Dissociable Effect of Stimulus Fluency on Accuracy and Confidence in Perceptual Decision Making

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Abstract

Perceptual decision making relies on collecting evidence from stimuli to make an accurate judgement. The decision is accompanied by a sense of confidence based on the same evidence. Although the accuracy and confidence of a decision are often correlated, it is important to understand cases when they are dissociable. The goal of this study was to investigate qualities of the stimuli that lead to these cases. A dot motion experiment was performed where participants were asked to judge the direction of the motion and report their subsequent confidence in the decision. The motion of the dots was varied in two ways: the strength of signal was controlled by adjusting the tilt difference and the noise of the signal was controlled by adjusting the coherence of the motion. It was discovered that in cases with high coherence and low or medium tilt, confidence was higher, but accuracy was lower than cases with low or medium coherence and high tilt. From this it was concluded that coherence has more of an effect on confidence while tilt has more of an effect on accuracy, causing a dissociation between accuracy and confidence. These findings are important because they provide insight into cases of over and under confidence that can allow for us to better gauge the validity of the confidence judgement as it relates to accuracy depending on the qualities of signal strength and noise.

Introduction

Decision making and confidence judgement formation are multifaceted processes that researchers have been interested in modeling as a means of better understanding the factors that influence adaptive decision making, which is the mental process of reacting to change in stimuli. Humans have the ability to reflect on decisions and estimate the likelihood that they are accurate judgements. These confidence judgments play a crucial role in adaptive decision making (Bonaccio & Dalal, 2006; Boldt et al., 2017). They help us determine whether we are ready to commit to a decision, or whether we should collect more information to avoid making a mistake (Gardelle & Mamassian 2015). Understanding the relationship between the evidence given and the resulting confidence judgement can help us determine what factors make a confident decision and why.

In visual perception tasks, where participants are shown a visual stimulus and asked to draw conclusions, studies had shown that confidence can be positively correlated with choice accuracy (Peirce & Jastrow, 1884; Pleskac & Busemeyer, 2010; Baranski & Petrusic, 1994; Barthelmé & Mamassian 2009, 2010; De Gardelle & Mamassian 2014, 2015). However, this generalization was not tested with many variations of visual stimuli. Therefore, a recent study was conducted to challenge the applicability of this correlation. To accomplish this, participants were asked to determine whether lines were slanted more or less than 45 degrees. The degree of tilt of the slanted lines was varied as well as their clarity. In this previous study, it was found that the clarity of a stimulus has a relatively small effect on subjects' accuracy but a very large effect on their confidence. This indicates that there is a need to better understand cases where accuracy and confidence are dissociated.

In this novel study, participants were asked complete a computer-based visual decision-making task. Subjects were asked to determine if sets of randomly moving dots in a circle moved toward a point on the edge of the circle that is either clockwise or counterclockwise of 45 degrees overall. Here, the difficulty of the task was varied by controlling the difference in angle of movement compared to 45 degrees and coherence of the dots. The program set stimulus difficulty using a training block that each participant completed at the beginning of the testing session. Stimuli were varied by "tilt" and "coherence" in order to determine the correlation of these conditions on accuracy and confidence.

The goal of this study is to determine characteristics of the evidence, in this case the tilt and coherence of the moving dots, that lead to over or under confidence as it is related to accuracy, by expanding on previous work using different stimuli. It is important to investigate these metacognitive processes to improve recognition of scenarios where confidence may be skewed by the quality of sensory evidence. This can help individuals better recognize the validity of their confidence in decision making.

Literature Review

Decision-making is part of everyday life. Adaptive decision-making is crucial to survival and is largely influenced by feelings of confidence and how it relates to accuracy. In the past decade, behavioral studies in humans and monkeys have aimed to explain specific relationships between these metacognitive functions. Specifically, researchers have investigated ways to manipulate visual stimuli to control for resulting choice accuracy, confidence or other elements of the decision, such as reaction time.

