A key component in understanding the content of a memory is the context in which that content occurred. This contextual component of memory is known as *source memory*, and its importance can be illustrated in a variety of applications. For instance, when identifying the suspect of a crime, memory arising from events at a crime scene will have very different implications than a chance encounter elsewhere. To successfully complete such an identification task, the witness needs to: 1) encode information about the suspect and the context in memory, 2) bind this information into an overall representation, 3) recognise the suspect at a later time, 4) retrieve the source memory representation, and 5) make a response decision on the basis of the retrieved representation.

## Models of Source Memory Retrieval

Characterising each of these components and how they interact is a task at forefront of memory research, and a variety of different models have been proposed to address this task. Source memory research has been largely concerned with the memory retrieval process, specifically whether retrieval is continuous or reliant on a threshold. These competing theories about retrieval make divergent predictions about the outcome of the subsequent response decision made on the basis of the retrieved information.

Continuous models of source memory predict that retrieved information may be inaccurate but not absent, allowing for a gradual decline in the quality of information retrieved (Banks, 2000; Mickes, Wais & Wixted, 2009). In contrast, discrete-state models hold that retrieval discretely fails, and so performance is comprised of either precise responses, or guesses when memory is subthreshold (Batchelder & Riefer, 1990; Klauer & Kellen, 2010). A third class of models can be described as a hybrid that draws on elements of both continuous and threshold processes, known as dual-process models.

## Dual-Process Models in Recognition Memory

The debate between continuous and discrete models of source memory is situated in the wider recognition literature, which has posed a range of various models to account for memory performance across experimental paradigms. While source memory is distinct from recognition memory, the two types of memory are often tested simultaneously, and models are accordingly developed to account for both types of tasks (Starns, Hicks, Brown & Martin, 2008). Dual-process models are a class of models which take this integrative approach, in which different kinds of retrieval mechanisms support different kinds of memory (Bowers & Schacter, 1990).Specifically, in the Yonelinas (1994) dual-process model, episodic memory involves a mixture of two processes—a fast familiarity-based process and a slower recollection process. Familiarity is defined in this framework as a quick judgment of whether or not an item has been encountered before based on the strength of its representation in memory (Yonelinas, 1994). Recollection is conceptualised as a slower search process for qualitative information about the item (Atkinson & Juola, 1974). Recollection is assumed to be a threshold retrieval process while familiarity is a continuous signal-detection process (Yonelinas, 1999). The basis for this theoretical assumption is that in recollection people either succeed or fail to retrieve information. While the level of detail retrieved may vary, Yonelinas (1999) argues that there is a threshold below which there is no information retrieved.

Within this framework, performance on an item recognition task is comprised of both familiarity and recollection processes, where targets which were studied will be more familiar than lures which were not (Yonelinas, 1994). If successful, recollection enhances recognition by providing details of the study event. Critically, both targets and lures have familiarity, and differ continuously on the degree to which they are familiar, but only targets can be recollected because they are associated with a study event. In source memory tasks, however, familiarity cannot be used to determine the source of items as they have all been studied, and are all equally familiar. Consequently, source memory was conceptualised as a pure recollection process, in that a correct response depends on successful recollection of contextual details of the study event.

Given that source memory is dependent on recollection in this way, and that recollection is thresholded, performance in source memory tasks should reflect a retrieval threshold. When forced to make a source memory judgement when recollection fails, participants can only guess in the absence of information. The dual-process model therefore predicts that overall performance on source memory tasks should be a mixture of two discrete components: informed responses and no-information guesses, depending on whether recollection succeeds or fails respectively.

**Recognition and Source Memory in Two-choice Tasks**

### Source ROC Predictions.

Traditionally, evidence both for and against a threshold in recollection has come from examination of Receiver Operating Characteristic (ROC) curves (Yonelinas & Parks, 2007; Yonelinas, 1999; Slotnick & Dodson, 2005). In a two-choice paradigm with two possible sources of information, each source in a continuous model is associated with a normally distributed memory strength, and these distributions overlap. As the criterion is varied, the ratio of hit rates to false alarms will be such that the resultant shape of the plot is curvilinear (Slotnick & Dodson, 2005). In contrast, in a discrete model, memory fails to meet either memory threshold in the overlap. As a result, the ratio of false alarms to hit rates across criterion points is constant, producing a linear ROC (Rouder, Morey, Cowan, Zwilling, Morey & Pratte, 2008). The dual process model, in which source memory is dependent on a thresholded process in recollection, also predicts linear source ROCs when familiarity is equivalent across both sources (Yonelinas, 1999).

