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Hazard versus History: Temporal Preparation is Driven by Past Experience

--Manuscript Draft--

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Dear Dr. Enns,

I have just completed the online submission of our manuscript "Hazard versus History: Temporal Preparation is Driven by Past Experience" which I wish to submit for publication in the Journal of Experimental Psychology: Human Perception and Performance. We believe this manuscript should appeal to a broad audience in the psychological sciences, because it challenges a central construct of the timing literature (the hazard function) and supports an alternative theory that is firmly rooted in general principles of learning and memory.

Thank you very much for your considerations.
Yours sincerely,

Sander los

On behalf of Wouter Kruijne and Martijn Meeter

Hazard versus History: Temporal Preparation is Driven by Past Experience

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Abstract

The hazard function describes the conditional probability that an event will occur at a given moment, given that it has not yet occurred. In warned reaction time tasks, it is a classical finding that the response to a target stimulus is faster as its hazard is higher, which has led to the wide-spread belief that hazard somehow *drives* temporal preparation. Alternatively, recent memory-based theories propose that temporal preparation is driven by memory traces of earlier timing experiences. To distinguish between these views, we presented different groups of participants with different distributions of foreperiods between temporal cues and target stimuli. Three experiments revealed clear transfer effects of this manipulation in a test phase where all participants received, after explicit instruction, the same uniform distribution. These findings demonstrate that temporal preparation is driven by memory, not by current hazard.

For an athlete who just heard the “ready” signal, accurate timing of the impending “go” signal may make the difference between fame and oblivion. Though less dramatically, accurate timing is important to every one of us when engaged in more mundane activities, such as driving a car, cooking a meal, or catching a ball. In all cases, we use temporal cues in the environment that allow us to prepare for speeded or accurate action to an event that is bound to occur in the near future.

While there is little controversy about the importance of cue-target contingencies in timing behavior, it is less clear how our knowledge of these contingencies is represented and how this representation affords preparation for action. In a widely held view, our representation is a direct reflection of the statistical properties of the environment laid down by the *hazard function*. The hazard function describes the conditional probability that a target event will occur at a given moment after the presentation of a cue given that it has not yet occurred (Luce, 1986). This function has been shown to be a good predictor of the behavioral outcome of timing processes across a wide variety of experimental paradigms (Nobre, Correa, & Coull, 2007; Vangkilde, Petersen, & Bundesen, 2013).

One specific area where the hazard function has been successfully applied is temporal preparation (Niemi & Näätänen, 1981). In a typical paradigm, participants are presented with a warning stimulus (S1; a mere time marker such as a brief tone), followed after a variable foreperiod by a target stimulus (S2), which requires a speeded response. It has often been found that current hazard well predicts the mean reaction time (RT) with respect to S2. For instance, in the case of a uniform distribution of foreperiods (i.e., when each possible foreperiod occurs equally often across the trials of a block), mean RT decreases as the foreperiod lengthens, closely matching the corresponding increase in hazard (e.g., Cui, Stetson, Montague, & Eagelman, 2009; Janssen & Shadlen, 2005). As the relative frequency of short foreperiods is raised (across different blocks), the RT – foreperiod function gradually lies down (e.g., Baumeister & Joubert, 1969), and becomes approximately flat in the case of an exponential distribution—when hazard is constant during the ("nonageing") foreperiod (e.g., Näätänen, 1970, 1971; Trillenberg, Verleger, Wascher, Wauschkuhn, & Wessel, 2000).

Despite these successful predictions, the role of hazard as an explanatory construct is profoundly limited in that it lacks a cognitive basis (Los, 2013). Any theory stating that temporal preparation is driven by hazard is incomplete as long as it is unclear how participants acquire knowledge of the hazard function, and how hazard drives temporal preparation. As it stands, no one has attempted to take the concept of hazard beyond its statistical properties.

Starting from an alternative perspective, it has been argued that timing behavior is driven by memory traces of preceding timing experiences (Howard & Eichenbaum, 2013; Los, Kruijne & Meeter, 2014; Taatgen & Van Rijn, 2011). According to the multiple trace theory of temporal preparation (MTP; Los et al., 2014), a timing experience during a trial involves the application of inhibition during the foreperiod, to prevent premature response (e.g., Duque & Ivry, 2009; Los, 2013; Narayanan, Horst, & Laubach, 2006), followed by a wave of activation when S2 is presented and responded to. MTP assumes that these dynamics are crucial in a process of trace formation and trace expression. Trace formation entails that a memory trace is created on each trial, which stores a temporal profile of the experienced levels of inhibition and activation on that trial. Trace expression entails that a newly created memory trace starts contributing to preparation on subsequent trials jointly with memory traces formed on earlier trials. Specifically, S1 serves as a retrieval cue of all past memory traces, which, at any moment during the foreperiod, contribute to preparation in accordance with their stored levels of inhibition or activation corresponding to that moment. Finally, since recent experiences are generally more accessible, MTP assumes that the contribution of a memory trace to current preparation is weighted by its recency.

