CAPTURING DECISION CONFIDENCE THROUGH RESPONSE TRAJECTORIES AND WILLINGNESS TO GAMBLE

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Abstract

We aimed to investigate whether action dynamics could be employed as an objective measure of decision certainty and the relationship between certainty and confidence. Twenty-eight participants were required to view a random dot kinematogram display and report the dominant dot direction by moving the computer mouse. Directly following this, they were required to report the amount of points they were willing to bet that the answer they gave was the correct one. Coherence of the stimulus was experimentally manipulated and participants were required to complete 11 experimental blocks, each containing 48 trials of varying dot coherence. Mouse trajectory information was not predictive of post-decision certainty but was strongly related to decision accuracy. The findings were in line with a view of confidence as an evaluation of evidence which continues to accumulate after a decision.

Typically in our day to day lives, as we make a judgement or decision, it is followed by a subjective sense of certainty that the right decision was made. This feeling of certainty in our choices is commonly termed decision confidence. In the context of perceptual decision making, two current accounts suggest different mechanisms behind formation of confidence. Van den Berg et al. (2016) argue that confidence arises from the same evidence accumulation mechanism that underlies the formation of the original decision. In contrast, Murphy et al. (2015) propose that confidence is a product of a higher-order meta-cognitive process evaluating evidence beyond the initial decision. Most recently, Fleming and Daw (2017) proposed a model of second-order decision confidence, which generalizes and unifies these two approaches.

The current study investigated whether characteristics of participants hand movements can act as an objective measure of on-line decision confidence. Comparing this measure to both performance accuracy and subjective confidence reports provides further insight into the process underlying retrospective confidence. Participants were required to make a perceptual discrimination task under differing levels of certainty and subsequently supply a measure of post hoc confidence. While previous research has often looked exclusively at associations between performance on a task and subsequent confidence judgements, the current study looks at associations between performance accuracy, confidence reports, and response trajectories. In this way, this research aims to provide another layer of evidence to the debates on the nature of decision confidence.

Methods

Undergraduate psychology students ($N = 28$, 4 male, 24 female, mean age 19.6 years) completed an experimental session in exchange for course credit. All study procedures

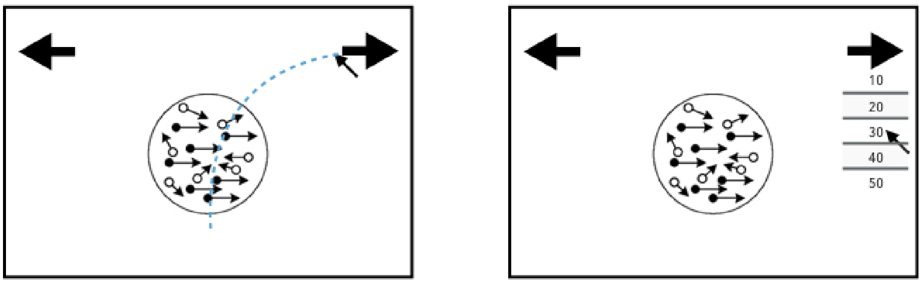

Fig. 1. Experimental setup: response screen during initial decision (left panel) and gamble selection (right panel)

employed were approved by the Research Ethics Committee at the National University of Ireland, Galway.

Participants made a series of 528 perceptual decisions, each followed by a "gamble". On each trial, participants were asked to judge the prevalent direction of a random dot kinematogram (RDK). The dot generation algorithm employed in this study was based on that of Shadlen and Newsome (2001) and programmed using PsychoPy (Peirce, 2007). The participants indicated their choice by moving the mouse cursor from the starting position at the bottom centre and clicking on one of the response locations in the top corners of the screen (Fig. 1). The RDK stimulus was present on the screen until one of the response locations was selected. Mouse coordinates during the response were recorded at 60Hz.

Motion coherence (the probability of any particular dot being displaced in the stimulus direction) constituted one independent variable and was manipulated within participants. The experimental session required participants to complete 11 trial blocks, each consisting of 48 trials. There were four coherence levels presented within each block (0.032, 0.064, 0.128, 0.256). All experimental blocks contained 12 trials of each coherence level, randomly shuffled, with stimulus direction (left or right) randomly determined for each trial.

On choosing a direction, participants were required to gamble 10 to 50 points on their answer using a drop-down menu. If the correct direction was chosen, a participant gained the chosen points, and if they chose the incorrect direction, the same number of points was deducted from their accumulated score. Participants were told at the beginning of the experiment that the aim was to earn as many points as possible by the end of the session. Upon making a number selection, a feedback stimulus appeared on the screen informing subjects whether they had answered correctly and the number of points won or lost.

