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Interruptions Reduce Confidence Judgments: Predictions of Three Sequential Sampling Models

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Abstract

The relationship between confidence and accuracy has been modeled many times. This paper compares and contrasts three decision-making mathematical models (2DSD, Poisson, RTCON2) of confidence and investigates how each model predicts the effects of interruptions on accuracy, decision response time, confidence, and confidence response time.

Keywords: 2DSD; Poisson model; RTCON2; confidence; accuracy; interruptions; response time; decision-making

Introduction

In 2016, the U.S. Justice Department released guidelines for law enforcement on how to collect confidence judgments for witness identification ("Justice Department Issues New Guidance On Securing Eyewitness IDs," 2016). These evidence-based guidelines consider the role memory plays in confidence judgments.

Memory researchers have found that the more an item is rehearsed in memory, the more confident a person will be in the accuracy of that retrieval (Busey, Tunnicliff, Loftus, & Loftus, 2000). For witnesses, repeating a testimony prior to trial is not uncommon. As a result, by the time a trial occurs, the confidence a witness has about their testimony has increased beyond the confidence of their first testimony (Wixted, Mickes, Clark, Gronlund, & Roediger III, 2015).

Inflated confidence is a concern for the justice system because of the often replicated finding that the relationship between accuracy in memory and confidence is positive (DeSoto & Roediger, 2014; Dunlosky & Metcalfe, 2008; Roediger & DeSoto, 2014; Roediger III & Desoto, 2012; Roediger III & DeSoto, 2014; Wixted et al., 2015). Because this positive relationship is often noticed by laypersons, jury's mistake inflated witness confidence for accuracy. The Justice Department encourages law enforcement to guard against inflated confidence by recording confidence during the first testimony so as to better reflect the accuracy that the testimony happened as described.

.Although this policy change at the U.S. Justice Department is likely to result in higher quality evidence in courtrooms, formally modeling the relationship between confidence and accuracy has been very difficult because it has been hard to determine when confidence judgments begin. There have been many attempts to model the relationship between confidence and accuracy (see Dunlosky & Metcalfe, 2008; Pleskac & Busemeyer, 2010; Ratcliff & Starns, 2013 for a review). It seems intuitive that the process of forming a confidence judgment should begin after some choice has been made. However, Petrusic & Baranski (2003) showed that when a confidence judgment was required, participant's response times for the primary choice were longer than when the confidence judgment was not required. Petrusic & Baranski (2003) interpreted this finding to mean that at least some of the processing for a confidence judgment occurs during the primary judgment. As a result, many researchers have attempted to extend previous models of primary choice to account for confidence judgments.

Three of the most popular models to attempt to explain confidence judgments are 2DSD (Pleskac & Busemeyer, 2010), the Poisson model (Merkle & Van Zandt, 2006; Van Zandt & Maldonado-Molina, 2004), and RTCON2 (Ratcliff & Starns, 2009, 2013). Each model relies on sequential sampling to determine the selection of a choice. Sequential sampling models assume that information is collected from memory or sensory input and summatively translated to evidence towards a particular choice.

Evidence collection through sequential sampling is a common theme across all three models. According to each model, choice is based on the collection of evidence. Evidence is collected until a threshold is reached for one of the choice alternatives. Crossing a threshold and the subsequent response (e.g key-press) is the decision time for a primary choice. The primary choice is the evidence accumulation and response to questions like “Did you see item ‘A’ or item ‘B’ before?” Confidence time is the time it takes to make a confidence judgment about the probability that the primary choice was correct. The confidence judgment is a secondary choice in response to questions like “How would you rate your confidence on a Likert scale of 1 to 6?” Thresholds are variable and so can be determined in a trial-by-trial and person-to-person basis (Audley, 1960; D. Vickers, 1970; Douglas Vickers, 2014).

Below is a description of each of the three models. The goal is to briefly summarize each model and highlight how each model suggests confidence judgments are calculated from evidence accumulation and how primary choice may relate to confidence judgments (when specified).