Figure 1 schematically shows how MTP accounts for different RT – foreperiod functions under an anti-exponential and exponential distribution (see Los et al., 2014 for more comprehensive coverage). When a new trial under the anti-exponential distribution is initiated by S1, the contribution of inhibition aggregated across memory traces quickly reduces relative to that of activation as time elapses during the foreperiod (Figure 1A). As a result, preparation rapidly increases during the foreperiod (Figure 1C) and RT correspondingly decreases (Figure 1E). By contrast, under the exponential distribution (Figure 1B), the ratio between inhibition and activation hardly varies during the foreperiod, which results in flat preparation curve (Figure 1D) and corresponding RT – foreperiod function (Figure 1F).

The aim of the present study was to distinguish between hazard-driven and memory-driven preparation by dissociating the contribution of current hazard and past trial history to temporal preparation. To this end, we presented different groups of participants with different foreperiod - distributions during an acquisition phase, and examined the effect of this manipulation in a test phase, where all participants received, after explicit instruction, the same uniform distribution. If preparation is driven by hazard, it should be possible for participants to quickly tune in on the new hazard function in the test phase, so there should be no transfer effect of the preceding distribution. However, if preparation is driven by memory, old memory traces should continue to contribute to preparation in the test phase, so there should be a clear transfer effect of the preceding distribution.

