IMPLICIT LEARNING OF TIME INTERVALS IN A DUAL TASK EXPERIMENT

Bachelor project

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Abstract: Previous studies on time estimation measure explicit responses to test if people have implicitly learned a time interval. In this study, we use eye movements as a measure to test if people have learned a time interval in a dual task setting. Eye movements are much less consciously controlled than explicit responses and are therefore a better measure of implicit learning. We found that people were able to learn the time interval. We also test the influence of the temporal structure of the main task on the time estimation of the secondary task. We did not find any difference between a main task with and a main task without a temporal structure.

1. Introduction

Estimating short time intervals plays an important role in everyday life. We estimate time intervals when we perceive a beat in a musical composition, when we judge whether we should brake for a yellow traffic light or when we judge how long it will take before an approaching football reaches us. These are all examples of prospective time estimation, because an estimate has to be made at the start of the interval. This can be contrasted with retrospective time estimation, in which the interval has to be estimated after it has passed. Prospective time estimation is often implicit and secondary to another task.

1.1. Learning of time intervals

Skinner (1938) showed that rats are able to learn a prospective time interval. In his experiment, rats had to press a switch in order to obtain food. However, the food was only provided when the switch was pressed after a fixed period of time. Switch presses before the interval had passed had no effect, and once the food was provided, a new interval would begin. The pattern of switch presses that emerged was characterized by and initial slow rate of switch presses that gradually increased over the interval to reach its maximum rate at approximately the end of the interval. The higher concentration of switch presses around the end of the interval indicates that the rats had learned the interval. This pattern of response is essentially universal, being found in rats, humans (Wearden & McShane, 1988), pigeons (Schneider, 1969), fish (Talton, Higa & Staddon, 1999) and many other species.

Taatgen, Van Rijn and Anderson (2007) showed that people are able to correctly estimate prospective time intervals when time estimation is secondary to another task. In their experiment, participants had to perform two tasks simultaneously. A time interval had to be estimated as part of one of the tasks. The primary goal from the perspective of the participants was to respond to the stimuli of the tasks (because that scored points directly) and estimating the time interval was only secondary (because it helped in scoring more points).

Miller and Fu (2007) showed that people are able to learn and use a temporal pattern to detect alarms in a visual monitoring task. In their experiment, participants had to monitor four gauges and respond if one of these gauges was in an alarm state. There was a temporal pattern in the order in which the gauges reached the alarm state. The performance of participants increased over time, but dropped dramatically when the temporal pattern was changed. This indicates that participants used the temporal pattern to perform the task.

These studies show that people are able to learn time intervals and use them to improve their performance on a particular task. However, these studies measure the learning of implicit time intervals by looking at explicit responses (i.e. key presses).

