

IMPLICIT MEMORY GUIDES THE ALLOCATION OF ATTENTION IN TIME: EVIDENCE FROM INTERTRIAL PRIMING

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Abstract

Attention can be allocated in time as well as in space. Previous studies have shown that repetition of target spatial position speeds visual search performance (Maljkovic & Nakayama, 1996), suggesting that spatial positions encoded in implicit memory guide attention. Here, we investigated whether repetition of the position of a target in time also speeds search. Observers had to look for a uniquely colored digit within an RSVP stream of uniformly colored digits and to respond to its value. Reaction times were faster when on two consecutive trials the target happened to appear at similar than at different temporal positions. This effect was eliminated when the expectations regarding the temporal position of the upcoming target were high. This novel temporal position priming effect suggests that implicit short term memory of temporal representations guides the allocation of attention in time, similarly to the way memory traces of spatial representations guide attention in space.

Selective attention is the process of choosing a subset of the sensory input for detailed perceptual analysis. Although the majority of research on attention has focused on the ability to select locations in space and the objects that occupy them, basic interaction with the visual world requires us to select moments in time and the events that unfold over them. In the experiment reported here, we investigated how temporal selection interacts with implicit short term memory.

Numerous studies in visual search have shown that attended display attributes such as colors and shapes are encoded in implicit memory, and bias the selection process in the moments that follow, (see Chun & Nakayama, 2000; Kristjansson & Campana, 2010 for a review). For example, in Maljkovic and Nakayama's (1994; 1996) studies observers had to search for a target defined as the uniquely colored item among uniformly colored items (distractors) and to react to its shape. The color, shape and position of each item changed unpredictably from trial to trial. Reaction times were speeded whenever target and distractor colors repeated in two consecutive trials, relative to when they switched. Maljkovic & Nakayama (1994) concluded that repetition of the target-defining attribute facilitates selection. This effect was found to include both a target-activation and a distractor-inhibition component (Lamy, Antebi, Aviani & Carmel, 2008)

In a later study, Maljkovic and Nakayama (1996) reported that observers also respond faster when the target on a given trial appears at a previous target location and slower when it appears at a previous distractor location, relative to a neutral (previously empty) position (see also Geyer, Muller, & Krummenacher, 2007; Yashar & Lamy, 2010b).

Most intertrial priming studies have focused on spatial visual search and have led to the conclusion that inter-trial priming affects the allocation of spatial attention either by enhancing target conspicuity (Becker, 2008) or by facilitating the allocation of focal attention and engaging attention with target (Yashar & Lamy, 2010a, , 2010b). In the present study we investigated whether, similarly to spatial selection, temporal selection is biased by implicit memory.

Temporal Selective Attention

A prevalent paradigm for studying temporal selection is visual search within a rapid serial visual presentation (RSVP) stream, in which items are presented successively at the same location. The to-be selected item (the target) is imbedded at an unpredictable temporal position within the stream. Recently, we combined the studies of intertrial repetition priming and temporal selection. A sequence of uniformed colored digits numbers was presented at the center of the screen and observers had to look for the singleton-color target and report whether it was an odd or an even number. Reaction times were faster on repeated-color trials. As attention remained focused at the center of the screen throughout the experiment, we concluded that intertrial repetition facilitates selection processes that do not necessarily pertain to shifts of attention in space but rather to the engagement of focal attention with the target. In addition, when RSVP trials were interleaved with spatial search trials, feature repetition priming occurred between successive trials involving different tasks (temporal followed by spatial search and vice versa), suggesting that selection of information in time shares common mechanisms with selection of information in space.

However, despite this association between spatial and temporal attention, the mechanisms that underlie the two search tasks are fundamentally different. Spatial selection relies on the representation of local contrast and attentional priorities in what is known as a *master map of location* (Treisman & Gelade, 1980) or *saliency map* (Itti, Koch, & Niebur, 1998). This spatial representation also underlies the spatial position repetition effect reported by Maljkovic & Nakayama (1996). By analogy, temporal selection could rely on temporal representations that code for temporally local contrast and temporal expectations (e.g., Coull & Nobre, 1998). However, some authors have suggested that temporal selection does not require temporal representation and instead likened temporal selection to a gate that can be described as a cue-impulse response function (Reeves & Sperling, 1986; Shih & Sperling, 2002; Vul, Nieuwenstein, & Kanwisher, 2008).

Here, we investigated whether temporal representations can guide temporal selection by examining whether, similarly to position priming in spatial search, repetition of the target position in time facilitates selection in time.