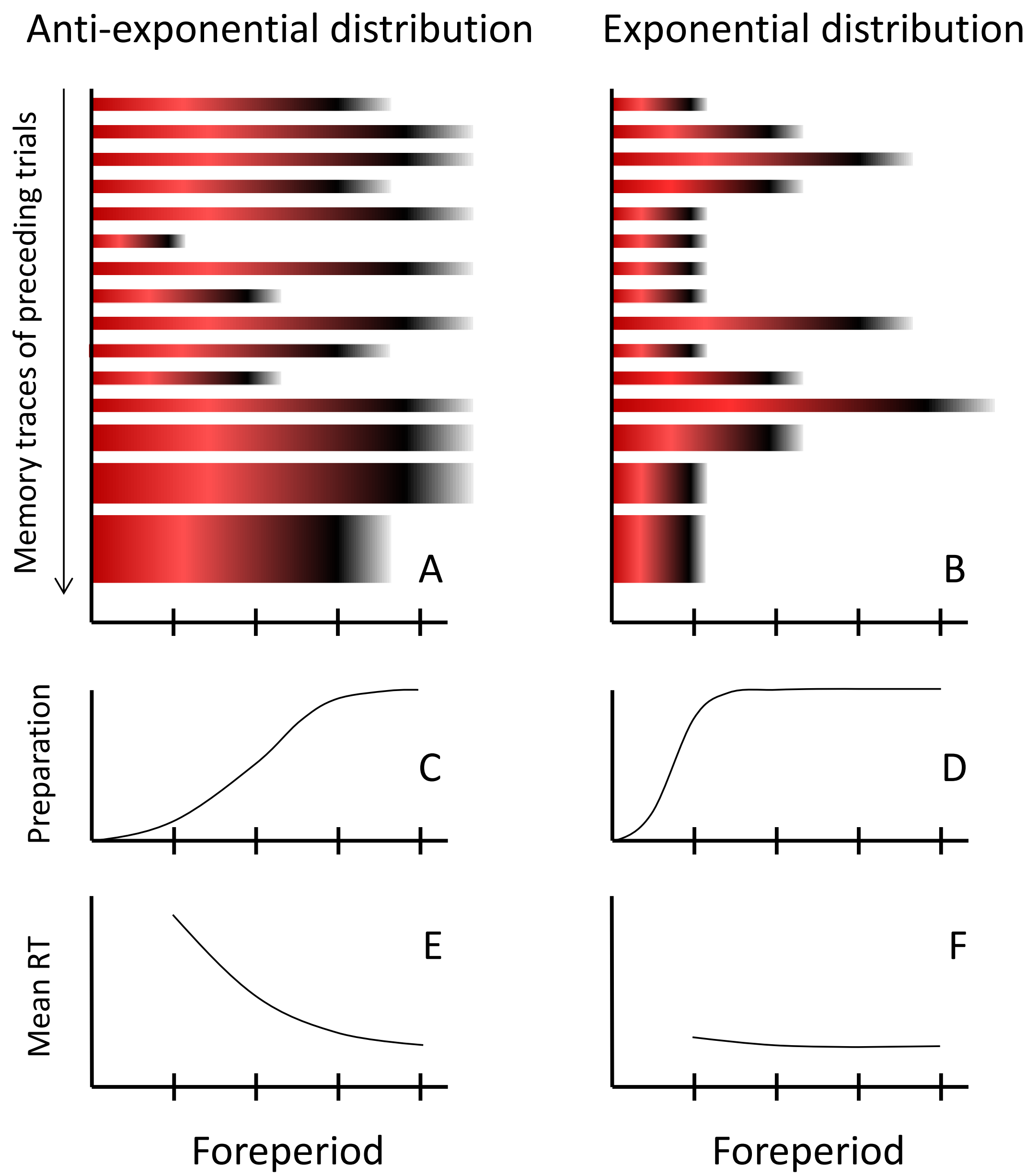

Figure 1. Schematic overview of how the multiple trace theory of temporal preparation accounts for effects of foreperiod on response time (RT) under an anti-exponential distribution (left) and an exponential distribution (right) of four different foreperiods (specified by tick marks on the horizontal axis). A, B. The bars represent memory traces, created over 15 trials. In each bar, inhibition is indicated by red and activation by black. The thickness of the bars represents the relative weight of the memory traces as they contribute to current preparation. C, D. Development of preparation during the foreperiod, driven by the ratio of activation and inhibition aggregated across memory traces. E, F. Predicted mean RT as a function of Foreperiod. Adapted from “Outlines of a multiple trace theory of temporal preparation” by S.A. Los, W. Kruijne, & M. Meeter, 2014, Frontiers in Psychology, 5: 1058. Copyright, 2014 by the authors.

Experiment 1

Method

Participants. Sixty-four students (mean age 22 years; 46 females) participated for course credits or a € 6 payment in a single session of about 40 minutes. They were randomly assigned to one of two groups, each consisting of 32 participants. We chose for a large sample size to provide sufficient power for the critical effect of this study, the interaction between foreperiod and group in the test phase, which was of uncertain size. All participants gave informed consent at the start of the experiment. Three participants of original sample were replaced because, in several conditions, more than 15% of their responses were erroneous or more than 10% of their responses were longer than 800 ms.

Procedure. The experiment took place in a dimly-lit, air-conditioned cubicle, equipped with a personal computer, which was connected to a 17 inch LCD screen and a standard QWERTY keyboard. The participants sat at a distance of 70 cm from the screen asserted by a chin rest, with the left index finger on the *z* key and the right index finger on the *m* key.

Each trial started with the presentation of S1, a black 0.6° plus in the middle of the white screen. After a foreperiod of 400, 800, 1200, or 1600 ms, S2 was presented, a black, 1.2° square, presented 1.9° to the left or to the right of S1 (center to center) with equal probability. Participants were instructed to press the *z* key when the square appeared left and the *m* key when it appeared right. After the response, the screen turned blank. The next trial started after a fixed 1.5 s intertrial interval.

Each participant completed 5 blocks of 120 trials each. The top panel of Figure 2 shows which distributions of foreperiods applied across consecutive blocks. The distribution was uniform (30 trials for each foreperiod) in Block 1, 4, and 5 for all participants. In Blocks 2 and 3, the distribution was exponential for the participants of Group 1 (64, 32, 16, and 8 trials for foreperiods of 400, 800, 1,200, and 1,600 ms, respectively) and anti-exponential for participants of Group 2 (8, 16, 32, and 64 trials for foreperiods of 400, 800, 1,200, and 1,600 ms, respectively). Within the constraints of these distributions, foreperiods were randomly selected on each trial.

