

Rhythms that speed you up

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ABSTRACT

This study investigates whether a rhythm can orient attention to specific moments enhancing people's reaction times (RT). We used a modified version of the temporal orienting paradigm in which an auditory isochronous rhythm was presented prior to an auditory single target. The rhythm could have a fast pace (450 ms Inter-Onset-Interval or IOI) or a slow pace (950 ms IOI). The target was presented after a variable foreperiod of either 200, 400, 900, 1400, or 1600 ms following the offset of the rhythm. In Experiment 1, the rhythmic pace validly predicted the moment of target appearance, i.e., the target appeared after a foreperiod that matched the rhythmic pace on 60% of the trials. The results showed an effect on RT performance of the fast rhythmic pace compared to the slow rhythmic pace at the 200 and 400 ms foreperiods, while no effects were found at the long foreperiods, probably due to a foreperiod effect. In Experiment 2, non-predictive rhythmic paces did not modulate the foreperiod effect. The addition of temporal uncertainty by including catch trials in Experiment 3 clearly unveiled the effect of non-predictive rhythmic pace at short and long foreperiods. Taken together, the results of the experiments reported here highlight the ability of rhythms to orient temporal attention enhancing participants' response speed not only at short intervals but also at long time intervals, suggesting the involvement of a flexible mechanism.

Introduction

*Runners take position...3! muscles get ready... 2! sweating starts...1!
adrenaline flows... boom! the 100 meters race starts!*

Speed runners achieve incredibly fast reaction times (RT) to the start shot by generating temporal expectancies. After numerous demonstrations of our capacity to orient attention in space voluntarily over the last three decades (see Posner, Cohen, & Rafal, 1982; Ruz & Lupiáñez, 2002), recent research has begun to unveil the mechanisms enabling the control of attention in the temporal domain. Temporal orienting reflects the ability to generate expectancies about when a relevant event is going to occur (see Nobre, Correa, & Coull, 2007, for a review).

In analogy to research in spatial attention, most investigations in temporal orienting have used single static cues. It has been repeatedly shown that participants can enhance both response speed to incoming stimuli (e.g., Nobre, 2001), and perceptual accuracy (e.g., Correa, Lupiáñez, & Tudela, 2005; Correa, Sanabria, Spence, Tudela, & Lupiáñez, 2006) by using symbolic cues that validly predict the temporal onset of a target stimulus. Now, think on the example above: Runners are confronted with a special temporal cue, a rhythm. The processing of the isochronous sequence of stimuli (3...2...1...) prepares their perceptual and motor systems for the imminent start shot achieving a fast reaction time. As we would like to prove here, presenting a regular sequence of stimuli could be an efficient procedure to generate temporal expectancies that enhance participants' RT.

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It has been proposed (e.g., Barnes & Jones, 2000; Jones, 1976; Large & Jones, 1999) that exposure to rhythmic regular sequences of stimuli produces attentional shifts (i.e., the onset of a stimulus in the sequence serves as a temporal cue for the next stimulus in the regular sequence) that do not necessarily entail conscious awareness. These temporal expectations based on auditory regular rhythms have been proved to influence performance in tasks measuring response accuracy. For instance, Barnes and Jones (2000; see also Large & Jones, 1999) reported that participants' accuracy of time judgments was highest when the duration of the critical IOI (time between the onset of the last tone in the rhythm sequence and the onset of the target) matched the dominant IOI from the preceding rhythm. Later, in an attempt to generalize the effects to other non-timing tasks, Jones et al. (2002), demonstrated that anticipatory attending could also affect auditory perceptual judgments, such as pitch identification. Both in discrimination of duration and pitch identification, the results were alike: An enhanced accuracy at the IOI that matched that of the context rhythm. This effect gave rise to a bell-shape in the accuracy distribution as a function of the critical IOI, with a peak in performance at the critical IOI and a decrement in performance as the temporal distance to that IOI increased (i.e., expectancy profile).