In the experiment reported here, we addressed this issue by conducting a post-hoc analysis of Yashar and Lamy's (2010b) data. We compared trials in which the target's serial position within the stream repeated on successive trials, relative to trials in which it differed. Furthermore, we measured the relative distance between target serial positions in the current and previous trial, in order to determine whether the effect of temporal position repetition, if found, gradually decays or perhaps affects only the specific temporal position in which the target appeared and was selected. To disentangle the contributions of selection and response-related mechanisms to the studied temporal inter-trial priming effect we also examined the role of response repetition.

Method

Subjects

Participants were 17 Tel-Aviv University undergraduate students who participated in the experiment for course credit. All reported having normal or corrected visual acuity and normal color vision.

Apparatus

Displays were generated by an Intel Pentium 4 computer attached to a 17 in. CRT monitor, using 640x480 resolution graphics mode. Responses were collected via the computer keyboard. A chin-rest was used to set viewing distance at 50 cm from the monitor.

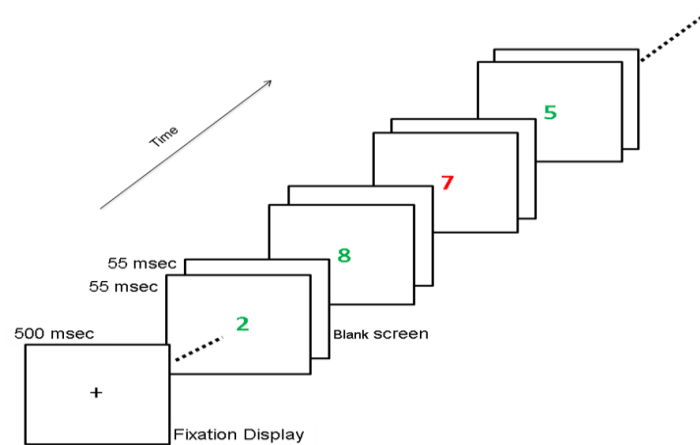


Figure 1. Illustration of the sequence of events.

Stimuli and Procedure

Examples of the stimulus displays are presented in Figure 1. Each trial began with a fixation display consisting of a gray $0.2^\circ \cdot 0.2^\circ$ plus sign (+), in the center of a black background. The fixation display was presented for 500 msec and was followed by a rapid serial visual presentation (RSVP) stream that consisted of 12 successively presented colored digits randomly selected among 1 to 9, with the restriction that no two consecutive digits were the same. The presentation duration of each digit and the inter-stimulus interval (ISI) between two digits were 58 msec, resulting in a stimulus onset asynchrony (SOA) of 116 msec. Each RSVP stream contained one digit with a unique color, the target, and 11 digits in a different color, the distractors. On each trial the target and the distractors colors were randomly drawn from four possible colors: red, blue, green and yellow. The target position was randomly selected but could appear only between the fifth and the ninth position, that is, in one of 5 possible temporal positions. On each trial, a blank screen followed the RSVP stream for 5 seconds or until the participant responded. Participants were instructed to report whether the target was an odd or an even number by pressing designated keys ('3' with their right hands for even numbers and on 'z' with their left hands for odd numbers), as accurately and fast as possible. A blank screen was presented for 500 ms before the next trial began. Error trials were followed by a 500-msec feedback beep sound. Eye movements were not monitored, but participants were explicitly requested to maintain fixation throughout each trial.

Design

The experiment began with a block of 20 practice trials, followed by 560 experimental trials divided into eight blocks. Participants were allowed a short rest after each block.

Results

Error trials (12% of all trials) as well as outliers (less than 2.5% of all correct trials) were removed from all RT analyses. The data from 3 participants were discarded because their accuracy rate (2 subjects) and mean RT (1 subject) exceeded the group's mean by more than 2 standard deviations. Here, we report only RTs analyses. Preliminary analyses showed no tradeoff between RTs and accuracy.

We first measured the effect of the variation between target positions in trial n and trial $n-1$. The size of the variation (or distance, d) was the absolute value of the outcome of the subtraction of the target temporal position (t) in the current trial (n) from that in the previous trial ($n-1$), that is, $d=|t_n-t_{n-1}|$. The minimum distance was thus 0 msec, indicating that the target appeared at the same temporal position on two consecutive trials, and the maximum distance was 4, indicating that the target position was 5 in trial n and 9 in trial $n-1$, or vice versa.

