

# Information and Time in Absolute Identification

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## Background

The aim of this research was to investigate the time course of basic cognitive process in the absolute identification. Two experimental series were planned to examine at the time course of (i) stimulus sampling and (ii) response selection in a variety of standard and modified absolute identification tasks, and their implications for relevant models.

We are pleased to report that the research has proceeded as planned, with the exception of the addition of some experiments, and that the experimental work has so far generated two journal submissions (to *Journal of Experimental Psychology: Human Perception and Performance*, and *Journal of Experimental Psychology: Learning, Memory, and Cognition*; these are the nominated outputs), and that the grant has also part-supported modelling work that has generated two submissions (to *Psychonomic Bulletin & Review* and *Quarterly Journal of Experimental Psychology*). There is also a clear path for modelling the remaining experimental data for an additional submission, discussed below.

The task of absolute identification is designed to tap the most basic representational and perceptual limits of the human cognitive system. Stimuli differ on a single psychophysical dimension, of which examples include in hearing, the pitch of tones, and in vision, the distances between dots. On each trial, participants are asked to respond to each stimulus with a number corresponding to its rank in the set, with corrective feedback given. Despite the long history of this task (e.g., Wever & Zener, 1928) and its apparent simplicity, a precise understanding of the processes involved in its performance has proved elusive and competing explanations continue to be posited (e.g., SAMBA: S. D. Brown, Marley, Donkin, & Heath-

cote, 2008; EGCM: Kent & Lamberts, 2005; RJM-LBA: Matthews & Stewart, submitted).

Some of the recent theoretical progress in absolute identification has come in the form of an emphasis on response times in these models. This involves the incorporation of hypotheses regarding information processing throughout a trial. There are two major types of hypothesis that might be integrated into the time course of processing that differ in their sensitivity to the presence of the stimulus. One regards the processing that proceeds from an established perceptual representation — response selection. The other regards the establishment of the representation of the stimulus from its presentation — stimulus sampling.

The EGCM emphasises the importance of stimulus sampling. Stimulus sampling over the (possibly several presentations of a) stimulus is implicated across a range of tasks (Loftus & McLean, 1999; Lamberts, 2000; Hsieh & Saberi, 2007). Analogously to the different latencies of inclusion of separable dimensions in categorisation, the EGCM posits that each perceptual dimension has components that are gradually included into the representation. It is the quality of the representation that controls the probability of making a response at any point in the trial. Stimulus sampling and response selection do not have distinct representations: Response selection operates stochastically on the instantaneous stimulus representation.

In contrast, both SAMBA and RJM-LBA (RJM-LBA was developed with support from this grant, and is discussed in more detail below) separate stimulus sampling and response selection into serial stages. Stimulus sampling culminates in a magnitude estimate in a stage whose duration is assumed constant. In SAMBA, the magnitude es-

estimate is generated from selective attention and is on a scale from nought to one. In RJM, the magnitude estimate is generated from the stimulus-change (i.e., estimated difference of the current stimulus to the preceding stimulus) and the presumed value of the preceding stimulus on a difference scale that mimics the psychophysical dimension but does not have a stable relationship to the psychophysical dimension, only with the response dimension.

This magnitude estimate, augmented in RJM with scaling to a portion of the response range, determines the drift rates for the response accumulators whose activation increases deterministically at rates determined by competition amongst accumulators and the response strength for that accumulator. Crucially, the response strength is determined from the output of a mapping process that maps the estimate of the stimulus magnitude onto the response accumulators. In SAMBA, RT effects emerge from the mapping, which relates drift rates to difficulty/accuracy only incidentally, and the two dissociate (Donkin, S. D. Brown, Heathcote, & Marley, in press). In RJM-LBA, difficulty enters drift rates through edge effects, and the strong tendency to only produce responses that are in the right direction from the previous stimulus, but not difficulty from any perceptual locus.