It has been proven that the relationship between accuracy and confidence can be dissociable in certain cases. For example, in a common binary decision task where a subject is asked to determine the direction of moving dots in one of two ways, the stimulus can be manipulated such that stimulus is varied in elements related to the effects on reported confidence, leading to no correlation between accuracy and confidence (De Gardelle & Mamassian 2015). This means that in such tests, dots can move coherently or incoherently—i.e. noise, variability, reliability, etc. and dots can move close to a boundary or far from a boundary—i.e. strength, mean, etc. and these variations affect the resulting accuracy and confidence disproportionately (Zylberberg et al. 2012; Gardelle & Mamassian 2015; Spence et al. 2016).

The mechanism of the accumulation of evidence theory states that sensory information is sequentially sampled until sufficient evidence has accrued to favor one decision over another or others. This can be used to explain the effect of stimulus signal-to-noise ratio, classified by the strength 'signal' and reliability 'noise' of the visual, on decision speed, accuracy and confidence. The higher signal has been shown to contribute to higher decision speed, accuracy and confidence. This is shown in the same type dot motion task as explained before. In both humans and monkeys, increasing the noisiness associated with the movement of the dots led to faster and more confident decision-making, just as the accumulation framework predicts (Zylberberg et al. 2016). The results suggest that the brain does not always gauge the reliability of the evidence.

It can also be shown how the signal detection theory, the ability to differentiate information signals from noise, can explain how quality of the evidence depends on its reliability. To this effect, in a study by Zylberberg et al. 2014 where subjects were asked to determine the orientation of bars, evidence strength and reliability were manipulated independently; the resulting choice accuracy and confidence ratings suggested that subjects did not optimally adjust their estimate of stimulus reliability according to the ambiguity of the evidence. This suggests that subjects' overconfidence in trials with unreliable evidence is caused by a reduced sensitivity to stimulus variability. Boldt et al. 2017 demonstrated findings that in a task where subjects were ask to determine if the average color of an array is red or blue, people struggle to assess the difficulty of a task at hand and fail to shift their confidence ratings to match changes in their choice accuracy for stimulus mean, but not stimulus variance.

This previous literature can be advanced with new experimental procedures. The current studies address the need to investigate a case of accuracy and confidence dissociation, where the signal-to-noise ratio is well controlled and calibrated. The results yielded from the novel stimuli and variation methods will be integrated with the decision making and confidence models to better explain the mechanisms of these metacognitive functions. A better understanding of these functions can help us explain how the brain makes a decision and how we compute confidence based on the evidence we see. This is important because we can begin to acknowledge how valid our feelings of confidence are and improve our decision-making processes.

Methods

Participants

The dataset is composed of n = 21 students ages 18-28 at Georgia Tech. Ten out of 21 were female. Participants were compensated with course credit for participating in the study. This demographic was accessible to the lab and yielded willing volunteers at no cost. All participants had normal or corrected to normal vision in order to ensure their ability to properly see the computer graphic stimuli. All participants gave informed consent before participating in this experiment. The study was approved by the Georgia Tech Institutional Review Board.

Stimuli and Apparatus

Participants were evaluated on a computer-based visual assessment. This was developed by members of the lab and conducted through a MATLAB user interface for ease of usability. Sensory decision making was evaluated with a field of moving dots within a black circle. The circle was defined with a radius of 128 degrees of visual angle and was displayed for 0.695 seconds. The dots moving within the circle were 3 degrees of visual angle set to be displayed for 0.3 seconds. The objective of the participant was to determine if the dots moved clockwise or counterclockwise with respect to 45°. This is a set of simple visual stimuli that could be easily manipulated for variations in coherence and tilt. Coherence of the dot movement was sampled from three values— low coherence = 0.3, medium coherence = 0.4, and high coherence = 0.7. The tilt of the dot trajectory was sampled from three values that were calculated for each participant base on a two-staircase procedure. A 2-down-1-up and a 3-down-1-up staircase were used in a training set of the experiment. From there the average threshold was set as the medium tilt condition. The low tilt condition was set to half of this value and the high tilt condition was set to twice this value. Participants reported two responses. The first was a binary decision on their determination of the dot direction—1 if clockwise, 2 if counterclockwise. Then the participant reported a scale ranking of confidence-- 1, 2, 3, or 4. The least confident being 1 and getting more confident respectively. Each participant went through a training set consisting of 1 run of 8 blocks with 30 trials each. Then each participant ran a session of 4 runs consisting of 5 blocks each. Each block consisted of 45 trials.