Block	1	2	3	4	5
Group 1	Uni	Exp	Exp	Uni	Uni
Group 2	Uni	Anti-exp	Anti-exp	Uni	Uni

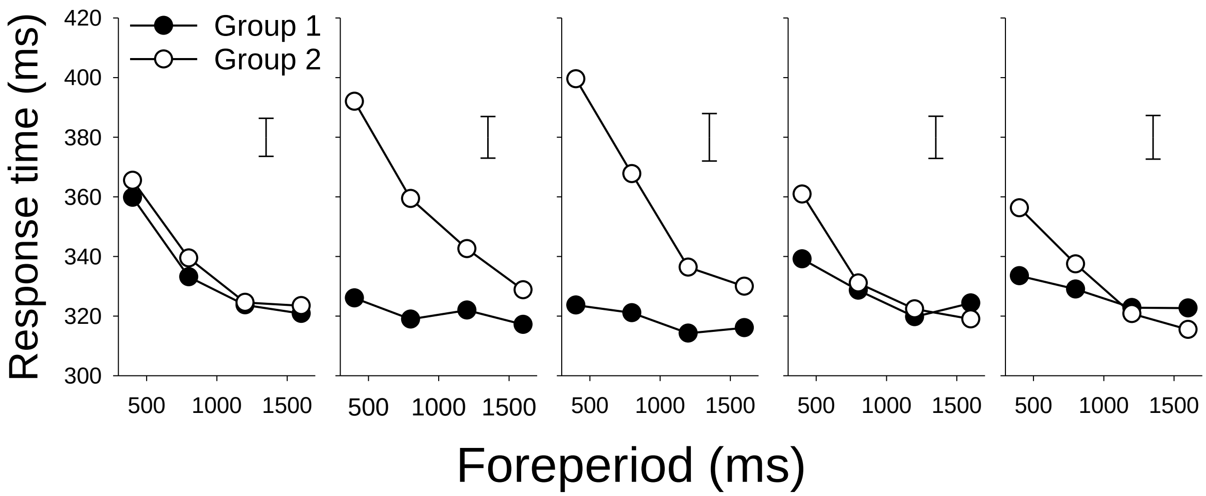

Figure 2. Design and data of Experiment 1. Top panel: Successive foreperiod distributions across blocks for Group 1 and 2 (Uni = uniform; Exp = exponential, Anti-exp = anti-exponential). Acquisition blocks are shaded. Bottom panel: Mean response time as a function of Group, Block and foreperiod. Error bars are 95% within-subjects confidence intervals, computed per block from the error term of the interaction between Group and foreperiod, using the method of Loftus and Masson (1994).

Participants were instructed to respond as quickly as possible while maintaining high accuracy. No information about the distribution of foreperiods was provided at the start of Blocks 1 – 3. However, prior to Block 4 participants were informed of the distribution of foreperiods that had applied in Blocks 2 and 3, and it was emphasized that the uniform distribution would apply in the two remaining blocks. After the completion of each block, mean RT and the percentage of correct responses of that block were shown on the screen. Participants copied these scores on a sheet of paper, which allowed them to keep track of their task performance.

<u>Results</u>

The first trial of each block was discarded, as were trials with incorrect key presses (1.0%) and trials on which RT was shorter than 150 ms or longer than 800 ms (0.4%). Because these percentages were very low, they were not analyzed any further. Mean RT was calculated on the basis of the remaining trials.

The bottom panel of Figure 2 shows mean RT as a function of foreperiod, Group and Block. On the data of each block, we applied a mixed Analysis of Variance (ANOVA), with group and foreperiod as factors. In this and all subsequent analyses, foreperiod was included as a (1 *df*) linear factor. All Blocks revealed a strong main effect of foreperiod, minimal F (1, 62) = 58.63, p < .001, partial η^2 = .48. The main effect of Group was significant in Block 2, F (1, 62) = 13.81, p < .001, partial η^2 = .18, and Block 3, F (1, 62) = 13.95, p < .001, partial η^2 = .18, but not in any of the other blocks (F < 1 in all cases). The interaction between foreperiod and Group was not significant in Block 1, F (1, 62) < 1, and, unsurprisingly, it was highly significant in Blocks 2 and 3, minimal F (1, 62) = 69.64, p < .001, partial η^2 = .53. Critically, the interaction was also highly significant in both test blocks; Block 4, F (1, 62) = 13.12, p = .001, partial η^2 = .18; Block 5, F (1, 62) = 19.05, p < .001, partial η^2 = .24. In the test blocks, the RT – foreperiod function of Group 1 was clearly flatter than the RT – foreperiod function of Group 2 although both groups received the same uniform foreperiod distribution and although participants were informed of this fact in advance.