In terms of predicted patterns of data for standard experimental designs, there is currently little to distinguish between the model. However, the models vary greatly as to the emphasis that they place on the underlying components that determine the responses participant make and the time it takes to respond. Despite the detailed modelling and the breadth of studies on absolute identification, there have been only a few studies that have attempted to investigate the time course of any of the component processes underlying performance in absolute identification. Thus, the present research addressed the problem of absolute identification by examining these constituent processes.

## Objectives

Our objectives were therefore to:

- To extend our understanding of the way information from simple perceptual stimuli is accumulated and integrated over time.

- To broaden the scope of existing models of absolute identification to manipulations of the time course of a trial, in a way that is generalisable to other paradigms.
- To provide data on the effect manipulations of the time pattern of stimuli on responses and response times in order to constrain models of absolute identification.

These objectives were all met across the several originally planned and additional experiments (total 20; the numbering below corresponds to the original proposal); in our development of the predictions of models described for Experiments 3 & 4; in EGCM and EBRW modelling described in a section below that was not included in the papers; and in the development of the RJM-LBA.

## Method and Results

### General Experimental Method

All our experiments were standard or modified absolute identification tasks. The modifications constituted variously (i) repetitions of the stimulus; (ii) the inclusion of masking; (iii) variations in the duration of the stimulus or stimuli; and (iv) the use of a signal-to-respond method.

In all cases, experiments were conducted with both the frequency (pitch) of auditory tones and the distance between visually presented white dots.

Participants were instructed as to the numerical labels for each stimulus at the beginning of a session, by simultaneous presentation of each stimulus with its label. Responses were then made on a standard computer keyboard (Experiments 1–4), or a custom response box (Experiments 5–12). The custom response box has several (12) response buttons arranged in a semi-circle, and a central waiting button that is held depressed until participants are ready to respond; this equalises the distance of travel for making each response, and removes the possibility of faster responses to certain stimuli because of a very biased resting position. Participants were always given corrective feedback after their response.

In Experiments 3–12, where we wished perceptual processing to be terminated at a specific timepoint, we used white noise masks, except where

noted. In vision, these were generated by filling all or most of the screen with each pixel on the computer screen taking a white, black or mid-grey colour at random. In audition, these were bursts of white noise that were higher in amplitude (by around 15dB) than the tones they were masking.

### Experiments 1 & 2

Our first investigation of the temporal element of absolute identification (Experiments 1 & 2 of the original proposal) related to our previous investigations of the impact of stimulus spacing — the size of difference between adjacent stimuli — on response times. Adelman and Stewart (2006) found with 500ms presentations of tones varying in frequency that narrow spacing yielded faster responses than wide, contrasting with the accuracy data, but Kent, Darowska, and Adelman (2006) found the opposite pattern — faster responses for the widely spaced stimulus set — with presentations of distances between dots until response.

We conjectured that one of the factors of duration of presentation or modality, would be critical in determining whether shorter RTs would be observed in narrow spacing. In our new experiments, we therefore compared 500ms presentations with presentations until response for both pitch of tones and dot distances with wide and narrow spacings. Contrary to our previous results, regardless of modality, it was the presentations until response that yielded faster responses for narrowly spaced stimuli than widely spaced stimuli, and 500ms presentations yielded faster response for wide spacing. It appears some other factor mediates the effect of spacing on response times.

Experiments 5 and 6, below, also include within-subject spacing manipulations with intensive testing of individual subjects. Even with the same stimuli, the effect was significant in different directions for different subjects. This suggests that in each case, we are not capturing a general directional effect, but rather that in each case, we are capturing individual sensitivity to particular stimulus characteristics, over individual differences that happen to average out to one direction or the other.

### Experiment 3 & 4

(These experiments were replaced with several; here we use a new numbering system to distinguish them.)

We went on to examine the manner in which participants can make use of multiple presentations of the stimulus, a manipulation suggested by Nosofsky (1983) who found increasing discrimination with additional presentations in absolute identification. We first performed a replication in our Experiments A1 & A2. We used our tone pitch (A1) and dot distance (A2) stimuli without masks. We found better discrimination in the two-presentation than the one-presentation condition, and further found much slower responses for the one-presentation condition. We had however observed in the original proposal that such a design did not control for the overall duration from the beginning to the end of the stimulus, and was subject to contributions from up to three components of stimulus sampling and representation.