1.2. The internal clock theory

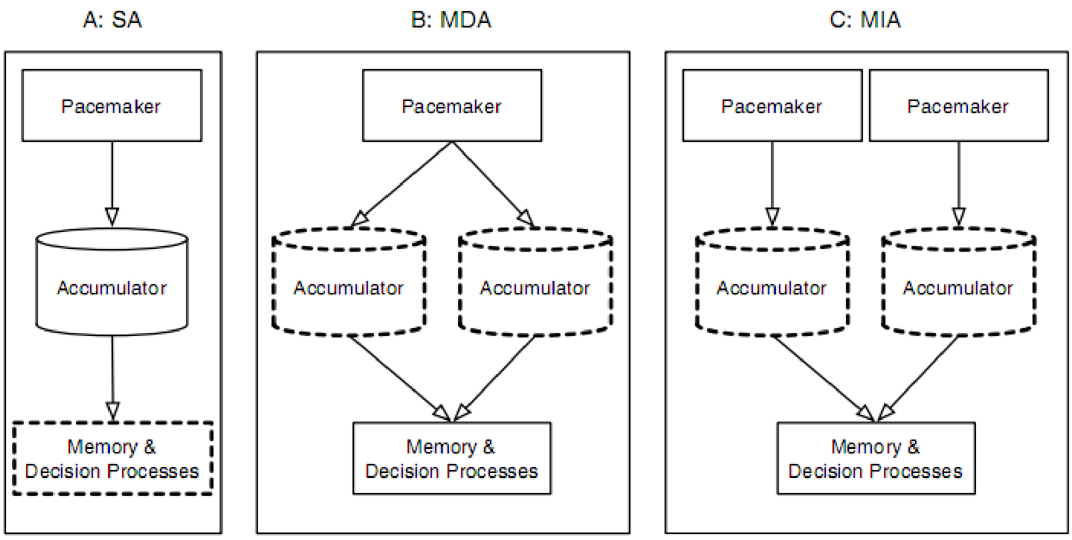

Figure 1. Three possible systems to account of parallel timing. Panel A depicts a single pacemaker, single accumulator (SA) system, Panel B a multiple dependent accumulators (MDA) system, and Panel C a multiple independent accumulators (MIA) system. The entities with the dashed lines denote the elements of the system that enable parallel time perception (Van Rijn & Taatgen, 2008).

According to the internal clock theory, people have an internal clock that they use for estimating time intervals. There are three possible models of the internal clock theory (see Matell & Meck, 2000, for an overview), but since they are functionally equivalent, we will only discuss the pacemaker-accumulator model. In this model, an accumulator counts the pulses generated by a pacemaker. The number of pulses collected in the accumulator indicates the amount of time that has passed. The accumulator functions as a "clock", indicating the amount of time that has passed since the beginning of accumulation (Michon, 1967; Treisman, 1963).

The ability of people to track multiple time intervals simultaneously can be explained either by assuming multiple internal clocks or by strategic arithmetic using a single clock (Van Rijn & Taatgen, 2008). A version of the pacemaker-accumulator model using a single clock is shown in Figure 1, Panel A. Two versions using multiple clocks are shown in Figure 1, Panel B and C. Van Rijn and Taatgen found that people are able to estimate multiple overlapping time intervals using only a single pacemaker and a single accumulator (Figure 1, Panel A).

1.3. This study

In this study we will test if people are able to learn an implicit time interval in a dual task setting. In contrast with previous studies, we will not measure explicit responses (i.e. key presses). Instead, we will measure eye movements. People have much less conscious control over their eye movements than they have over their explicit responses. Therefore, eye movements are a better measure of implicit learning than explicit responses.

The main task of our experiment will be presented in the center of the screen. In this task, participants see a stream of numbers and they have to respond when they see a 4. The secondary task will be presented in the upper right part of the screen. It consists of a stimulus that changes to a target after 8 s. When the participant responds to this target, it changes back to normal and 8 s after a response it changes to a target again. This cycle is repeated for twenty minutes. When the frequency of eye movements increases over the 8 s interval and reaches its maximum rate at the end of the interval (when the stimulus changes to a target), this is a good indication that participants have implicitly learned the interval. We hypothesize that people are able to learn this time interval.

We will also test the influence of the temporal structure of the main task on the time estimation of the secondary task. In the non-structured condition, the time interval between two targets is random. In the structured condition, there is regularity in the presentation of the targets.

Based on Van Rijn and Taatgen's (2008) view that people strategically use a single internal clock to estimate time intervals, we hypothesize that the ability to learn the time interval of the secondary task improves when the main task has a temporal structure. The temporal structure of the main task could make the arithmetic needed to track multiple intervals easier and therefore allow for a more accurate estimation of the time interval of the secondary task.

A theory using multiple internal clocks would predict no difference in performance on the secondary task when the main task has a temporal structure, because the clocks are independent of each other. The clock tracking the main task does not influence the interval estimation accuracy of the clock tracking the secondary task.

2. Method

Participants. Forty-five undergraduate students from the University of Groningen participated in this study (14 female, age range: 17-50, mean age: 21.7). All participants had normal or corrected to normal visual abilities.

Apparatus. The stimuli were presented on a Dell 2007FPb 20.1" monitor with a 1600 x 1200 resolution, controlled by an Apple Mac Mini, processor type T7200, with Windows XP SP2. We used MATLAB 7.9.0 (R2009b) with Psychtoolbox 3.0.8 to run the experiment and EyeLink II CL v4.40 with an EyeLink CL Version 1.4 camera to track eye movements. The sample rate of the eye tracker was 500 Hz. Responses were made on a Cherry G230 keyboard.

Materials. The stimuli for the main task (presented in the center of the screen) were numbers ranging from 0 to 9. The number 4 was a target, the rest were non-targets. The numbers that were presented between targets were chosen randomly.

