The role of memory processes in interval timing

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Abstract

The purpose of this paper is to understand the role of memory in human interval timing. We perform and model an experiment and from the data, show that past timing encounters can have an effect on current decisions. We elaborate this by using special conditions in the experiment where the subjects are divided into two groups, each group is shown a biased timing (either long or short) and their responses are recorded. Finally, we conclude it by testing our hypothesis against the experimental and model data.

Keywords:Memory;Timing;Experiment;Model;ACT-R;Bias;Long;Short;

Introduction

Timing has been an important mechanism in humans and animals for decision making and their behaviour (Buhusi and Meck (2005)).Our sense of time can be used to analyze relationships between events and predict actions. By modelling human timing, we can simulate human-like behaviour in cognitive models. Small tasks like crossing a road, playing music, driving a car require timing. Traditional timing is measured using the pacemaker accumulator model (Buhusi and Meck (2005)), it is straightforward but also powerful in explaining behaviour.
The internal clock in humans can be represented as a temporal reference memory (Taatgen and Rijn (2011)) which is a pool of their past timing encounters. These past experiences have weights, with the most recent experience holding more weight. These experiences are 'blended' together (H. Rijn, Gu, and Meck (2014)) to replicate the most recent timing. The main purpose of our experiment is to see how the temporal memory effects the timing by biasing the past experiences to the extremes and collecting the resulting replicated timings.

The Experiment

A total of 62 subjects participated in the experiment.

Method

The experiment consisted of showing a subject a green circle on the screen for a set duration. Then after a minor delay, they were shown a red circle and were asked to press any key when they think they have seen the red circle for the same duration as the green circle. We call this one trial.

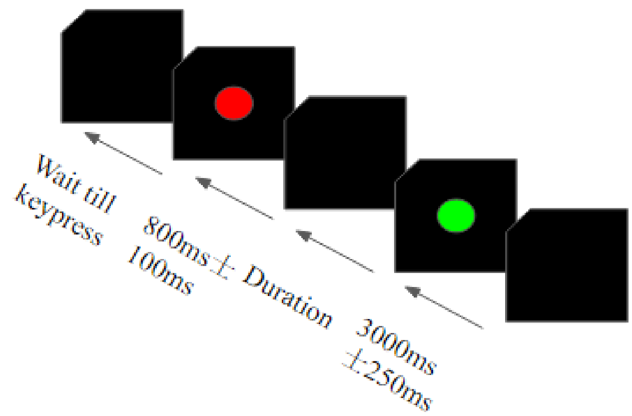

Figure 1: One Single Trial. First fixation point(delay) is 3000ms ± 250ms. The green circle is shown for 'Duration' amount of time. Then the second fixation point(delay) is 800ms ± 100ms. Then the red circle is shown until a key is pressed upon which the duration of the red circle is recorded.

The subjects were divided into two groups, group A and group B. The experiment consisted of a total of 160 trials for each subject, where the first 80 trials were categorized as block one and the last 80 trials were categorized as block two.

In the first block all subjects were shown durations picked from a uniform distribution of discrete durations. This was to give them a pool of initial timing experiences. In the second block, group A was shown durations with a bias towards the shorter duration i.e they were shown shorter duration more frequently than the other durations. Similarly, subjects of group B were shown longer biased durations in block two.
The experiment was performed using *OpenSesame* (Mathot, Schreij, and Theeuwes (2012)), the durations that were chosen for the experiment were $[1165, 1265, 1395, 1535, 1675]$.In block one, for 80 trials all subjects were shown each duration at least 16 times in a random order. We can say the $frequency$ of occurrence of each duration is $[16, 16, 16, 16, 16]$, each frequency corresponds to its respective value in the duration array. In block two, for group A (short biased) the frequency of durations shown is $[32, 12, 12, 12, 12]$, note that the frequency of occurrence for the shorter duration is higher, hence we say it is biased towards shorter duration. Similarly, for group B (long biased) the frequency of durations is $[12, 12, 12, 12, 32]$. Each duration has an equal chance of being selected for a trial, but the shorter duration appears in more trials than other durations in short bias and vice versa for long bias.