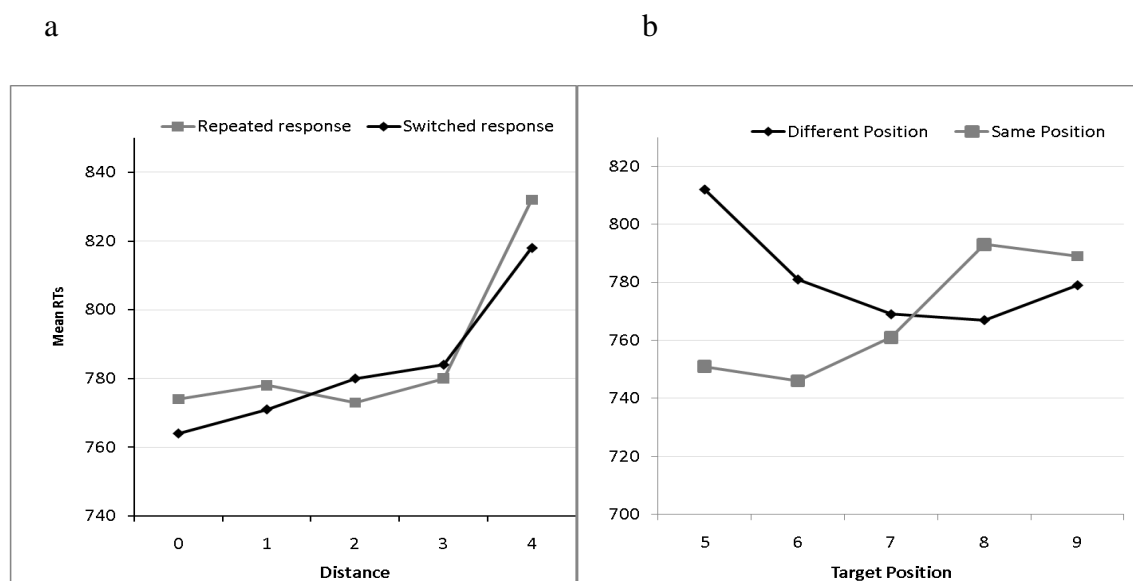


Figure 2. (a) Mean RTs for repeated vs. switched response trials as a function of temporal distance. (b) Mean RTs for same vs. different position trials as a function of target serial position on the current trial

An Analysis of Variance (ANOVA) was conducted with distance and response repetition (same vs. different) as within-subject factors. Mean RT are depicted in Figure 2a. The main effect of distance was significant, $F(4, 52)=7.73$, $p<0.0001$, reflecting that RTs increased as the distance between the target positions in successive trials increased. The main effect of response repetition was not significant, nor was the interaction between the two factors, $F_s < 1$.

Next, we measured the effect of the temporal position repetition effect for each target serial position. An ANOVA was conducted with position repetition (same vs. different) and target serial position as within-participant factors. Mean RT are depicted in Figure 2b.

Neither the main effect of position repetition $F(1, 13)=2.79$, $p>0.11$ nor that of target serial position, $F(4, 52)=1.63$, $p>0.18$, reached significance. However, the interaction between the two factors was significant, $F(4, 54)=5.44$, $p<0.002$. Paired comparisons revealed that repetition of target position facilitated RTs in when the target in the current trial appeared early in the stream, positions 5 and 6, $F(1, 13)=12.31$, $p<0.004$ and $F(1, 13)=7.18$, $p<0.02$, respectively but not when it appeared in later positions, 7, 8 and 9, all $F_s < 2$.

Discussion

Our results show that the closer the target temporal position in the current trial is to the temporal position in the previous trial, the faster the search. This finding suggests that during search, observers encode the target's temporal position in a short-term memory store, and that this representation subsequently guides the allocation of attention in time. The fact that RTs increased as a function of temporal distance indicates that this representation follows a gradient that peaks at the encoded target location. This temporal inter-trial priming effect did not interact with response repetition, supporting the claim that the effect is related to attentional selection rather than response-selected processes.

It is noteworthy that repetition of the target's temporal position on successive trials speeded search for the early temporal positions (5 and 6) but not in the following positions. The contingency of the effect on serial position might result from variations in observers' expectations during the RSVP stream. As the target appears on every trial and is equally likely to appear at each possible temporal location, if the target did not appear in position n , the probability for it to appear in position $n+1$ increases. This probability reaches 100% when the stream of letter reaches the last possible position. Thus, the later the target's serial position, the higher the expectation that the target will occur on the next position. It is therefore reasonable to assume that at later target positions, such expectations override the benefit of temporal position priming. We are currently testing this hypothesis.

Conclusion

The results of the present study demonstrate a novel intertrial priming effect: temporal position priming (TPP), by which temporal selection is biased by the memory traces of previously selected temporal positions. This effect suggests that just as the target position in space is encoded in spatial maps during spatial search, its temporal position is encoded in "temporal maps" during visual search in time.

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