2DSD

The 2-stage-dynamic-signal-detection theory (2DSD) was first introduced by Pleskac & Busemeyer in 2010 and suggests that confidence judgments involve post-decision processing of the primary choice. 2DSD is specifically adapted to a 2-alternative forced-choice task (2AFC).

In the 2DSD model, participants make a primary choice by collecting evidence that pushes a single counter towards one choice alternative or the other. When the counter reaches a criterion for one alternative, a primary choice is made. If a decision is prompted before a threshold is passed, the alternative choice that is closest to the counter is selected.

After a primary choice is made, evidence continues to be collected for a confidence judgment. Evidence continues to accrue for the single counter until evidence passes a threshold for a particular confidence judgment and a secondary choice is made. Each possible confidence response has a separate threshold. Similar to primary choice, if a choice is prompted before a threshold is passed; the confidence judgment that is closest to the counter is selected.

According to 2DSD decision time for primary and secondary choice is the product of drift rate. Drift rate is determined by the quality of the evidence collected. Because drift rate towards one alternative or the other determines how fast a choice is made, response time is a function of the quality of the evidence.

2DSD extends the idea that high drift rates lead to fast choices to confidence judgments. The often replicated finding that there is a negative relationship between confidence judgments and response times (Baranski & Petrusic, 1998; Petrusic & Baranski, 2003) suggests that lower drift rates will produce lower confidence responses.

Poisson Model

The Poisson model was introduced by Pike (1971;1973) and modified for confidence by Merkle & Van Zandt, (2006). The Poisson model assumes that in a 2AFC task, there is one counter of evidence for each of the possible primary choice alternatives. Counters accrue evidence for each alternative. Whichever counter reaches its respective choice threshold first is the primary choice. If the decision is prompted, whichever counter is closest to the criterion threshold is selected.

After the primary choice is made, evidence collection stops and a secondary choice for confidence is ready to be made. In the Poisson model, confidence is a function of the difference in evidence between counters. If the difference between the collected evidence is large, confidence is high. If the difference between the collected evidence is small, confidence is low.

The idea of confidence being generated by separate counters was made most popular by the balance of evidence hypothesis (D. Vickers, 1970; Douglas Vickers, 2001, 2014). The balance of evidence hypothesis suggests that the difference in evidence between counters is scaled to produce a confidence response. The Poisson model is unclear about whether or not confidence is scaled immediately after a choice is made or a computation is required first.

According to the Poisson model, decision time for the primary choice is the sum of the time to retrieve each piece of evidence and increment the winning counter. The model does not specify confidence as a second choice that is calculated as a post-decision. However, Van Zandt & Maldonado-Molina (2004) have suggested that additional evidence collection and post-processing could occur after a primary choice but may not always be necessary.

RTCON2

RTCON2 is a model of making confidence judgments only and not of primary choice (see Ratcliff, 1978 for their diffusion model of primary choice). As a result, it is unclear from RTCON2 how primary choice influences confidence judgments.

RTCON2 suggests that there is a separate counter for each of the possible confidence responses. A confidence judgment is selected when a counter reaches a predefined threshold. According to RTCON2, participants do not have access to the amount of evidence each counter has accrued and therefore can only make a choice when a counter has reached a threshold. In addition, because people do not have access to the evidence, there is no comparison between the amount of evidence for different confidence judgments.

Importantly RTCON2 differs from the original RTCON (Ratcliff & Starns, 2009) in that each counter for a confidence judgment is affected by the behavior of other counters so as to maintain no net difference. As a result, if evidence facilitates an increment in one counter, the other counters decrease so as to have a net zero effect.

Similar to 2DSD, RTCON2 also uses higher drift rates to explain faster response times and higher confidence responses.

Memory

One major component of the 2DSD, Poisson model, and RTCON2 models is their reliance on memory for their evidence counters. A sufficient model should be able to predict what happens when memory quality changes.