### Conditioning Source Memory on Recognition Confidence.

The premise that recollection is thresholded was challenged by a reanalysis of the Yonelinas(1999) data by Slotnick and Dodson (2005), which conditioned source performance on recognition confidence ratings for each item. This reanalysis demonstrated that if source ROCs were plotted separately for different levels of confidence reported in the item recognition task, the highest confidence source ROCs were in fact curvilinear, contrary to the predictions of the dual process model. As items rated with lower recognition confidence were included, the shape of the overall source ROC became increasingly linear, and more consistent with the predictions of the threshold model. The authors argued that only the items that were recognised with high confidence contained diagnostic source information, and that the linearity of source ROCs observed by Yonelinas (1999) was an artefact of collapsing across all recognition confidence ratings, and was thus not evidence of a recollection threshold.

Yonelinas and Parks (2007) responded to the Slotnick and Dodson (2005) analysis by proposing that source ROCs are typically linear, but become more curvilinear under a number of conditions. On such condition was when an item and a source were treated holistically as one item, known as *unitised familiarity*. While this represented a concession of a continuous contribution under certain circumstances, Klauer and Kellen (2010) were later able to account for curvilinear ROCs using only discrete states by allowing for variable mapping between recognition confidence ratings and source memory thresholds.

## Continuous Report

From the above review, it can be seen that ROC data, which has been central in the debate surrounding source memory, has not been able to distinguish between the competing models of source memory retrieval. Harlow and Donaldson (2013) addressed the need for more diagnostic data by replacing binary decision outcomes with continuous report . In the Harlow and Donaldson (2013) continuous report paradigm, source information was provided by a point located on the circumference of a circle, which was paired with a word item and represented context. When later cued with that word, participants were required to reproduce the paired location, which allowed for an objective measure of error in the angle between the reported and true source locations. Continuously distributed source information allowed for measurement of not only response accuracy in source memory tasks, but also the distribution of response errors . Instead of categorising responses as either correct or incorrect as in a two-choice task, capturing a whole distribution of response error provides considerably more information, which can be more diagnostic of underlying models. The threshold and continuous models of source memory make divergent predictions about the distributions of response errors in such a task.

Under the threshold model, for any items that fall below the recollection threshold, responses will be guesses distributed uniformly across all possible response options. Items that are successfully recollected by exceeding this threshold then fall on a Gaussian distribution centred on the correct response with high accuracy and precision. A mixture of these two processes then produces a high-peaked, heavy tailed distribution (Harlow & Donaldson, 2013). This work is paralleled in the visual working memory literature, where Zhang and Luck (2008) found that the resolution of working memory representations were fixed, and items are therefore encoded in a discrete manner. Source accuracy data was found to fit the Harlow and Donaldson (2013) threshold model better than its continuous counterpart, which instead predicts that responses made with moderate memory strength would be reflected a wider spread of responses around the true location with no uniform guessing structure.

**Source Memory for Unrecognised Items.**

An additional dimension to this debate revolves around the existence of source memory for items which are not recognised. DeCarlo (200) built upon continuous models of source memory to propose that in addition to two response probability distributions associated with each source in a two-choice task, there was a third distribution for items which were not in memory. A mixture model that consisted of a process each for recognised and unrecognised items was found to account for source ROCs. Again using data from Yonelinas (1999) and Slotnick et al. (2000), Hautus, MacMillan, and Rotello (2008) improved upon this initial mixture model by introducing source-guessing for unrecognised items. With this mixture component, which describes a state in which source memory retrieval is simply not present, continuous models are able to produce similar predictions to threshold models without reliance on a source memory threshold. Consequently, continuous, discrete-state and dual-process models were all able to produce similar predictions about responses in two-choice source memory tasks, and were therefore all viable models of source memory retrieval.

Malejka and Broder found evidence that there was no source memory for unrecognised items. Our study kind of uses the same logic, we avoid implicit feedback by testing all items on source, unlike Starns

Hautus model said that source retrieval isnt even attempted for unreconigsed items, this can be an explanation from a continuous model to account for heavy tails in the data.

Predicts that if unrecognised items are excluded, the heavy tailed tails will disappear

Elaborate further empirical finding.