Hypothesis

Before we analyze our data, we want to build up a hypothesis on what our results may look like. We estimate due to pooling that the average response for each duration in block two will either shift upward or downward from block one depending on the condition(long or short respectively), here upward means longer response time and downward means shorter response time. The reason can be that the bias in block two is more recent than the experiences in block one which causes the shift either or upward or downward i.e if the past experiences contain more longer durations, the average response will also be longer and vice versa. We also assume that the shift for all different durations will be the same i.e the intervals in block two will have the same slope as in block one.

Results

We use R to analyze the data obtained from the experiment. There were a total of 62 subjects, one subject's data was erratic and was removed. We then analyzed the data of the remaining 61 subjects.
In Figure 2 we can see the plot of the durations shown vs the average response time for all subjects for group A and group B over block one and block two. We can observe that the slopes of the lines between block one and block two remain the same, but they are shifted according to the bias. This shift seems to be higher than expected which can be due to a gradual lengthening of responses from block one to block two. The reason for this gradual lengthening is unknown, but it can be a case study for future research. Apart from the lengthening of response, the experimental data seems to fit the hypothesis. Subjects in the longer group gave a longer response than the subjects in the shorter group. By the end of block one, the memory pool is filled with encounters of the durations, during block two the short or long durations are encountered more often which manipulates their responses.

Elements	**P value**	**Significance**
Intercept	0.02696	*
dur	$< 2e\text{-}16$	***
block	$< 2e\text{-}16$	***
list	0.45155	
dur:block	0.00179	**
dur:list	0.75373	
block:list	3.84e-06	***
dur:block:list	0.94669	

Table 1: Table from *lme*4. **dur**:effect of Durations presented, **block**:the block effect, **list**:effect of the bias condition(short or long), the others are an interaction between the elements. The significance of an element on $rtdiff$ can be shown by the P-value, if it is below a certain threshold(0.01), then we can say it has a significant effect.

We use *lme*4 (Bates, Mächler, Bolker, and Walker (2015)) in R to find the effect of duration, block and list(bias condition) on $rtdiff = ResponseTime - dur$. Table 1 shows us the P-values obtained from *lme*4, if the P-value is below a certain threshold(here we consider 0.01), it is more significant