Many researchers have investigated the relationship between accuracy and confidence by manipulating memory (see Dunlosky & Metcalfe, 2008 for a review). One well-researched way of manipulating memory is using interruptions. A long history of research has shown a decrease in task performance (e.g increased response time, decreased accuracy, increased time to return to the task) following an interruption (Altmann & Trafton, 2007; Altmann, Trafton, & Hambrick, 2014; Cades, Boehm-Davis, Trafton, & Monk, 2011; Gillie & Broadbent, 1989; Trafton, Altmann, & Ratwani, 2011; Trafton, Jacobs, & Harrison, 2012).

More recently, confidence in the accuracy of a memory has been shown to be lower after an interruption (Aguiar, Zish, McCurry, & Trafton, 2016; Zish, Hassanzadeh, McCurry, & Trafton, 2015). In an experiment we replicate these findings and discuss the predictions of each of the three models.

Model Predictions

All of the models suggest that decision-making is the result of some form of sequential evidence collection. There are two primary differences between each of the models. First, decisions are either the result of the use of one counter for evidence (2DSD) or multiple competing counters (Poisson and RTCON2). Second, confidence judgments are the result of the winning counter choosing the confidence response (2DSD and RTCON2) or the winning counter choosing the time when the delta between multiple counters is used to calculate confidence (Poisson).

The number of counters (one or multiple) and the role of the counter (choosing a response or calculating the delta between counters) results in testable predictions for how interruptions will affect performance.

For all three models accuracy should be lower after an interruption because drift rates will experience more fluctuations when the quality of the evidence collected decreases. Fluctuations in drift rates can result in an error if noise allows for evidence to increment towards the incorrect choice threshold.

Drift rates also drive response time for all three models. Any decrease in the drift rate should increase response time. Because interruptions increase the amount of time to retrieve an item from memory, interruptions should increase decision response times and confidence response times.

As for confidence, 2DSD and RTCON2 predict that confidence decreases whenever drift rate decreases. Although 2DSD relies on one counter and RTCON2 uses multiple counters, both models suggest that confidence is chosen when one counter crosses a threshold for a confidence judgment. Alternatively the Poisson model uses two counters where confidence is the delta between the two counters. An interruption is likely to slow the increment of both counters equally. Therefore, the Poisson model predicts that confidence should be no different after an interruption trial than a non-interruption trial.

Given the predictions of these three models, the number of counters clearly does not matter when it comes to predicting accuracy or response time. The primary difference between the predictions of the three models is whether or not confidence will be the same after an interruption trial as compared to a non-interruption trial.

Methods

Participants

Fifty-five George Mason University undergraduates participated for course credit.

Tasks

Primary Task The primary task consisted of a simulated stock exchange where participants filled out Buy and Sell orders. Each order had 12 widgets that needed different information about the state of the stock market and the Buy or Sell request (e.g Stock Symbol, Exchange, Transaction Type).

To begin, participants were presented with an auto-selected Buy or Sell request at the bottom of the screen (colored gray) and a red arrow designating which of the 12 widgets required information first. The red arrow's location was randomized so that participants learned to start from multiple widgets.

Participants located and selected a "Start" button on the side of the widget designated by the red arrow. Selecting "Start" would teleport the widget to the bottom middle of the screen so that it became the main focus of the task.

Participants would use information from the gray-colored request and the stock market information along the middle of the screen to fill in the widget with the correct information. When the correct information was selected from the widget's dropdown menu, the widget would return to its original place on the screen (Figure 1). Participants repeated the process by finding information for the next widget. Widgets were completed left-to-right and top-down.

A trial ended when the active order was replaced by another auto-selected Buy or Sell request.

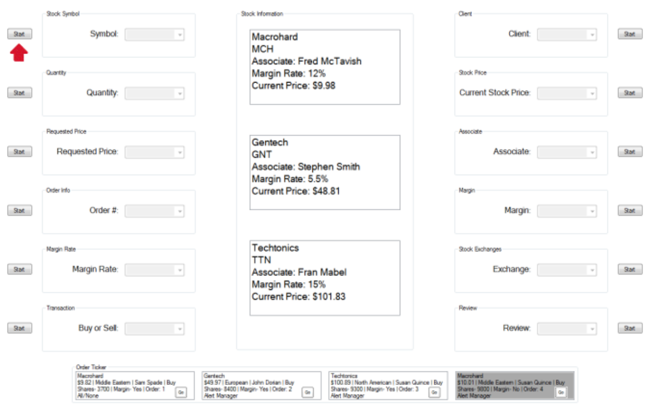

Figure 1: Primary task with auto-selected order and widget.