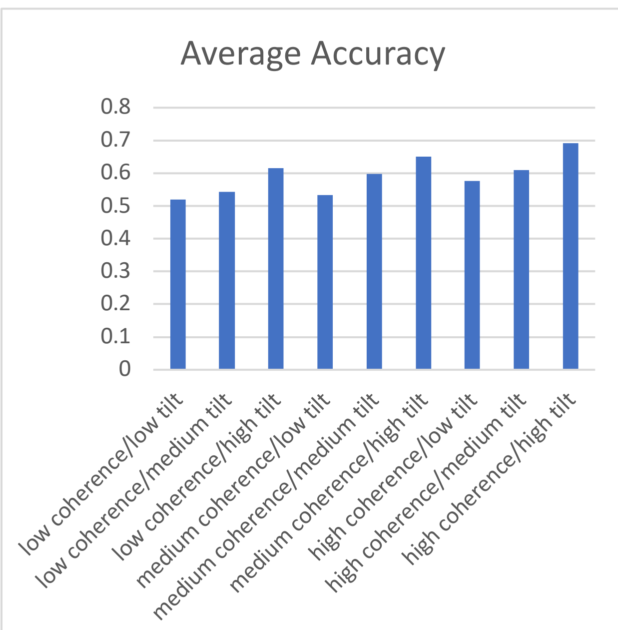
Analysis

The resulting average accuracy, confidence and reaction time for each participant was calculated for each of the 9 variations of dot movement —low coherence/low tilt, low coherence/medium tilt, low coherence/high tilt, medium coherence/low tilt, medium coherence/medium tilt, medium coherence/high tilt, high coherence/low tilt, high coherence/medium tilt and high coherence/high tilt.

Averages were taken across the 21 participants to evaluate the data set as a whole. Specific T-tests were run to compare certain dot motion variations for significant differences. These statistics were evaluated in order to determine relationship of each condition of the evidence with the participants' accuracy and confidence.

Results

The average across the 21 participants for accuracy (Figure 1a) and confidence (Figure 1b) was calculated for each stimulus condition, as addressed above.



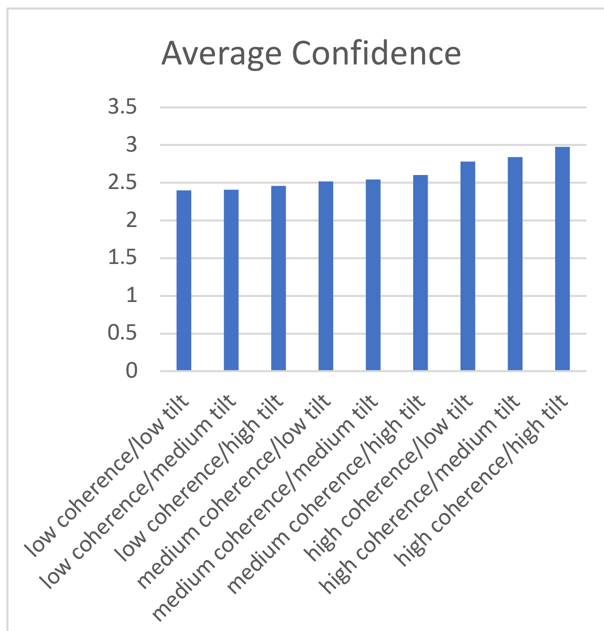


Figure 1. (a) The average accuracies for each stimulus condition. (b) The average confidences for each stimulus condition