A clear parallelism between the fields of endogenous temporal orienting and stimulus-driven attention in time can be drawn from the results described above: Attention can be oriented to specific points in time by means of both informative static cues and exogenous dynamic cues. However, while temporal orienting paradigms use symbolic static cues that highly predict the moment of target appearance (e.g., an early cue is associated with the target appearing at the short interval on 75% of the trials), in studies using rhythms, the context IOI (i.e., the rhythmic pace) does not predict the time

interval at which the target appears¹. Therefore, any temporal expectancy generated by the rhythms is not based on the (a priori) probability of target appearance, but on the sequential structure of the rhythm.

A crucial aspect of endogenous temporal orienting refers to its flexibility. Despite most studies in endogenous temporal orienting having reported significant effects only at short intervals, Correa and colleagues (Correa, Lupiáñez, & Tudela, 2004, 2006) have demonstrated that attention can be endogenously oriented to both early and late moments in time. However, whether a fast rhythmic pace can capture attention to early moments in time and a slow rhythmic pace can capture attention to late moments in time, remains unexplored. Proving the flexibility of the process is important to rule out explanations of the effects of rhythms on RT based on pure motor or alerting effects. That is, if RT facilitation was only observed at short intervals it could be argued that rhythms just exerted an alerting effect that vanished at long intervals. Similarly, a slow rhythm would entrain the motor system leading to slow RTs. Therefore, finding facilitation effects of both fast rhythmic pace (compared to slow rhythmic pace) and slow rhythmic pace (compared to fast rhythmic pace) on RT is important to demonstrate the attentional nature of the mechanism.

The work on endogenous temporal orienting with single cues has recurrently shown benefits on participants' RT to the cued target (Nobre et al., 2007). Even the mere passage of time produces faster RT to the target stimulus, i.e., the foreperiod effect, which has been ascribed to strategic temporal anticipation (Niemi & Näätänen, 1981). In contrast, the majority of the research on stimulus-driven temporal orienting has measured accuracy as the dependent variable, presumably with the purpose of ruling out a pure motor explanation typically related to rhythmic responding, and to

demonstrate the attentional nature of the effects. However, as suggested by our introductory example, stimulus-driven temporal attention should also facilitate reaction time. Finding that rhythmic pace can also enhance participant's RT would support that stimulus-driven temporal attention is a general mechanism that affects both accuracy and reaction time measures.

To the best of our knowledge, only three studies have tried to tackle the potential shortcomings detailed above. In a study reported by Doherty and colleagues (Doherty, Rao, Mesulam, & Nobre, 2005) participants had to track a ball that moved across the monitor screen with a regular or irregular pace, went behind an occluder column, and reappeared with, or without, a black dot that participants had to detect. The authors observed facilitation in participants' RT to the target and modulation of response-related electrophysiological components (P3) by the regular rhythmic pace as compared to the irregular rhythmic pace (cf. Jones et al., 2002; Experiment 2). A RT facilitation was demonstrated, but, since only one temporal rate was used, the flexibility of stimulus-driven temporal orienting was not tested. In addition, following the regular rhythm the target reappeared from behind the occluder after a time interval that matched that of the IOI of the regular rhythm so that participants could predict the moment at which the target would appear (i.e., the rhythmic pace validly predicted the moment of target appearance). Analogous results were obtained by Lange (Lange, 2009) in an ERP study investigating the effect of a regular auditory rhythm on an auditory gap detection task. In her study, similar to Doherty et al.'s study, the regular rhythm always predicted the moment of target appearance. Since the rhythmic pace predicted the moment of target appearance in the two studies cited above, the pure stimulus-driven effect of rhythms on RT performance remained to be investigated.