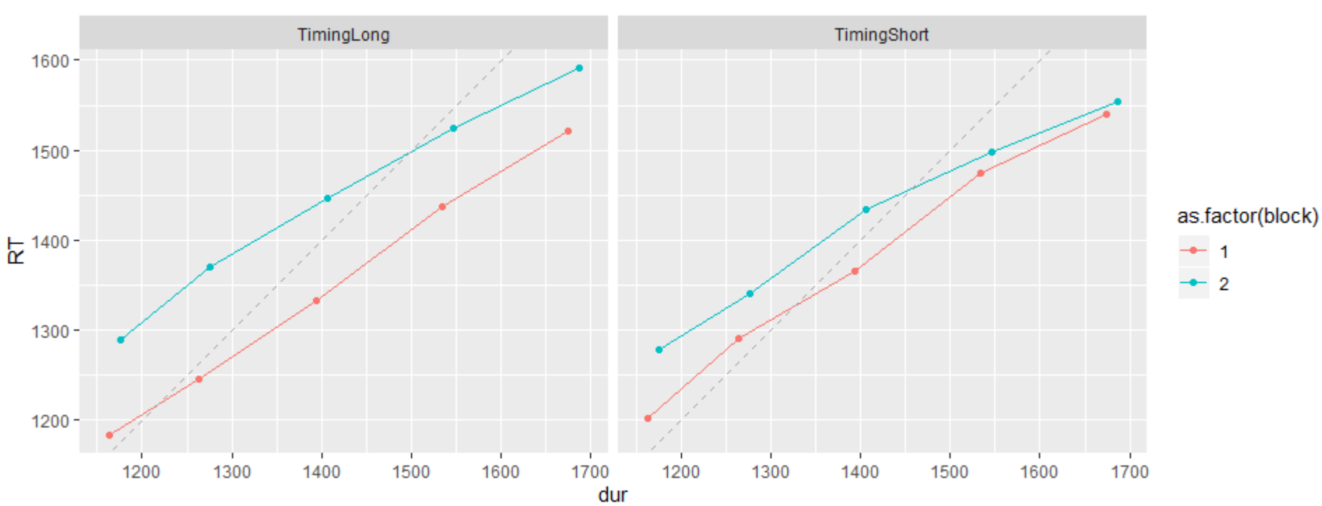

Figure 2: The Experiment data. Left: Long biased block 1 and block 2. Right: Short biased block 1 and block 2. X-axis: Durations shown, Y-axis: Average Response time of all subjects

on the value of $rtdiff$. Based on this, we can see that duration and block have the most significant effect, so we can say duration has a central tendency and reproductions are longer in the second block. Next, the block:list and duration:block have significant effects, as the duration effect in the second block is stronger it has a central tendency and in the second block as seen from the list effect, the productions in long condition are longer. One important thing to note is that there is no effect of list(bias condition) on duration.

The Model

We now try to model the experiment using ACT-R (Anderson et al. (2004)). The ACT-R is a cognitive model that can be used to replicate the functions of a human mind. It contains a declarative memory module that stores encounters of durations and will be able to retrieve them at will. We use a python implementation (H. van Rijn and Taatgen (2018)) of the declarative memory of ACT-R model. We use 60 subjects to recreate the experiment, where each subject is a separate ACT-R model with its own memory. The subjects are divided into two groups(Group A, Group B) for short and long bias conditions. Each subject is then processed through the experiment with two blocks of 80 trials each, similar to the original experiment. During each trial, a duration is selected randomly(still keeping track of the frequencies of occurrence), this duration is converted into pulses, which is the human representation of time(Pacemaker model) (Buhusi and Meck (2005)). These pulses are stored in the declarative memory as an encounter. When the model is asked to replicate the duration, it retrieves a *blended* value from all its past experiences giving more weight to its most recent encounter. This value is a pulse which is converted into the response time and recorded. In block two, there is a change in the frequency of durations based on the condition.

Model Results

Looking at Figure 3, we can clearly observe that in block two the longer biased response times are longer than the shorter response times in shorter bias.

Elements	P value	Significance
Intercept	0.01517	*
dur	$< 2e\text{-}16$	***
block	0.00123	**
list	0.18963	
dur:block	3.77e-15	***
dur:list	0.09318	
block:list	0.00246	**
dur:block:list	0.22797	

Table 2: Table from $lme4$ for model data.

Upon looking at the $lme4$ results of the model data in Table 2, we can see that duration still has the most significant effect, which implies central tendency. In second block, duration effect is also significant which also implies central tendency