The stimuli for the secondary task (presented in the upper right part of the screen, coordinates (1400,100)) were the words *BONEN* (Dutch for *beans)* and *BONUS. BONUS* was a target and *BONEN* was a non-target. The word *BONUS* was chosen because it indicates that participants can earn bonus points. The word *BONEN* was chosen because it has a similar orthographic pattern as *BONUS.* This makes it harder to detect the change between the non-target and the target than when dissimilar words are used. It was vital for our experiment that participants were unable to detect this change in their peripheral visual field, because then they would not have to make an eye movement to the upper right part of the screen.

Design and Procedure. Participants had to perform two tasks simultaneously. The main task consisted of a sequence of numbers shown in the center of the screen. The numbers changed every 150 ms. Participants had to respond to a 4 by pressing the z-key on a keyboard. If they did this within 500 ms, they heard a high pitched beep indicating they made a correct response. If they pressed z too late they heard a low pitched buzzer indicating they responded too slowly. 10 points were awarded for a correct response and 10 points were subtracted for an incorrect response. No action was taken when a target was missed.

The secondary task consisted of a word presented in the upper right part of the screen. At the start of the experiment, the word was *BONEN,* but after 8 s it changed to *BONUS,* indicating participants could earn bonus points. To earn these bonus points, they had to press the m-key. If they did this correctly, they heard a high pitched bell sound and earned 50 points. If they pressed m while *BONUS* was not on the screen, they heard a low pitched buzzer and got 50 penalty points. After the word had changed to *BONEN* again, it took another 8 s for it to change back into *BONUS.*

The word was updated on the screen every 150 ms (like the stimuli in the main task). This was done because it was possible to detect the change from *BONEN* to *BONUS* in the peripheral visual field when it was only updated when this change occurred.

The experiment consisted of five sessions, each with a duration of four minutes. After each session the number of points the participant had scored on that session was shown. The sum of the points over all sessions was also shown.

The experiment had two between subject conditions. Participants were assigned to a condition such that the sexes in both conditions were counterbalanced. In one condition the main task had a temporal structure, in the other condition no temporal structure was present in the main task. In the condition with a temporal structure, the time interval between targets in the main task was either a fixed interval of 1500 ms or a random interval ranging from 600 to 2400 ms. The time between two targets was alternately fixed and random. We used a random interval after each fixed interval to prevent participants from knowing exactly when a target would appear. This also prevented participants from simply using the number of targets they saw before *BONUS* appeared as an accurate measure for the time interval of the secondary task (i.e. "*BONUS* will appear shortly after the fifth 4").

In the condition without a temporal structure, the time interval between two targets in the main task was always a random interval ranging from 600 to 2400 ms. This range was chosen so that the mean of the intervals would be around 1500 ms, which is the same as in the condition with a temporal structure.

The reason for the bonus points being five times as high as the points for responding to a 4 was that during the 8 s *BONUS* was not on the screen, participants would on average see five 4s and thus be able to obtain 50 points just by looking at the main task.

When participants looked towards the secondary task, it was likely they would miss a 4. Therefore it was beneficial to only look towards the secondary task when *BONUS* had just appeared. Given the fact that the 8 s interval of the secondary task started when a response to *BONUS* had been made, it was best to respond to *BONUS* as fast as possible so there would be more opportunities to gain the bonus points.

The variables we measured were the coordinates of where the participants were looking, the reaction times of their responses and the number of points they obtained on each session.

3. Results

Most participants did not adhere to task instructions in the last session because of fatigue. Therefore this session was not included in the analysis. Due to a technical error in our experiment, there were only eight participants who performed the structured condition. One of these was removed from the analysis, because he did not adhere to task instructions. From the thirty-seven participants who performed the non-structured condition, six were removed because they did not adhere to task instructions and three were removed because the data gathered by the eye tracker were incomplete.

For every eye movement to the upper right part of the screen, we calculated the time this eye movement occurred relative to the start of the time interval. The upper right part of the screen was defined by an x coordinate bigger than 1060 and a y coordinate smaller than 400. We counted the number of eye movements to the upper right part of the screen in eight intervals of 1.5 s. We chose this interval size because we wanted to get the interval 7.5 – 9 s, which is the optimal interval in which to look to the upper right part of the screen.

Figure 2 shows the frequency of eye movements to the upper right part of the screen per interval for each session for participants in the non-structured condition. In session 1, the distribution is quite flat, indicating participants look to the upper right part of the screen randomly. In session 2, a peak has formed at the 6 – 7.5 s interval. In sessions 3 and 4, a peak has formed at the 7.5 – 9 s interval, indicating participants have learned the 8 s interval of the secondary task. The overall frequency of eye movements to the upper right part of the screen drops over the sessions, while the performance on the task does not decrease. This also indicates participants have learned the temporal structure of the secondary task, because they had to look less often to check if *BONUS* was on the screen.