Interruption Task For half of the trials, participants were given a secondary task that served as an interruption. The interruption lasted for 20-seconds after completing an order. The interruption consisted of a series of addition problems. Addition problems completely occluded the screen until the secondary task was complete. Participants were instructed to complete the addition problems as quickly and as accurately as possible.

Signal Position Question After a trial ended or after a trial and interruption ended, participants were presented with a facsimile of the stock order screen. A blue arrow pointed to one of the 12 widgets with the question: "Is the arrow pointing to the next correct step?" Participants would respond by clicking the word "Yes" in the top left corner or the word "No" in the top right corner (Figure 2). Once the participant made a selection, they were presented with the next order to complete with a new Buy or Sell request.

The placement of the blue arrow was evenly split between the next correct or incorrect step.

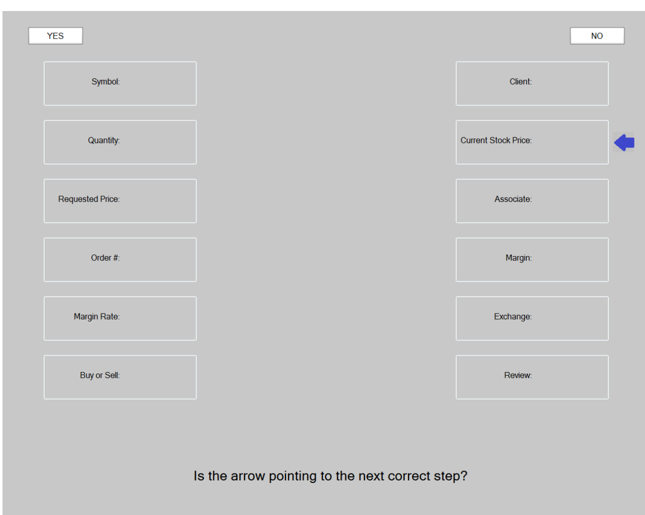

Figure 2: Signal Position Question with a blue arrow pointing at a possible next correct step.

Confidence Question Once the signal detection question was complete, the screen was replaced with a question that asked: "How confident are you that the [widget name] was the next correct step?" The participant selected a button on the bottom of the screen that represented their confidence on a scale of 1 through 6 with 1 being "Not at all Confident" and 6 being "Entirely Confident."

Design

The study was a 2 factor (interruption/non-interruption) repeated measures design.

Each participant had 32 interruptions across 64 trials. The order of screens participants saw was the primary task for 2-5 completed widgets, a 20-second secondary task after half of the trials, a signal position question, and a confidence question.

The 64 trials were equally divided between 2, 3, 4, and 5 completed widgets in length. The length of the trial was varied to reduce the likelihood that participants could prepare for an interruption and/or signal position question.

Each participant had half of the signal position arrows pointing to the next correct step.

Procedure

Participants filled out an approved IRB consent form as well as biographical information. Participants were seated approximately 47cm from the computer monitor. The task was first described using screenshots of the primary and secondary tasks as well as the signal position and question.

Three practice trials were completed that were each 12 widgets long. This was to give the participant the opportunity to experience the order of the widgets before being given partial orders to fill. The experimenter provided the opportunity for participants to ask clarifying questions about the behavior of the task. Participants could begin once the experimenter left the room and were debriefed and dismissed once finished.

Measures

Behavioral data based on mouse clicks was collected for all participants in addition to screen recordings. Accuracy for identifying the next correct step in the task, response time (RT) for identifying the next correct step in the task, confidence in identifying the next step of the task, and response time for the confidence judgment were calculated.

Results

Fifty-five participants made 3176 correct responses and 3520 confidence responses.