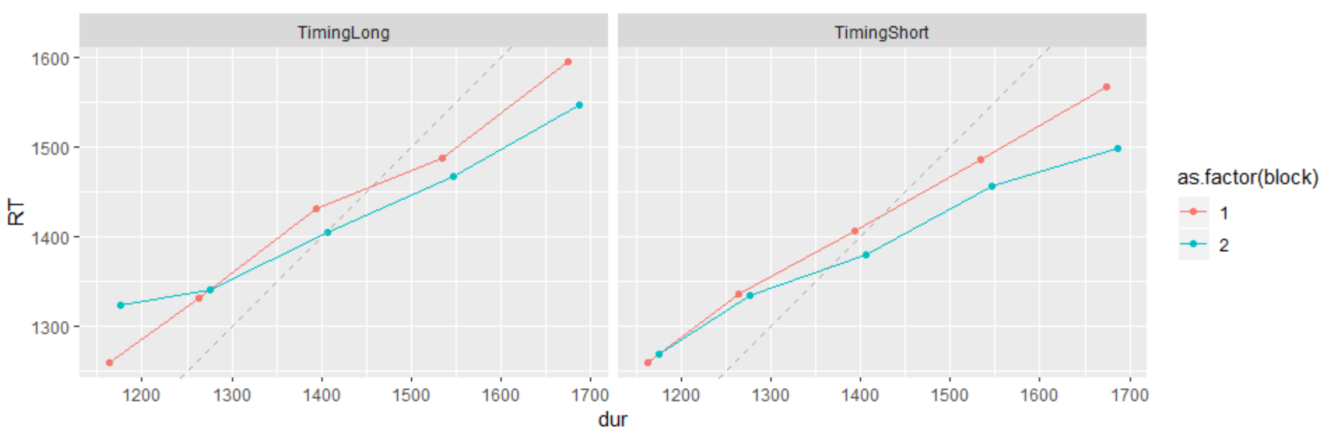

Figure 3: The Model Data. Left: Long biased block 1 and block 2. Right:Short biased block 1 and block 2. X-axis: Durations shown, Y-axis: Average Response time of all subjects

and the importance of the role of memory. The block effect has decreased which means that reproductions of block two are not always longer than block one(but the reproduced duration of block two long bias is longer than short bias), we investigated further to find the cause for this.

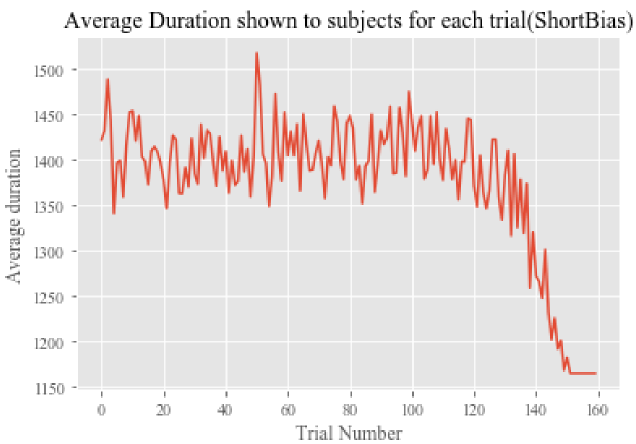

Figure 4: The durations showed to all subjects over 160 trials have been averaged to see when they encountered short bias during the experiment.

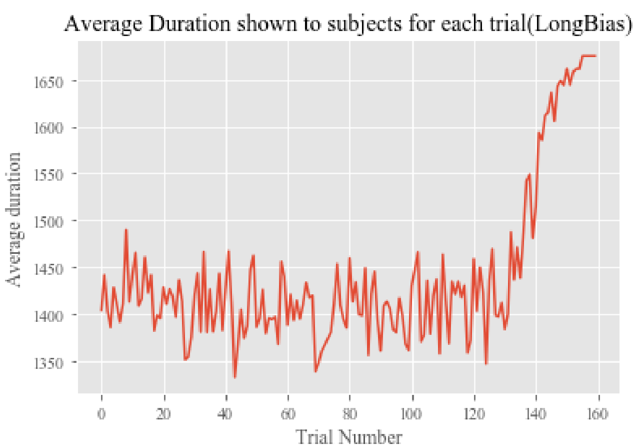

Figure 5: The durations showed to all subjects over 160 trials have been averaged to see when they encountered long bias during the experiment.

We can see from Figure 4 and Figure 5 that when the durations are randomly chosen with equal probability, due to the high frequency of each bias, they appear more frequently near the end of the trials. This may imply that there are not enough past experiences of long/short bias for it to actually affect the replicated timing. We performed an extra model experiment where, in block two, the biased durations had a very high probability of being selected, where they would exhaust all their chances of occurring in the first few trials of block two. This helped the models to actually use the biased encounters in later trials to replicate the biased timings, this is another hypothesis and is out of the scope of this paper, hence will not be discussed further.

Discussion

We see from both the model and the experimental data that memory does in fact have an effect on timing replications. In both model and experimental data, when subjects were exposed to a bias, they stored it in a memory pool and replicated the durations based on their memory of past encounters, this is seen when the long bias responses are higher than short bias responses in both the model and experiments. In this particular scenario, the model data fits the experimental data(long bias replicates longer durations than shorter bias) which implies that the human mind may in fact be using a technique similar to *blending* to store, pool(gather and weigh) and retrieve from memory.

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