Figure 3 shows the frequency of eye movements to the upper right part of the screen per interval for participants in the structured condition. In session 1, a peak is present at the 3 – 4.5 s interval and at the 7.5 – 9 s interval, indicating participants have not quite learned the time interval. In sessions 2, 3 and 4, a clear peak has formed at the 7.5 – 9 s interval, indicating the participants have learned the time interval. The frequency of eye movements to the upper right part of the screen does not decrease over the sessions.

To obtain a measure we could use to test whether participants learned the 8 s interval, we took the time each eye movement to the upper right part of the screen occurred and calculated for each participant the deviation of each eye movement time from 8 s. We averaged these

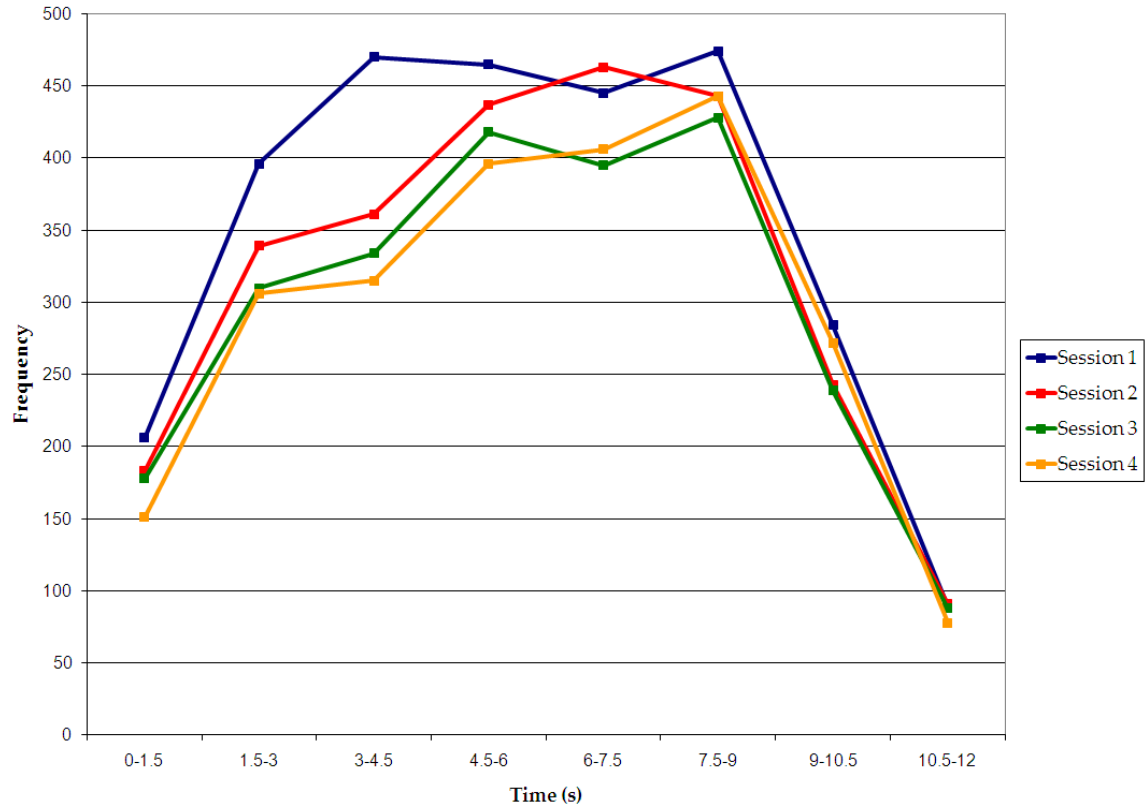

Figure 2. Frequency of eye movements to the upper right part of the screen for participants in the non-structured condition. The x-axis is divided into intervals of 1.5 s. The target appears after 8 s.

