories, the *dual information-collection stage theories* (henceforth dual-stage theories) stresses the importance of novel evidence, which is collected only after the decision has been made, as an input to the confidence-calculation process. Such theories thus deny that confidence is determined based solely on aspects of the decision process.

Our experiments were carried out to distinguish between these families of confidence theories by testing the effects of post-choice perceptual availability manipulations on the resolution of confidence judgments. To anticipate, our results provide support for dual-stage theories. We find that during the time lag between the decision and confidence responses, participants continue to collect information about the choice alternatives from the environment and this information affects the calculation of confidence judgments.