<u>Discussion</u>

Experiment 1 revealed a substantial transfer effect, not only in block 4 but even in block 5, after 120 intervening trials with the uniform distribution. This finding is hard to reconcile with hazard-driven preparation and clearly indicates a key role of preceding timing experiences stored in memory, as proposed by MTP (Los et al., 2014).

One could argue that, according to MTP, the transfer effect in block 4 should have been much greater, approximating the distribution effect in block 2. After all, both at the end of block 2 and at the end of block 4, half of the memory traces were formed under the uniform distribution and the other half under the alternate distribution. However, it should be recalled that, according to MTP, recent memory traces are weighted more heavily than older ones, such that the effect of a transition to a new distribution should be both quick and substantial. Crucially, though, there should still be a distinctive contribution of older memory traces created in the more distant past. This is precisely what we observed in Experiment 1.

Experiment 2

According to MTP, it should be possible to undo the lingering transfer effect observed in the last block of Experiment 1 when this block is preceded by a reversed-acquisition phase, in which the two non-uniform distributions are swapped between groups. In Experiment 2, we tested this critical prediction. We also added a third (control) group that was presented with the uniform distribution throughout all blocks of the experiment, thus providing a baseline for the other two groups. Finally, we inserted a query after block 3 to examine the participants' awareness of the foreperiod distribution.

Method

Participants. A new sample of 48 students (mean age 24 years; 33 females) participated for course credits or a € 8 payment in a single session of about 60 minutes. Participants were randomly assigned to one of three groups, each consisting of 16 participants. The original sample included two additional participants, who were replaced because, in several conditions, more than 15% of their responses were erroneous or more than 10% of their responses were slower than 800 ms. Since the critical interaction between foreperiod and Group turned out to be quite pronounced in Experiment 1, we expected that the present sample size should still provide adequate power to detect this effect in the first test block, where it was predicted by MTP.

Procedure. The sequence of events on each trial was identical to that of Experiment 1. Each group completed eight blocks of 120 trials, with foreperiod distributions shown in the top panel of Figure 3. Specifically, Group 3 (control) received the uniform distribution in each block. Groups 1 and 2 received the uniform distribution in blocks 1, 4, 6, and 8. Critically, Group 1 received the exponential distribution in the initial acquisition phase (Blocks 2 and 3) and the anti-exponential distribution in the reversed-acquisition phase (Blocks 5 and 7), whereas this was reversed for Group 2.

Block	1	2	3	4	5	6	7	8
Group 1	Uni	Exp	Exp	Uni	Anti-exp	Uni	Anti-exp	Uni
Group 2	Uni	Anti-exp	Anti-exp	Uni	Exp	Uni	Exp	Uni
Group 3	Uni	Uni	Uni	Uni	Uni	Uni	Uni	Uni

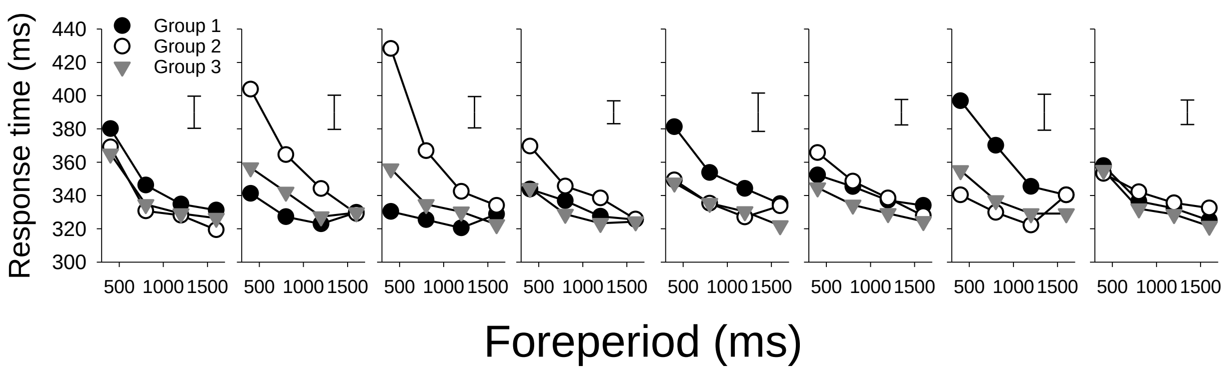

Figure 3. Design and data of Experiment 2. Top panel. Successive foreperiod distributions across blocks for Groups 1, 2, and 3 (Uni = uniform; Exp = exponential; Anti-Exp = anti-exponential). Acquisition and reversed-acquisition blocks are shaded. Bottom panel. Mean response time as a function of Group, Block and foreperiod. Error bars are 95% within-subjects confidence intervals, computed per block from the error term of the interaction between Group and foreperiod, using the method of Loftus and Masson (1994).