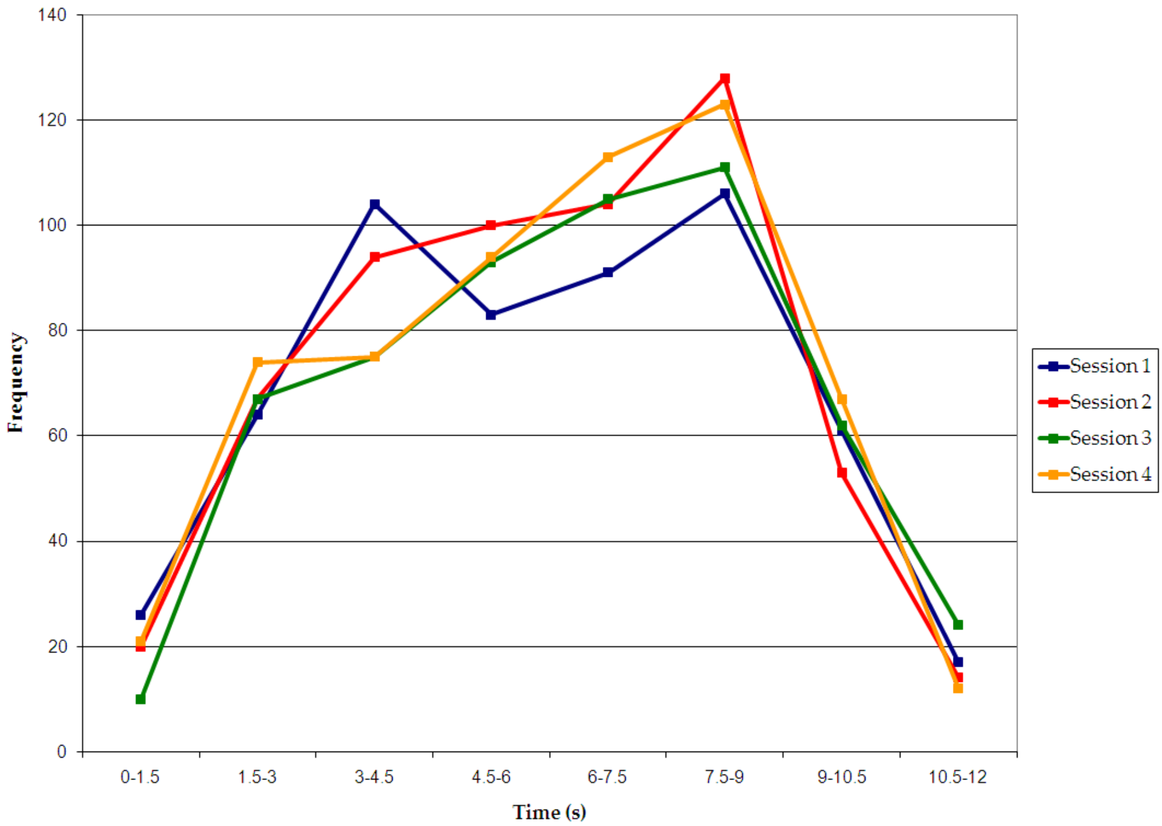

Figure 3. Frequency of eye movements to the upper right part of the screen for participants in the structured condition. The x-axis is divided into intervals of 1.5 s. The target appears after 8 s.

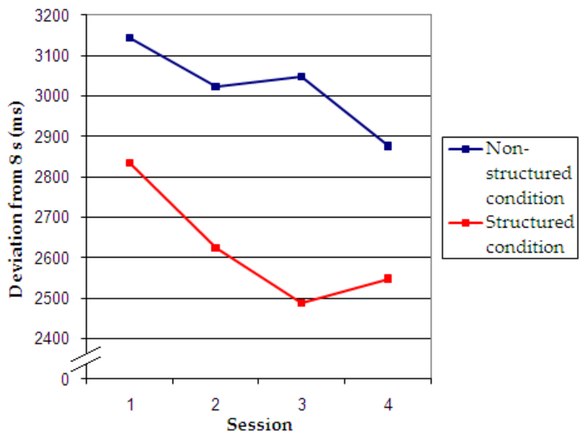

Figure 4. Deviation of eye movement times from 8 s for the non-structured and the structured condition.

values over all eye movements. Figure 4 shows this deviation for each session for both conditions.

A repeated measures ANOVA for the non-structured condition with session as within-subject factor showed that there was a main effect of session in the non-structured condition [$F(3,81) = 2,83$, $p = 0.043$].

A repeated measures ANOVA for the non-structured condition with session as within-subject factor showed that there was no main effect of session in the non-structured condition [$F(3,18) = 2,53$, $p = 0.090$].