Two aims

Emprical, recognition phase, condition source on recognition to evaluate if a continuous model can account

Second is to model with circular diffusion model to determine the extent to which RTs constrain the results

## Decision-Making

In completing a memory retrieval task, not only do participants need to retrieve information from memory, they must also make a decision on how to respond based on the information retrieved. In this sense, the information retrieved from memory can be thought of as evidence for the decision process. Much of the existing body of source memory research, particularly in the emergent continuous report paradigm, lacks a rigorous account of properties of the decision making process. Past research in the recognition memory literature has demonstrated that when such decision processes are accounted for, conclusions that can be made about recognition memory diverge from those made when decision-making is not explicitly considered (Dube, Starns, Rotello & Ratcliff, 2012; Ratcliff & Starns, 2013).

Diffusion models have emerged as increasingly influential accounts of both response time (RT) and response accuracy data in decision tasks, and naturally explains well-documented phenomena like speed-accuracy trade-off effects (Ratcliff, Smith, Brown & McKoon, 2016). Diffusion models have also been used extensively in the past to model memory retrieval, and more recent research has proposed a general theory of memory and decision making in which decisions about stimuli in visual working memory are made using a diffusion process (Smith & Ratcliff, 2009). A counter-intuitive property of diffusion is that on any one trial, response and error RT are the same, its only when this varies across trial and are averaged that we get a slow error pattern

The diffusion model has additional sources of variability, including moment-to-moment variability in the accumulation of evidence and trial-to-trial variability in the quality of evidence entering the decision process (Figure 6). The former moment-to-moment variability relates to strength of the evidence provided by the retrieval process, and can be thought of as noise in the evidence accumulation process. The rate of evidence accumulation on any trial is known as the drift rate. Drift rate can vary across trials, with high drift rate trials resulting in high accuracy and fast RTs, while trials with lower drift rates resulting in slower and less accurate responses (Ratcliff, Smith & McKoon, 2015).

The relationship between accuracy and RT is intuitive: when evidence for the correct response is good, trial responses will be more accurate on average, and for each trial, the accumulator will move towards the correct boundary more than the error, resulting in higher drift rates and hence faster RT. If, on the other hand, decisions made on the basis of lower quality information will take longer to make, and will on average be less accurate. Consequently, when drift rate varies between trials, then the mean RT for correct responses will be shorter than mean RT for errors, because drift rates are faster in the former. This phenomenon, known as a *slow error* pattern,has been reliably observed when decision making is difficult (Ratcliff et al., 2016).

By introducing the Circular Diffusion Model, Smith (2016) extended the standard diffusion model, which models decision making between two discrete options, to account for continuous report tasks. In the circular model, evidence accumulation is defined as a vector in 2-dimensional space, in that it has both a direction towards any point on the circular boundary, and a distance travelled to reach that point. When a response is made, the magnitude of the drift vector determines RT like drift rate does in the standard model, while the point at which it exits the boundary determines the response outcome.

Although the circular diffusion model does not categorise responses as correct or incorrect, the same relationships between RT and response accuracy are predicted when RTs are considered as a continuous function of accuracy, quantifiable by the angle between the true and reported locations on the criterion boundary. Trial-to-trial variability in drift rate results in responses closer to the true location having faster RTs, while those further away will have slower RTs, producing slow errors. Variability in criterion leads to the inverse, producing fast errors.

Critically, while a fixed drift rate produces a von Mises response error distribution, the introduction of trial-to-trial variability in drift rate results in high, narrow peaks which reflect those trials with fast, accurate responses, while the subset of trials with low drift rates produce much wider error distributions. The effect of averaging across all trials is an overall distribution that can have a narrow peak and raised tails (Smith, 2016). In this way, the circular diffusion model is able to produce heavy-tailed distributions which have, to this point, been thought to characterise an underlying memory retrieval threshold.

## The Current Study

The primary motivation for the current research is to determine if such a model, which provides an elaborated account of the decision-making process, accounts for performance in continuous report source memory tasks without requiring a retrieval threshold mechanism. In doing so, we aim to provide an account of both response times and response error distributions in such a task. The experimental task also introduces a word imageability and concreteness manipulation, as rated on the MRC Psycholinguistic Database. Harlow and Donaldson (2013) selected words for low ratings on both metrics to prevent participants from visualising a concrete object in a source location. We draw stimuli from pools of low and high imageability and concreteness to examine the effect of these attributes.