Participants received no information of the foreperiod distribution that applied in the first three blocks. After finishing block 3, two questions were successively presented on the computer screen, asking participants about their experience in the last two blocks they completed (i.e., Block 2 and 3). In the first question, participants were asked how many different foreperiods they believed were used in the experiment, and they answered by entering a number between 1 and 10. After that, participants were informed that the correct answer was four. Then, in the second question, participants were asked for an estimate of the percentage of trials for each foreperiod. They entered four numbers, representing the estimated percentages for the shortest up to the longest foreperiod. If the numbers did not add up to 100, participants were asked to enter their estimates again. Following these queries, participants completed blocks 4 – 8. Prior to each of these blocks they were explicitly informed of the foreperiod distribution that would apply.

In all other respects, the procedure of Experiment 1 was followed.

Results

The first trial of each block was discarded, as were trials with incorrect key presses (1.6%) and trials on which RT was shorter than 150 ms or longer than 800 ms (0.4%). These percentages were very low, and not analyzed any further. Mean RT was calculated on the basis of the remaining trials.

Figure 3, bottom panel, shows mean RT as a function of foreperiod, Group, and Block. On the data of each block, we applied a mixed Analysis of Variance (ANOVA), with group and foreperiod (the linear component) as factors. All Blocks revealed a strong main effect of foreperiod, minimal $F(1, 45) = 41.65$, $p < .001$, partial $\eta^2 = .48$. The main effect of Group was significant in Block 2, $F\ (2, 45) = 3.83$, $p = .029$, partial $\eta^2 = .15$, Block 3, $F\ (2, 45) = 6.85$, $p = .003$, partial $\eta^2 = .23$, and Block 7, $F\ (2, 45) = 4.40$, $p = .018$, partial $\eta^2 = .16$, but in none of the other blocks, maximal $F\ (2, 45) = 1.64$, $p = .205$. The interaction between foreperiod and Block was not significant in Block 1, $F\ (2, 45) < 1$. Unsurprisingly, the interaction was highly significant in acquisition blocks 2 and 3, minimal $F\ (2, 45) = 21.08$, $p < .001$, partial $\eta^2 = .48$, and, to a lesser extent, in the reversed-acquisition blocks 5 and 7, minimal $F\ (2, 45) = 3.93$, $p = .027$, partial $\eta^2 = .149$. Critically, the interaction was also highly significant in the first test block (Block 4), F (2,

45) = 7.97, p = .001, partial η^2 = .17, still significant in the second test block (block 6), after interposition of the first reversed-acquisition block, F (2, 45) = 3.75, p = .031, partial η^2 = .14. Finally, the interaction was completely absent in the last test block after interposition of the second reversed-acquisition block, when all participants had experienced an approximately equal number of trials with each foreperiod, F (2, 45) = 1.64, p = .205.

We analyzed the critical interactions between Group and foreperiod in Blocks 4 and 6 in greater detail by contrasting each pair of groups. This analysis revealed a significant interaction for the contrast between Groups 2 and 3 (initially anti-exponential versus control) both in Block 4, F (1, 30) = 11.96, p = .002, partial η^2 = .29 and in Block 6, F (1, 30) = 4.70, p = .038, partial η^2 = .14. The corresponding contrasts between Groups 1 and 2 (initially exponential versus initially anti-exponential) were also significant, in Block 4, F (1, 30) = 10.14, p < .003, partial η^2 = .25, and in Block 6, F (1, 30) = 4.46, p = .043, partial η^2 = .13. However, the contrasts between Groups 1 and 3 (initially exponential versus control), were neither significant in Block 4 nor in Block 6, F (1, 30) < 1 in both cases. These null effects are inconsistent with the predictions of MTP and further examined in Experiment 3.

Finally, to assess the participants' awareness of the foreperiod distributions that applied in Blocks 2 and 3, we analyzed their answers to the queries. Participants were reasonably accurate in their estimate of the number of foreperiods in these blocks (M = 3.65, sd = 1.09). This estimate did not vary significantly among groups F (2, 45) < 1. Regarding the estimate of the relative frequency of the different foreperiods, we calculated, for each participant, the difference between the estimated percentages for the shortest and the longest foreperiod. The objective differences for Group 1 (exponential), Group 2 (anti-exponential), and Group 3 (uniform) were 46.7%, -46.7%, and 0%, respectively. The corresponding observed mean differences (+ 1 sd) were 10.0 (14.6), -0.25 (19.54), and -0.94 (14.52), respectively. These difference scores did not significantly differ among groups, F (2, 45) = 2.24, p = .119.