Behavioral Results

A within-subjects ANOVA between interruption and non-interruption trials show that interruptions hurt performance metrics for accuracy ($F(1,54) = 132.4$, $MSE = 0.59$, $p < .05$, $\eta^2=.56$), confidence ($F(1,54) = 135.7$, $MSE = 22.813$, $p < .05$, $\eta^2=.73$), decision response time ($F(1,54) = 134.8$, MSE

= 78,277,425, p < .05, η^2=.75), and confidence response time (F(1,54) = 30.47, MSE = 844,342, p < .05, η^2=.11). A summary of the means of each performance metric across interruption condition can be found in Table 1.

Table 1: Means of performance measures.

Performance Metric	Interrupted Trials	Non-Interruption Trials
Accuracy	82.9%	97.5%
Confidence	4.95	5.86
Decision RT (ms)	4493.96	2806.82
Confidence RT (ms)	1492.30	1317.08

Empirical Data and Model Predictions

All three models predicted the decrease in accuracy, the increase in decision response time, and the increase in confidence response time that appeared after an interruption trial compared to a non-interruption trial. Most importantly, only 2DSD and RTCON2 predicted a decrease in confidence after an interruption.

Discussion

In this paper we describe three sequential-sampling models of decision making and apply their predictions to the results of an experiment.

2DSD used one counter to make a primary choice and then subsequent post-decision processing to provide a confidence judgment once the single counter passed a threshold. The Poisson model used two counters to make a primary choice where the first counter to cross a threshold determines the time when a delta between the two counters is calculated for confidence. Finally, RTCON2 is a multiple counter confidence-only model where the winning counter crosses a threshold that informs the confidence judgment.

We compared the predictions of these three models to the results of an experiment where participants completed a task in a simulated stock market. Participants were interrupted 50% of the time and then asked to choose if a widget was the next correct step of the task followed by a confidence judgment.

This study replicated the results of many other interruption-based studies in that performance suffered after an interruption. An addition to previous work is that confidence response times are slower following an interruption.

In terms of model predictions, all three models can account for a decrease in accuracy after an interruption. All three models suggest that accuracy is a function of the fluctuations in the drift rate. Counters can reach the threshold for the incorrect choice first when there is more noise in the drift rate, particularly when the thresholds are lowered. To fully explain a decrease in accuracy after an interruption, each model would need to explain why there is more noise in drift rate and/or lower choice thresholds after an interruption trial than a non-interruption trial.

A strength of each model is a fairly comprehensive explanation for decision response time and confidence response time after an interruption. All three models suggest that response times are a function of the speed of evidence collection. As a result, anything that reduces the speed of evidence collection should reduce response time. While no link has been produced that shows that quality of evidence decreases after an interruption, there is certainly a large amount of literature showing interruptions increase retrieval time (Altmann & Trafton, 2007; Altmann et al., 2014; Cades et al., 2011; Trafton et al., 2011, 2012). An increase in retrieval time would slow down evidence collection and lead to longer decision and confidence response times.

As for confidence only 2DSD and RTCON2 were able to predict lower confidence judgments after an interruption. In both models confidence decreases when the drift rate is lower. Therefore, interruptions are likely to lower the drift rate.

The Poisson model is unclear about explaining a change in confidence after an interruption. Confidence in the Poisson model is driven by the balance of evidence hypothesis and calculated by scaling the delta between the counters. According to the Poisson model, confidence after an interruption should stay the same as before an interruption because both counters in a 2AFC would be affected by the interruption equally. Thus, the Poisson model does not predict the difference in confidence found in this study.

This paper compared and contrasted three mathematical models of decision making. The 2DSD, Poisson model, and RTCON2 can explain changes in accuracy with drift rate but do not provide a clear mechanism to explain the effect of interruptions. However, each model does have a fairly robust explanation of decision response times and confidence response times via speed of evidence collection. As for confidence judgments, it is easier for models to explain changes in confidence judgments when there is a single counter that chooses a response than models that use multiple counters to calculate the delta between alternatives.

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