Based on these results, the highest accuracy (69%) and confidence (2.97) were correlated and completed on the high coherence/high tilt dataset. Additionally, the lowest average across the 21 participants accuracy (52%) and confidence (2.40) were correlated and completed on low coherence/low tilt dataset. This suggests that on average the increased coherence and increased distinction of tilt led to an increase in both accuracy and confidence. However, it can be noted that accuracy increases with more distinction in tilt. Accuracy on the low coherence/high tilt set (62%) and medium coherence/high tilt set (65%) are higher than the high coherence/low tilt set (58%) and high coherence/ medium tilt set (61%). While confidence increases with more coherence. Confidence on the high coherence/low tilt set (2.78) and high coherence/ medium tilt set (2.84) are higher than the low coherence/high tilt set (2.46) and the medium coherence/high tilt set (2.60). This may suggest that accuracy is more affected by signal strength while confidence is more affected by signal noise.

To further develop this analysis, a two-tailed, paired t-test was run on the accuracies of the low coherence/high tilt dataset as compared to the high coherence/ low tilt dataset among the 21 subjects. It showed that the accuracies of the low coherence/high tilt dataset were significantly higher than the high coherence/low tilt ($p=0.0261$). A two-tailed, paired t-test was run on the confidences of the same two sets. This test showed that the confidences of the high coherence/low tilt dataset were significantly higher than the low coherence/high tilt dataset ($p=0.0282$). This emphasizes the findings from above that accuracy is more affected by signal strength (tilt) while confidence is more affected by signal noise (coherence).

Discussion

It is seemingly unexpected that there would be a condition where accuracy could increase without a confidence increase. The study sought to better understand cases where accuracy and confidence are dissociated. The moving dot stimuli were able to be adjusted in tilt and coherence to provide insight into the qualities of the evidence that contribute to the dissociation. The conclusion that accuracy is more affected by signal strength while confidence is more affected by signal noise is significant because the dissociation between accuracy and confidence is correlated with a change in signal. This finding has important implications about theories of confidence that claim that confidence is optimal. It yields an indication that the characteristics of the stimuli have a dissociable effect on accuracy and confidence; which is evidence of a bias in the way we process visual signals.

It appears that subjects are underconfident in cases where they do not believe the evidence is reliable- i.e. low coherence. By the evidence that the accuracy is higher, but the confidence is lower in the low coherence/high tilt dataset than the high coherence/low tilt dataset, it suggests that the lack of coherence in the motion creates uncertainty but does not cause as many inaccuracies. There is a bias in confidence when it comes to clarity and added noise has a significant effect. To the same point, subjects may be overconfident in the high coherence cases, which is concluded based on higher confidence but lower accuracy in the high coherence/low tilt dataset compared to low coherence/high tilt dataset. This finding is supported by a previous study (Boldt et al. 2017). In this previous study the prediction that evidence variance would have a more pronounced effect on confidence than evidence strength was supported when participants exhibited relative overconfidence when evidence was weak. Though this study evaluated subjects' perception on color, rather than motion, these studies reaching similar insights have larger impact on the way visual perception stimuli of different types affect choice accuracy and confidence.

Though this study may be limited by a small sample size, there is some significance in these results to establish correlations between accuracy, confidence and the characteristics of signal strength and noise of the stimuli. Noting that confidence heavily relies on the coherence of a signal, while accuracy is more related to the strength of the tilt signal, lets us know that these qualities of the evidence are able to create the dissociable cases between accuracy and confidence we sought to investigate. This conclusion provides the insight into cases of over and under confidence which can be used to better gauge the validity of confidence judgements. The noise of evidence may be indicative of a higher potential for one of these cases which means that the subject can be more aware of these cases and can lead to more informed decision making and confidence judgements.

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