Discussion

Overall, the data of Experiment 2 revealed a clear rise and fall of the transfer effect of foreperiod distribution across subsequent test blocks. Whereas it is unclear how this pattern could be explained by hazard-driven preparation, it is fully consistent with the predictions of MTP. At the start of block 4, there was a clear disparity among groups regarding the relative frequency of distinctive memory traces, but this disparity was gradually undone across subsequent reversed-acquisition blocks.

A further notable finding of Experiment 2 was that the relative frequency estimates of foreperiods in Blocks 2 and 3 did not differ much among groups, which indicates that participants were generally unaware of the prevailing foreperiod distribution. Furthermore, explicit information of the distribution provided at the start of the first test block (block 4), which should have led to the same estimate of the hazard function across groups, did not prevent the expression of a clear transfer effect. These findings characterize temporal preparation as an implicit process, which naturally follows from MTP, but not from hazard-driven preparation (e.g., Vallesi Lozano, & Correa, 2013).

Experiment 3

According to MTP, a transfer effect should be observed whenever two groups are presented with substantially different foreperiod distributions during acquisition. The failure to observe, in the first test block of Experiment 2, the expected difference between the RT – foreperiod functions of Group 1 (previously exponential) and Group 3 (control) would therefore severely compromise the generality of MTP. However, this inconsistency might reflect a Type II error, noting that the distribution effect in the two preceding blocks was relatively small. To test this possibility, we raised statistical power in Experiment 3 by doubling the number of acquisition blocks as well as of participants.

Method

Participants. A new sample of 64 students (mean age 24 years; 39 females) participated for course credits or a € 7 payment in a single session of about 50 minutes. Participants were randomly assigned to one of two groups, each consisting of 32 participants. The original sample included three additional participants, but their data were discarded, because their percentage of responses out of range exceeded 10% in several conditions.

Procedure. The procedure of Experiment 1 was used with the following changes. First, in the acquisition phase, Group 1 was presented with the exponential distribution, while Group 2 was presented with the uniform condition. Second, the acquisition phase lasted four blocks (i.e., Block 2 – 5) and was followed by two test blocks (Block 6 and 7). Figure 4, top panel, shows the sequence of blocks that applied in both groups. Participants received no information about the foreperiod distribution in the first five blocks of the experiment, but received full disclosure prior to the start of block6, emphasizing that the distribution in the last two blocks would be uniform.

Block	1	2	3	4	5	6	7
Group 1	Uni	Exp	Exp	Exp	Exp	Uni	Uni
Group 2	Uni	Uni	Uni	Uni	Uni	Uni	Uni

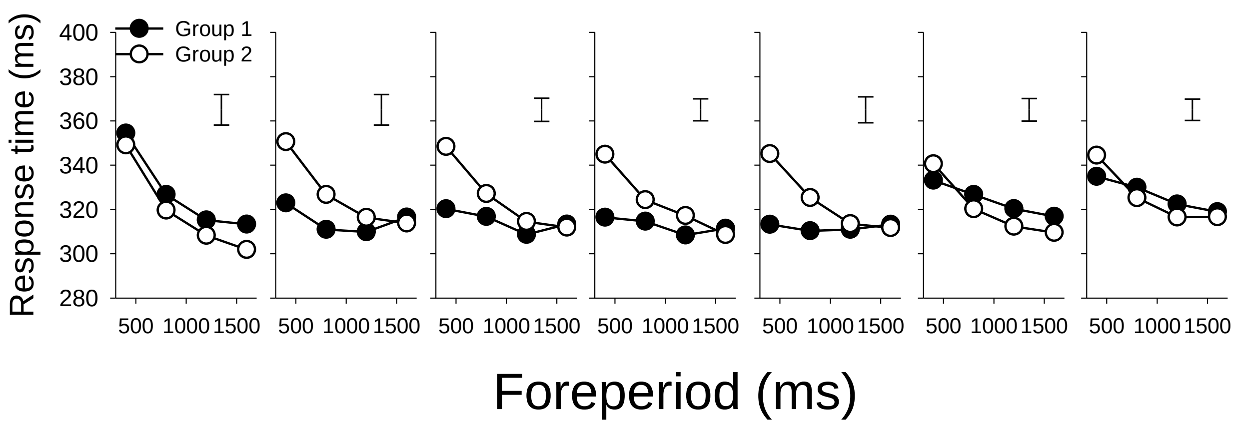

Figure 4. Design and data of Experiment 3. Top panel. Successive foreperiod distributions across blocks for Group 1 and 2 (Uni = uniform; Exp = exponential). Acquisition blocks are shaded. Bottom panel. Mean response time as a function of Group, Block and foreperiod. Error bars are 95% within-subjects confidence intervals, computed per block from the error term of the interaction between Group and foreperiod, using the method of Loftus and Masson (1994).