The first of these corresponds to Nosofsky's explanation in terms of number of presentations that each (sufficiently temporally separated) stimulus presentation gives an independent (noisy) sample of the stimulus, and these can be combined to select a response.

Second, the total duration of stimulus presentation may have an effect. Ward (1991), for instance, has found increasing discrimination with increasing presentation duration; and our later Experiments 5 and 6 also replicate this (see below).

Third, residual echoic/iconic activation may act as an extended stimulus in the inter-presentation interval.

Our original plan was to factorially manipulate these factors, but we instead simplified the design into several sub-experiments testing each hypothesis.

In Experiments B1 and B2, we took the last of these points first. We added noise masks to the beginning and end of a the two-presentation trials. We then compared conditions with and without masking with white noise in the inter-presentation interval. Masking should prevent activation from echoic/iconic activation contributing any improvement accruing from the non-

stimulus interval. No advantage was observed for the unmasked version, and no response time difference, suggesting there was no role for such activation in the originally observed effect. We used masks in all non-stimulus intervals during a trial in the remaining experiments.

In Experiments C1 and C2, we turned to the issue of total presentation time of the stimulus. We controlled total trial time at 2500ms, and placed a stimulus at the beginning and end of the trial. We compared 500ms vs. 250ms total stimulus time: That is, we compared 2 x 250ms presentations with a 2000ms interval against 2 x 125 ms presentations with a 2250ms interval. There was no accuracy/discrimination advantage for the longer stimuli, nor a difference in response times. This suggested exposure duration did not contribute to the effect of additional presentations.

In Experiments D1 and D2, we therefore looked for the direct advantage for more stimuli under very controlled conditions. 3 x 167ms presentations (with 2 2000 ms inter-presentation intervals) were compared with 2 x 250ms presentations (with a single 4000 ms inter-presentation interval). The advantage in accuracy and discrimination was present only for the dot distance stimuli in accuracy — and there was also an benefit for both types of stimuli in RT — but all of these were considerably weaker than those seen in the simple addition of a presentation from Experiments A1 and A2. We concluded that the influence of independent representations was not always found, and did not contribute the majority of the effect in Experiments A1 and A2.

We therefore proceeded in Experiments E1 and E2 to manipulate the remaining uncontrolled factor from Experiments A1 and A2 (which had been controlled in our other experiments): the total time of the trial. We compared an immediate with a delayed response signal after a single presentation of the stimulus to reproduce the delay caused by the second stimulus in Experiments A1 and A2. This affected neither accuracy nor RT.

Conjecturing that this reflected an immediate decision after the stimulus in both cases, in Experiments F1 and F2, we instead manipulated the interval between a pair of presentations to vary the time from first onset to final offset, comparing a

200 ms interval with a 2000 ms interval. An advantage was found in proportion correct and response times for the long interval, but this only carried over to a measure of discrimination for the dot distances and not the tones.

We conjectured that the duration benefit occurred relatively early in processing. In Experiments G1 and G2, we therefore performed near-replications with an even shorter (50ms) short interval, and allowed the response signal to coincide with the onset, not the offset, of the post-stimulus mask. All of proportion correct, response time and discrimination showed the benefit for the longer interval for both tone pitch and dot distance. The differences observed were similar in magnitude to those from Experiments A1 and A2.

From these experiments, we conclude that the majority of the advantage from additional presentations comes from additional response selection time, and the contribution from stimulus sampling is comparatively weak. In terms of implications for models of these results, the EGCM has major difficulties, because within the EGCM only additional stimulus sampling can increase accuracy — and stimulus sampling cannot occur in the absence of a stimulus (especially with masking) — and response times are also linked to stimulus sampling. In terms of the effect of total trial time, a higher criterion in the long inter-presentation interval condition could account for improved performance within SAMBA and RJM. As it stands, the data are insufficiently constraining for mechanistic accounts of these strategy changes.

