Consciousness and Cognition 38 (2015) 107–117

Contents lists available at ScienceDirect

Consciousness and Cognition

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

Perceptual confidence demonstrates trial-by-trial insight into the precision of audio–visual timing encoding

Brendan Keane [a,*], Morgan Spence [a], Kielan Yarrow [b], Derek Arnold [a]

[a] School of Psychology, University of Queensland, Australia
[b] Department of Psychology, City University London, United Kingdom

ARTICLE INFO

Article history:
Received 23 July 2015
Revised 28 October 2015
Accepted 31 October 2015

Keywords:
Confidence
Metacognition
Temporal
Perception
Insight

ABSTRACT

Peoples' subjective feelings of confidence typically correlate positively with objective measures of task performance, even when no performance feedback is provided. This relationship has seldom been investigated in the field of human time perception. Here we find a positive relationship between the precision of human timing perception and decisional confidence. We first demonstrate that subjective audio–visual timing judgements are more precise when people report a high, as opposed to a low, level of confidence. We then find that this relationship is more likely to result from variance in sensory timing estimates than the application of variable decision criteria, as the relationship held when we adopted a measure of timing sensitivity designed to limit the influence of subjective criteria. Our results suggest analyses of timing perception and associated decisional confidence reflect the trial-by-trial variability with which timing has been encoded.

1. Introduction

It has repeatedly been shown that humans can successfully report when their perceptual judgements have been accurate, even in the absence of explicit feedback regarding task performance (for reviews see Fleming, Dolan, & Frith, 2012; Yeung & Summerfield, 2012). This insight has been demonstrated in a number of contexts, including the differentiation of motion direction (Zylberberg, Barttfeld, & Sigman, 2012), spatial frequency, orientation (de Gardelle & Mamassian, 2014), and when judging luminance-contrast (Song et al., 2011). This suggests that, in each case, humans have access to an accurate reportable estimate concerning the strength of evidence underlying their perceptual decisions. Therefore, confidence has been classified as a form of metacognition (Fleming et al., 2012).

Despite its demonstration in many types of perceptual judgements, metacognitive insight into human time perception has seldom been investigated. One study, however, has provided suggestive evidence. Allan (1975) had participants make audio–visual temporal order judgements, followed by a confidence categorisation (high or low) concerning their timing judgement. Visual appraisal of distributions of high-confidence order judgements showed a discrepancy relative to overall distributions (which comprised both high and low confidence order judgements). The different sets of distributions seemed non-parallel, suggesting different computational processes had been involved in judgements of the two temporal orders.

* Corresponding author at: McElwain Building, University of Queensland, Brisbane, QLD 4072, Australia.
E-mail address: brendan.keane1@uqconnect.edu.au (B. Keane).

http://dx.doi.org/10.1016/j.concog.2015.10.010
1053-8100/

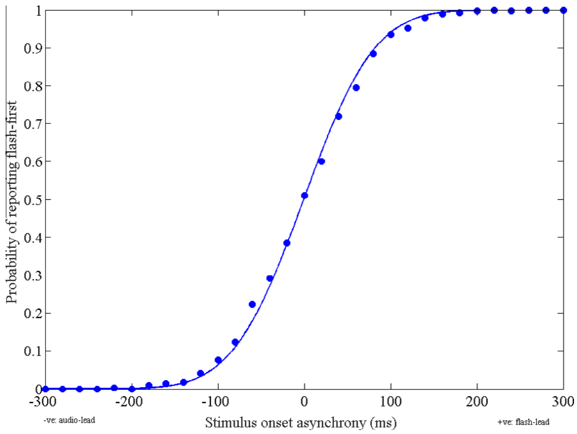

Fig. 1. Simulated temporal order judgement data. The arrival times of audio and visual signals at a central comparator are assumed to be variable from trial-to-trial, generating a Gaussian distribution of encoded arrival time differences for any given physical offset. Here mean arrival time differences are assumed to be equal to the physical timing difference, with standard deviations of 50 ms. These differences in encoded arrival time are compared against a fixed order criterion of 0 ms. Presentations yielding a negative encoded difference are reported as an audio-lead presentation, whereas presentations yielding a positive encoded difference are reporting as a visual lead. The prediction is well established analytically, but for comparison with subsequent simulations, here each physical stimulus onset asynchrony was sampled 1000 times.

Allan's (1975) observations have interesting implications, as they would contradict a prominent class of timing perception models. These assume that encoded signals must propagate to a common neural site, with relative subjective timing scaling with differences in arrival times at the central comparator (e.g., Sternberg & Knoll, 1973). Further, these models assume that neural propagation times vary from trial-to-trial, obeying a Gaussian distribution, and that encoded timing differences are referenced against fixed timing criteria (for instance, to denote when a given signal has preceded or lagged another). Predicted discriminant functions can take the form of a cumulative Gaussian, with a slope determined by trial-to-trial variance in encoded signal arrival time differences (Baron, 1969, see Fig. 1). For simplicity, we can assume an unbiased observer, such that the criterion used for categorising timing differences as denoting a lead or lag is physical synchrony (0 ms), with negative and positive encoded values prompting audio lead and lag categorisations respectively.

The above generic class of human timing perception models can be extended to capture confidence by assuming 2 additional criteria, one denoting the extent by which an encoded signal must fall under the fixed timing criterion to prompt a high-confidence *lead* response, and another denoting the extent by which an encoded signal must exceed the fixed criterion to prompt a high-confidence *lag* response. Low confidence is reported when encoded differences fall between these two confidence criteria. The important point of difference between predictions of this class of model, and Allan's suggestive report, is that they predict *parallel* high-confidence discriminant functions (see Fig. 2, left panel).

Response simulations, based on a generic model of human timing perception, reveal that this scheme also predicts a difference in low and high-confidence discriminant function slopes (see Fig. 2, right panel), something that Allan (1975) did not directly investigate. For audio–visual judgements, this implies one should transition from predominantly responding sound first, to predominantly responding light first, over a smaller expanse of test offsets when confident than when unconfident. This prediction depends on all combinations of order and confidence relying on the same source of information, in this case encoded signal arrival time differences, which vary from trial-to-trial (e.g., Sternberg & Knoll, 1973). This contrasts with Allan's suggestion, that discrepant processes underlie confident sound and light first reports.

An alternate possibility is that, instead of trial-by-trial variability in encoded timing differences, there is little or no such variability. Instead, discrepant low and high-confidence discriminant functions could result from people adopting variable decision criteria from trial-to-trial (Ulrich, 1987; Yarrow, Jahn, Durant, & Arnold, 2011; Yarrow, Sverdrup-Stueland, Roseboom, & Arnold, 2013). For instance, people might adopt more variable criteria when low in confidence. This would predict that confidence-based differences in the precision of timing perception should be minimised, or eliminated, by limiting the influence of subjective decisional criteria.

In this study we aimed to determine whether subjective confidence predicts the precision of human timing perception, and to assess whether high-confidence categorical discriminant functions for timing are parallel. We present two experiments. In Experiment 1 we show that high-confidence temporal order judgements are more precise than low-confidence order judgements, and that high-confidence light-first and sound-first discriminant functions are, on average, parallel. In Experiment 2 we show that the greater timing precision suggested in Experiment 1 for high-confidence trials generalises to objective performance in a task designed to minimise the influence of subjective decisional criteria. In combination, our data are consistent with models of human timing perception that assume Gaussian trial-by-trial distributions of encoded timing differences, which are referenced against fixed decisional criteria.