In addition to this, we also aim to address the potential influence recognition has on performance in continuous source memory tasks by conditioning source responses on recognition confidence, as Slotnick and Dodson (2005) did in the 2AFC domain.

## Computational Modelling

Within this conceptual framework there are three alternative versions of the circular diffusion model that express different hypotheses about the process of memory retrieval. The first model is a single-process continuous model of source memory with trial-to-trial drift rate variability in decision-making. The second model is a threshold diffusion model can be constructed with two processes for decision making in information-driven and guessing states, in which the former has a positive drift rate and the latter has a zero drift rate. The third model is a combination of the first two alternatives may be considered, with a mixture of two processes as well as drift rate variability. The supplementary material attached to this paper demonstrates that the third alternative performs similarly to the threshold model, with the additional model complexity resulting in little to no improvement in fit. For conciseness in this paper, only the continuous and threshold variants of the circular diffusion model will be compared.

### Generalised von Mises

Introduce parameters, how its gonna be diagnostic

Unrecognised items did not appear to have source memory. Do a Rayleigh test on the unrecognised set. Even with those excluded, it looked like there was a high tail.

# **Method**

## Stimuli and apparatus

Stimuli were presented on a 20’’ Dell 2009W LDC Monitor, set with a screen refresh rate of 60 Hz. Software written in MATLAB controlled stimulus presentation and recorded responses. Stimuli consisted of words generated from the MRC Psycholinguistic Database, selected/ for low concreteness (minimum 100, maximum 456) and imageability (minimum 100, maximum 481) in the low stimulus set, and high concreteness (minimum 543, maximum 611) and high imageability (minimum 545, maximum 609) in the high stimulus set. Words were displayed in size 24 point “Courier New” white font positioned in the centre of a uniform mean luminance field.

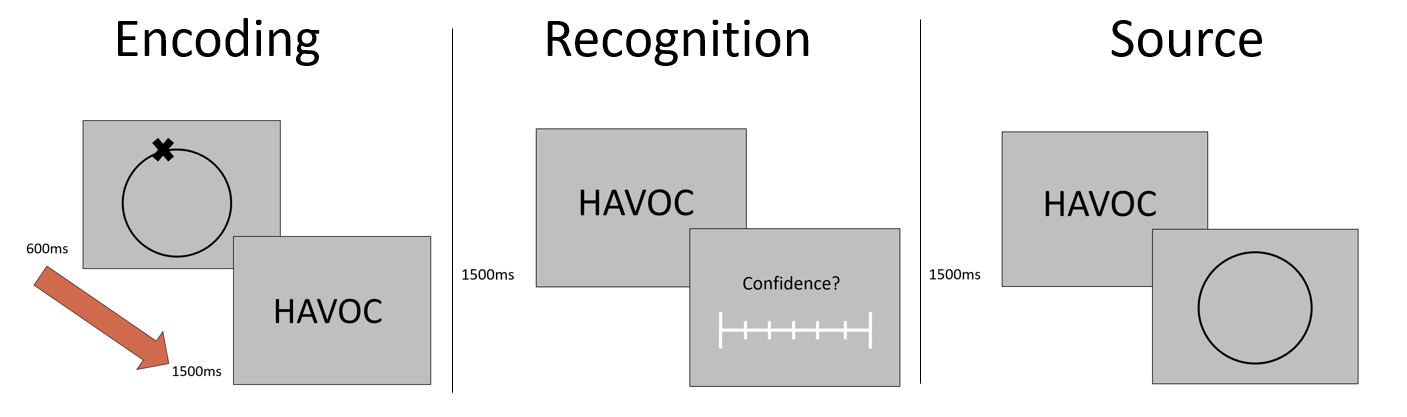
## Participants

Twenty participants were recruited online through the University of Melbourne SONA system. Each participant was expected to complete four 60-minute sessions, for which they were paid $12 at the completion of each session. One participant who did not complete all four sessions was excluded from analysis (*N* = 19). All participants were provided with plain language statements and consent forms, and gave informed consent prior to data collection.

## Design

Participants completed the experimental tasks over four sessions, Each of the four sessions consisted of 180 trials, which was broken up into 18 blocks of 10 items each. Blocks were comprised of a study phase, followed by a test phase (Figure X).

