

## An extra short duration cue improves both accuracy and decision metacognition beyond expectations

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### Abstract

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**Introduction:** In real-life decision-making, in many cases, evidence becomes available separately over time. Individuals are able to integrate evidence well and make a decision after receiving double brief information pieces. However, it is not clear how confidence is formed in such circumstances. The present study aims to investigate the confidence of participants after receiving an extra piece of information.

**Methods:** In order to create a perceptual decision-making situation, an experiment was designed with random-dot-motion stimuli. In each trial, one or two information pieces were displayed to the participants, and participants had to declare their decision and confidence simultaneously. In order to understand the effect of the time interval between information pieces, the second piece was displayed to participants immediately or at most one second after the offset of the first piece. In addition to analyzing behavioral data, computational models were used to explain the integration of evidence and confidence formation.

**Results:** Accordingly, although the participants' accuracy in the experiments containing double-piece trials improved more than expected, the confidence in these trials was not much different from the single-piece trials and was less than the prediction. Also, the metacognitive sensitivity of individuals, which indicates the coordination of accuracy and confidence, improved more than expected in double-piece trials.

**Conclusion:** These results revealed that providing brief and gradual information leads to more confident and sustainable decisions despite the time gap between presenting evidence. These results are applicable to marketing and behavioral economics.

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## Extended Abstract

### Introduction

In many cases, when making real-life decisions, the evidence does not come to a human on a continuous basis; instead, the individual receives separate pieces of evidence during a period. While previous studies supported

the ability of humans to integrate information perfectly from separate pieces of evidence to improve their accuracy, confidence formation is controversial. Decisions are often accompanied by confidence, which is closely

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related to changes of mind, attentional bias, and error prediction. Furthermore, a more confident individual can impact others' decisions. A decision is held when the accumulated evidence for one option, called a decision variable, crosses a threshold or bound. In addition, confidence originates by mapping between the decision variable and the probability that a decision relying on this decision variable will be correct. The computational description of confidence in decision-making is significantly controlled by the attendance of both decision and confidence performance.

Consequently, suboptimalities in confidence could be caused by noise. When we need to make a decision based on discrete pieces of evidence, the decision is determined by integrating the decision variable of cues. As a result, the confidence can be estimated as the likelihood that the decision is correct based on gathering discrete pieces of evidence, but a theoretical prediction is that the temporally separated sources of evidence will affect confidence.

## Methods

To specify confidence formation in the presence of discrete pieces of evidence, we tested 12 healthy adults using a Random Dot Motions (RDM) paradigm. Participants had to distinguish the predominant direction of moving dots by saccadic eye movement after receiving one or two pieces of 120ms of information (cue). The interval of two pieces was selected randomly from 0, 120, 360, and 1080ms. The direction and the strength of the motion stimulus changed randomly trial by trial. However, the direction of both pieces in double-piece trials was the same, and participants were aware of that. While on single-piece trials, motion coherence was randomly selected from these following values, 0, 3.2%, 6.4%, 12.8%, 25.6%, 51.2%, on double-piece trials, motion strength of each piece was randomly chosen from, 3.2%, 6.4%, 12.8%. Color-coded targets helped subjects, indicating

confidence simultaneously. Altogether there were 200 trials in each block and four blocks for each participant. In addition to empirical analysis, this study applied a set of computational models to discuss how accuracy and confidence have changed receiving two brief RDM stimuli. In binary decisions, signal detection theory has provided a simple yet powerful methodology for distinguishing between an observer's ability to categorize the stimulus and the behavioral responses. Moreover, it can also provide a method to characterize how well the observer performs to report confidence ratings. Accordingly, the present study uses this model here too. First, we fitted a standard signal detection model to participants' choices and confidence to directly estimate each participant's evidence sensitivity ( $d'$ ), confidence criteria, and metacognition sensitivity (meta- $d'$ ). Second, based on the task's nature and considering the single-piece trials' data, a perfect accumulator model and an optimized model were fitted to participants' choices and confidence. These models were used to predict the accuracy, confidence, and metacognition of double-piece trials. The current study evaluated the models both quantitatively —Maximum Likelihood Estimation— and qualitatively —parameter recovery exercises in which data were simulated from models' parameters.

## Results

The results showed that participants integrate the decision evidence invariant to gap interval to form their decision and confidence after receiving the second piece of information. To address accuracy variation in double-piece trials compared to single-piece trials, the present study consider the accuracy of each coherence in single-piece trials as a baseline and measure the accuracy variation of any corresponding sequence in double-piece trials. Generally, in all combinations, accuracy increased. In contrast, when considering all the trials, confidence increased whenever the other piece was a strong piece but decreased or not

changed significantly while the other piece was weak. We separate correct and incorrect trials and do the same analysis for each separately. In correct-choice trials, the increasing effects were more considerable. Nevertheless, interestingly, in incorrect trials, the confidence decreased in all sequences. Although previous studies showed a positive relationship between accuracy and confidence, double-piece trials' confidence did not improve along with improved accuracy in the current study. This is in line with the concept of metacognition sensitivity, which means higher confidence ratings with correct responses and lower ratings with incorrect responses. The obtained data suggested that receiving an extra short piece of information improves participants' confidence in correct choices, but worsens participants' confidence in incorrect decisions. To discuss the metacognitive sensitivity across double versus single piece trials, we use signal detection theory. Results from computational models showed that the perfect accumulator could not predict the confidence of double-piece trials. Moreover, by optimizing the perfect accumulator, the model could predict the confidence in double-piece trials well. The evaluation of the models both quantitatively and qualitatively confirmed the superiority of the latter model. Based on the reported data and computational modeling results, participants reallocate their confidence criteria slightly after receiving the second piece to report their confidence more accurately.

## Conclusion

The investigations indicated that although participants integrate the decision evidence perfectly and improve their accuracy and decision metacognition, their confidence did not improve significantly. In that way, providing brief information over time is more effective in persuading participants to make a more sustainable choice and prevent changes in decisions. These findings have implications for many areas such as marketing and behavioral eco-

nomics; providing limited information over time helps people make more stable choices in purchasing goods or receiving services. Also, in situations such as elections, if the information presented in favor of a candidate is offered over time and in several phases, it can have a more significant impact and improve decision stability.

## Ethical Considerations

### Compliance with ethical guidelines

In order for the test conditions to be stable, instructions on how to perform the test were provided to the participants. The ethics committee of the Iran University of Medical Sciences (IR.IUMS.REC1399648) approved the experimental protocol. Written informed consent was obtained from all participants. They were assured that all information would remain confidential and would only be used for research purposes. The details of the participants were not recorded for privacy reasons. They were also allowed to leave the study at any time.

### Authors' contributions

Zahra Azizi: Conceptualization, data acquisition, analysis, visualization, writing original draft - review and editing; Sajjad Zabbah: Conceptualization, supervision, writing - review and editing; Azra Jahanitabesh: Supervision, writing - review and editing; Reza Ebrahimpour: Conceptualization, supervision, writing - review and editing.

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#### **Conflict of interest**

The authors declare no conflict of interest.