Results and Discussion

The present analysis excludes the participants who could not perform the task accurately enough. Specifically, we excluded 12 participants who had accuracy below 75% at the coherence level of 0.256 and/or accuracy below 65% at the 0.128 coherence level.

The rest of the participants ($N = 16$), as expected, were more likely to correctly discriminate the direction of the RDK stimulus with increasing coherence (Fig. 2). In approximately 50% of the trials, the mouse trajectories indicated that the participants changed their preference during the course of the trial. Such trials were labelled as

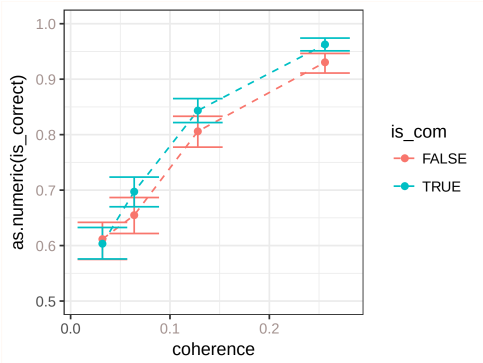

Fig. 2. Psychometric functions (averaged across 16 participants) for change-of-mind and non-change-of-mind trials.

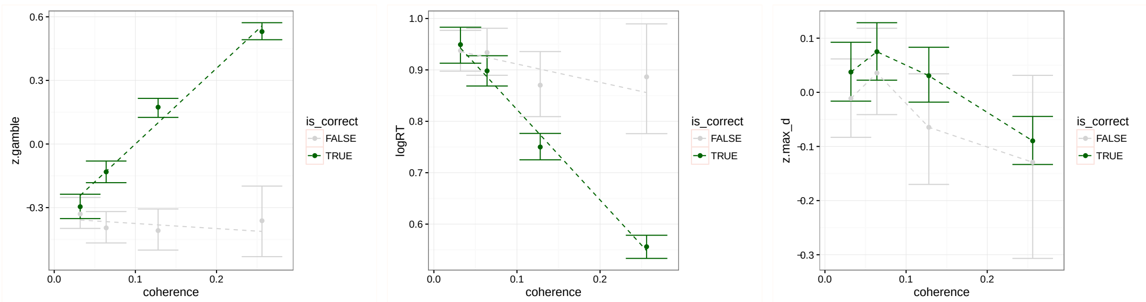

Fig. 3. Gamble value (z-scored), response time (log-scaled), and mouse trajectory curvature (z-scored) as a function of coherence for correct and incorrect trials. Correct responses are depicted in green and incorrect responses in grey. Whiskers denote bootstrapped 95% confidence intervals.

changes-of-mind. In accordance with the previous studies (e.g., Resulaj et al., 2009), changes-of-mind improved accuracy (Fig. 2). This might reflect the fact that after initial decision, additional evidence was continuously available to the participants until they clicked on one of the response locations.

The amount of points gambled after each decision increased with coherence for correct trials (Fig. 3, left panel). For incorrect trials, the amount gambled remained consistently small across coherence levels, which indicates that the participants could reliably detect their erroneous responses post-decision when the stimulus coherence was high (0.128 or 0.256). Together, these patterns suggest that gambled amount reflects subjective post-decision confidence of decision makers.

Previously in the mouse-tracking literature on value-based decision-making it has been suggested that mouse trajectories are linked to relative subjective value of the available options (e.g., McKinstry et al., 2008; Dshemuchadse et al., 2013; O'Hora et al., 2016). Here we hypothesize that in perceptual decision making, mouse trajectories may provide a measure of confidence within the response. To this end, we analyse response time and trajectory curvature as a function of RDK coherence.

As expected, response time decreased with coherence for correct responses (Fig. 3, centre panel). Error response time tended to remain high for all coherence levels. This is in line with consistently high values of gamble value, and thus reinforces the view of response times being related to decision confidence.

To measure trajectory curvature, we calculated maximum deviation (max-d) of each trajectory from the shortest trajectory towards the corresponding response area. In correct trials, max-d for correct trials exhibited non-monotonic relationship with coherence (Fig. 3, right panel). Although one might expect trajectory curvature to decrease as coherence increased (that is, as decisions became easier), mean max-d initially increased as coherence increased from 0.032 to 0.064. When coherence increased further to 0.128 and then 0.256, mean max-d decreased, in line with the expected pattern. As higher values of max-d in the present paradigm indicate greater rate of changes-of-mind, this finding is consistent with the post-decision evidence accumulation account of changes-of-mind (Resulaj et al., 2009).

Overall, our results suggest that changes of response direction during motor execution of a decision are informed by late-coming signal rather than by noise in the stimulus. Moreover, decision confidence as reflected in post-decisional wagering is related, but not equivalent to curvature of the response trajectories. Further investigations will shed light on the nature of relationship between within- and post-decision confidence.

Acknowledgements

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