In the study phase, participants were presented with a black cross on a dark grey circle outline at the start of each trial for (600 ms), which was followed by the display of a word in the centre of the screen (1500 ms). To ensure source information was attended to, participants then indicated the former location of the cross on a now-blank circle using a computer mouse. Responses made within 6 degrees of the true target location were classified as a successful verification of attention and advanced participants to the next item. Responses further away were deemed unsuccessful, and the words “TRY AGAIN” was displayed for 1000 ms, the location was then re-presented for 250ms, and the verification task was repeated. Participants were then instructed to complete a distractor task, which involved 30 seconds of arithmetic problems. Following this, participants were shown a scrambled list of 10 previously studied items and 10 foils, and asked to rate each item on a six-point confidence Old/New scale. Finally, in the source memory retrieval task, participants were cued with the words for 1500 ms, and then indicated the recalled location by a clicking a mouse on the circumference of a grey response circle. There was no time limit on the decision task. A schematic for one trial in each of the phases is shown in Figure X.



# **Results**

**Data Screening**

Preliminary inspection of the data suggested that a proportion of the participants were performing the task with very low accuracy. A Rayleigh test for uniformity identified two participants whose data did not indicate evidence for a departure from uniformity in at least one condition, interpretable as completely random responding (Table X; Fisher, 1993). These participants will be referred to as a *low response accuracy* subgroup, with the expectation that the data from the remaining *high response accuracy* group will be more diagnostic for the purposes of distinguishing between the models.

|  |  |  |
| --- | --- | --- |
| Table X  Rayleigh Test for Uniformity | | |
| Participant | *χ2* | *p* |
| 1 | 0.60 | 0.74\* |
| 2 | 258.00 | <.01 |
| 3 | 86.76 | <.01 |
| 4 | 134.83 | <.01 |
| 5 | 133.01 | <.01 |
| 6 | 30.74 | <.01 |
| 7 | 208.44 | <.01 |
| 8 | 409.09 | <.01 |
| 9 | 3.35 | 0.19 |
| 10 | 476.01 | <.01 |
| 11 | 56.96 | <.01 |
| 12 | 283.65 | <.01 |
| 13 | 1.66 | 0.44\* |
| 15 | 6.69 | 0.04 |
| 16 | 159.31 | <.01 |
| 17 | 3.83 | 0.15 |
| 18 | 240.61 | <.01 |
| 19 | 12.65 | <.01 |
| 20 | 13.12 | <.01 |

\* *p* values greater than 0.05, indicating no evidence of a departure from uniformity for participants 1 and 13.

**Introduce Data subsets**

* + Recognition Confidence: Unrecognised (=<3), Recognised (>3), Recognised with High Confidence (=6)
  + Super-participants (?)

**Simple Mixture Model (Marginal Response Error)**

**Continuous and Threshold Model Comparison**

**Parameter Space of Generalised Von Mises**

* + Criterion Variability on High Confidence subset
  + Need to have a sense of why its coming out like a mixture model
  + QQ plots will be helpful, shows joint distribution.

# **Discussion**

In this study, we aimed to apply the Smith (2016) circular diffusion model to provide an account of performance in a continuous source memory task with an elaborated decision component. Being the first application of the circular diffusion model to the source memory literature, this study demonstrates that a source memory continuous report task like that of Harlow and Donaldson (2013) can successfully be modelled using a diffusion process.

In comparing the Continuous and Threshold diffusion model analogues of source memory retrieval, we show that the Threshold model is preferred. The relative advantage the Threshold model has in fitting the source data comes from the addition of a zero-drift mixture component. This finding holds when source responses are conditioned on successful recognition of the word item. This indicates that two components underlie responses in the task, in support of the original conclusion of the Harlow and Donaldson (2013) paper. Overall precision in the task was low, and varied substantially between participants. Set up future experiment with multiple correlated sources, see what happens to response and RT distributions when task is easier.

[finding of gvm, why we did it]. Within the parameter space of the Generalised Von Mises variant, best fits were attained when [kappa high, rho low]. This indicates that..

Methodological point: sequential presentation of source and item made task difficult, items may not be bound. Original point in doing this in Harlow and Donaldson (2013) was to prevent unitisation, but is circular in its reasoning. No reason that actual source memory should be temporally separated from memory for item, actually ecological validity argument would claim the opposite. Future experiment to present source and item simultaneously.