Results

The first trial of each block was discarded, as were trials with incorrect key presses (1.0%) and trials on which RT was shorter than 150 ms or longer than 800 ms (0.3%). These percentages were very low, and not analyzed any further. Mean RT was calculated on the basis of the remaining trials.

Figure 4, bottom panel, shows mean RT as a function of foreperiod, Group, and Block. On the data of each block, we applied a mixed Analysis of Variance (ANOVA), with group and foreperiod (the linear component) as factors. All Blocks revealed a strong main effect of foreperiod, minimal F (1, 62) = 36.38, p < .001, partial η^2 = .37. The main effect of Group was not significant in any of the seven blocks, maximum F (1, 62) = 2.49, p = .120. The interaction between foreperiod and Block was not significant in Block 1, F (1, 62) < 1 and, unsurprisingly, it was highly significant in Blocks 2 - 5, minimal F (1, 62) = 21.25, p < .001, partial η^2 = .26. Critically, the interaction was also significant in both test blocks; Block 6, F (1, 62) = 8.01, p = .006, partial η^2 = .11; Block 7, F (1, 62) = 5.89, p = .018, partial η^2 = .09 . In the test blocks, the RT – foreperiod function of Group 1 (previously exponential) was clearly flatter than the RT – foreperiod function of Group 2 (control), although both groups received the same uniform foreperiod distribution and although participants were informed of this fact in advance.

Discussion

Experiment 3 revealed a clear transfer effect of the exponential distribution relative to the control condition both in the first and second test block. We therefore conclude that the transfer effect is real and that insufficient power prevented its manifestation in Experiment 2.

General Discussion

All three experiments showed clear transfer effects of foreperiod distribution. Transfer was particularly strong for highly different foreperiod distributions during acquisition (exponential versus anti-exponential), but it could also be demonstrated for less dissimilar distributions (exponential versus uniform), provided that sufficient power was employed. The transfer effect turned out to be persistent, lasting hundreds of trials, but it could be quickly undone after reversed acquisition. Finally, the transfer effect was observed despite full disclosure of the previous and forthcoming foreperiod distribution at the start of the test phase.

These findings indicate a key role of previous timing experiences in current temporal preparation. In particular, the observed rise and fall of transfer are principled predictions from MTP, and the implicit nature of these effects follows naturally from multiple trace theories (e.g., Logan, 1988, 1990). By contrast, since the hazard function is derived from the prevailing distribution in a block of trials, it cannot account for persistent transfer effects of foreperiod distribution.

The inconvenient relation between hazard and trial history has been noted before in relation to the asymmetric sequential effect of foreperiod (Los & Van den Heuvel, 2001). This effect implies that, on any given trial, RT is slower to the extent that the foreperiod on the preceding trial is longer than the foreperiod on the current trial (e.g., Los, 2010; Steinborn & Langner, 2012; Zahn, Rosenthal & Shakow, 1963). MTP readily accounts for this short-term effect in that memory traces contribute to preparation in proportion to their recency. By contrast, hazard-driven preparation cannot account for it, because the hazard function is fixed for any given foreperiod distribution and should drive preparation in the same way on each and every trial. To solve this problem, it has been proposed that short-term effects proceed from an ephemeral process that operates alongside the more enduring hazard-controlled process (Vallesi & Shallice, 2007; Vallesi, et al., 2013). However, the presently observed long-term effects of trial history show that the problems with hazard-driven preparation are more fundamental.

In conclusion, the hazard function appears to be the wrong construct to account for effects of trial history, whether short-term, as revealed by earlier studies, or long-term, as revealed by the present study. MTP naturally accounts for these effects, in that memory traces contribute to preparation in proportion to their recency and frequency. Furthermore, as an explanatory construct, the hazard function is limited in that it lacks a cognitive basis, whereas MTP is firmly rooted in general principles of learning and memory.

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