In order to compare the two conditions, we randomly selected seven participants from the non-structured condition to ensure that both groups were of equal size. A repeated measures ANOVA with session as within-subject factor and condition as between-subject factor revealed that was no main effect of condition [$F(1,12) = 0.97$, $p = 0.344$].

To test if participants in the structured condition were able to learn the temporal structure in the main task, we compared the performance on the main task between the structured and the non-structured condition. We used the average reaction times of correct responses per session for each participant as a performance measure. Because of an error in our experiment, all reaction times between 350 and 400 ms were stored as 400 ms. To compensate for this error, we replaced every value of 400 ms with 375 ms. A repeated measures ANOVA with session as within-subject factor and condition as between-subject factor revealed that there was no main effect of condition [$F(1,12) = 0.099$, $p = 0.76$]. To ensure that both groups were of equal size, we used the same seven participants from the non-structured condition in this analysis as in the previous analysis.

It could be that participants in the structured condition did learn the duration of the fixed interval, but performed worse on the random interval because they expected another fixed interval. In this case the increase in performance on the fixed interval would be cancelled out by a decrease in performance on the random interval. To test this, we compared the reaction times on the fixed and random intervals for this condition. A repeated measures ANOVA with session as within-subject factor and interval as between-subject factor revealed that there was no main effect of interval [$F(1,12) = 0.112$, $p = 0.74$].

4. Discussion

In this study we tested, by measuring eye movements, if people are able to learn an implicit time interval in a dual task setting. We expected that this was possible. We found a similar distribution of eye movements to the upper right part of the screen as Skinner (1938) found with key presses of rats. The increase in frequency of eye movements over the 8 s interval, with its maximum rate at the end of the interval, is a good indication that participants implicitly learned the interval.

We also showed that participants in the non-structured condition had learned the interval by showing that the deviation of eye movement times from 8 s decreased over the sessions. We did not find a significant decrease in the structured condition, but this could be due to the fact that there were only seven participants in this condition.

In this study we also tested the influence of the temporal structure of the main task on the time estimation of the secondary task. We expected that the ability to learn the time interval of the secondary task would improve when the main task had a temporal structure. We did not find any difference between a main task with and a main task without a temporal structure.

This finding would provide evidence for a model of the internal clock theory with multiple internal clocks, because the time estimation of the main task did not interfere with the time estimation of the secondary task. This is exactly what a model with multiple internal clocks would predict. However, we found that participants in the structured condition did not learn the temporal structure of the main task. Therefore, we cannot conclude anything about the number of internal clocks, because both the non-structured and the structured condition only tracked one time interval (that of the secondary task).

Future research should make sure that the temporal structure of the main task can be learned. The timing of the main task should be more structured than in our experiment. For example, instead of alternating a fixed and a random interval, two fixed intervals with a different duration could be alternated.

In our experiment, the random intervals in the main task were generated by a uniform distribution between 600 and 2400 ms. This distribution has the disadvantage that it has a memory. That is, the likelihood that the target will appear increases with every moment that it does not appear. For example, when a participant has learned this fact, he knows that when the target has not appeared for 2300 ms, it will certainly appear in the next 100 ms. Participants should not be able to predict a random interval and therefore it is better to generate the intervals from a negative exponential distribution, which is memoryless.

Despite this objection to using a uniform distribution, the data we obtained are still usable, because we did not find any indication that participants used the properties of the uniform distribution to their advantage.

Another advantage of using a negative exponential distribution is that the probability of short intervals in this distribution is higher than in a uniform distribution. This means that the probability that participants miss a target when they look to the upper right part of the screen is also higher. The cost of looking to the upper right part of the screen is therefore increased and this makes it more advantageous to lean the time interval of the secondary task.

Figures 1 and 2 indicate that the distribution of eye movement times changes over the sessions, but it is difficult to find a way to analyze this change. There is no gold standard in statistics on how to analyze the difference between these kinds of distributions. We used the deviation of eye movement times from 8 s as a measure for the difference between the sessions and even though it says something about the extent to which participants learned the 8 s interval, it is far from a perfect measure. Future research should find a better way to analyze these kinds of data.

With this study we have shown that eye movements can be used to measure the implicit learning of a time interval. Future research on implicit time estimation should take into account that explicit responses are not a completely correct way to measure implicit learning and that eye movements provide a usable and theoretically superior alternative.

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