The work in this section has been written up and submitted (Guest, Kent, & Adelman, submitted-a) to the *Journal of Experimental Psychology: Human Perception and Performance*.

## Experiments 5 & 6

We (Experiments 5 and 6 of the proposal) went on to examine the effect of the duration of the presentation of the stimulus at shorter durations (10–300ms) extending previous work particularly by examining response times. This manipulation was combined with the standard manipulations of number of different stimuli (set size) and spacing. There was a considerable effect of presentation duration on accuracy, as well as of set size and

spacing. Accuracy reached asymptote rapidly, by ca. 40–55ms for tones and 67–100ms for dot distances. However, the effect of presentation duration on RTs was weak and inconsistent. The effects of set size and stimulus on RTs were by comparison strong and consistent.

For SAMBA (S. D. Brown et al., 2008) and RJMLBA (Matthews & Stewart, submitted), allowing psychophysical noise to decrease with exposure duration would allow the models to fit accuracy increases with increasing exposure duration, without changing the RT predictions, although this would not create a model of the stimulus sampling process per se.

We also attempted to simulate the effect in the EGCM, but the accumulation of perceptual samples controls RTs in this model, and the effects of perceptual sampling are rapid in the data. This means that if the model's perceptual parameters are set to capture the accuracy effects, it can no longer capture key RT effects, such as the advantage for stimuli at the edges of the range. We conjecture that the EGCM may be extended to incorporate the retrieval mechanism suggested by Kent and Lamberts (2008), thus even though stimulus sampling is completed rapidly, retrieval of information about the identity of the representation is slowly retrieved from memory. Additional mechanisms will likely to be needed to allow the model to fit accuracy and RT dissociations, however.

Our development of an EBRW-PE model for absolute identification to attempt to account for these data is described in the Modelling section below.

Previous examination of the bow effect and set-size effects on accuracy and RT has suggested a clear link between accuracy and RT in which stimuli and conditions with more accurate responses also have faster responses. This strong relationship between accuracy and RT has led to the development of absolute identification models in which response accuracy and RT are linked by a common difficulty factor, for example, the similarity between stimulus representations (Kent & Lamberts, 2005; Nosofsky, 1997). However, in both tasks there were clear deviations from this relationship. Increasing exposure duration improved response accuracy up to an asymptotic

level, but had small and inconsistent effects on RT. Similarly increasing stimulus spacing led to large gains in accuracy, but inconsistent effects on RT with some participants showing faster responding for widely-spaced stimuli and others showing faster responding for narrowly-spaced stimuli. Moreover, whilst most of these effects were relatively small, some were large (e.g.,  $\pm 100$  ms). Critically, these differences were observed in extensive testing conditions, and reflect something stable about the interaction between particular participants (i.e., individual differences) and the experimental conditions, and not chance variation.

If psychophysical noise is greater for narrowly-spaced stimuli and when exposure duration is short, then SAMBA predicts that stimulus spacing and exposure duration will influence accuracy but not RT. Similar considerations apply to the RJMLBA (Matthews & Stewart, submitted). On the one hand, averaged across participants, the absence of an RT effect would be correctly reflected in the model. On the other hand, however, the within-participant patterns were stable, and this dissociation is so severe that it would prevent the model fitting the observed slopes at the individual level.

We have written up the experimental portion of the work in this section of the proposal, and submitted to the *Journal of Experimental Psychology: Learning, Memory, and Cognition* (Guest, Kent, & Adelman, submitted-b).

### Experiment 7–12

The remaining planned experiments related to the time course of response selection. We merged Experiments 7, 9 and 11 (tone distance) and 8, 10 and 12 (dot distance) to use the same participants. The experiments involved a response deadline procedure in which participants had a limited period (400ms to release the red button, then 400ms to the black button) to respond after a signal. Some trials involved a single presentation, and the response signal was delayed after the end of the presentation by a variable interval. The other trials involved two presentations with the response signal at offset of the second, with the interval between the presentations varying. Participants first