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Correa and Nobre (2008) went a step further by adapting Doherty et al.'s paradigm to study the flexibility of temporal orienting induced by rhythms. The temporal rate of the rhythm was held constant during each trial, and could have a random IOI value ranging between 200 and 900 ms. The ball was occluded for two steps, which duration could be in accordance to the rhythmic pace, shorter, or longer (the foreperiod duration, the interval between the offset of the rhythm and the onset of the target, was randomly varied between 400 and 1800 ms). This manipulation gave rise to valid (e.g., the interval between each step was 200 ms and the ball reappeared after 400 ms) and invalid trials (e.g., the interval between each step was 400 ms and the ball was occluded for 200 ms or 600 ms). Participants' RT distribution showed the typical foreperiod effect with a reduction in RT with the passage of time. Crucially, temporal orienting produced by rhythms modulated this RT's negative linear function. Following short occlusions, participants responded faster if the rhythmic pace had been fast rather than slow. However, the complementary effect, i.e., faster RT after the long occlusion following a slow rhythm than following a fast rhythm, was not found.

In the present study, an adaptation of the classical endogenous temporal orienting paradigm was used to investigate stimulus-driven temporal preparation. Instead of two symbolic cues meaning early/late target onsets, auditory rhythms with a fast (IOI of 450 ms) or slow (IOI of 950 ms) pace were presented to the participants. This manipulation allowed us to evaluate the potential flexibility of temporal orienting guided by rhythms. Participants' RT distribution was obtained by manipulating the foreperiod between the offset of the last tone in the rhythm and the onset of the target with the values of 200, 400, 900, 1400, and 1600 ms².

RHYTHMS THAT SPEED YOU UP EXPERIMENT 1

Experiment 1 tested whether two different predictive rhythmic paces (the rate of the rhythm was most likely associated with the moment at which the target would appear; i.e., the rhythmic pace was regular and predictive) could speed up responses to the auditory target. Based on previous research using symbolic static cues, we predicted a significant interaction between rhythmic pace and foreperiod, with faster RTs at short foreperiods following a fast rhythmic pace than after a slow rhythmic pace. The key issue was to investigate whether a slow rhythmic pace would produce faster RTs than a fast rhythmic pace at long foreperiods.

Methods

Participants. Twenty-seven (ten females; age range: 18-30 years old; mean age: 21 years old) undergraduate students from the Faculty of Psychology (University of Granada) took part in Experiment 1 in exchange of course credits. All reported normal hearing and normal or corrected-to-normal vision. All the experiments reported in this paper were conducted according to the ethical requirements of the local committee.

Apparatus and stimuli. The experiment was conducted on an Intel Core 2 Duo PC computer connected to a 17" LCD monitor. The auditory stimuli were presented through two loudspeakers, one located at each side of the monitor. The E-prime software (Schneider et al., 2002) was used for stimulus presentation and to collect participants' responses. The viewing distance was approximately 60 cm. The auditory rhythm

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consisted of a sequential presentation of six 50-ms pure tones separated by either 450 ms IOI (fast rhythmic pace) or 950 ms IOI (slow rhythmic pace). The first five tones had a frequency of 700 Hz. The last tone in the sequence (the warning signal) had a frequency of 1000 Hz. The target sound was a 50-ms pure tone with a frequency of 400Hz. All sounds were presented at a comfortable intensity. The fixation point consisted of a grey plus sign subtending $1.5^{\circ} \times 1.5^{\circ}$, and presented on the centre of a black background. This fixation point remained on and steady during the trial and went off after the participant's response.

Procedure. Participants sat on a chair in front of the computer in a silent and dimly illuminated room. They were given verbal and written instructions to respond to the appearance of the target tone as fast as possible, while avoiding anticipations, by pressing the space bar with their dominant index finger. Participants were also informed that the pace of the rhythm predicted the appearance of the target (i.e., after the fast rhythm there was a high probability that the target appeared early while the reverse was true for the slow rhythm). They were also told that the last tone in the rhythm sequence marked the beginning of the foreperiod preparatory interval. At the beginning of the experimental session participants listened to the target tone to ensure that they would discriminate it from the rhythm tones. A trial started with the presentation of the fixation point, which remained on the screen until the end of the trial (see Figure 1). 500 ms after the onset of the fixation point, either the fast or slow auditory rhythmic pace was presented. The sixth tone in the auditory sequence marked the end of the rhythm and the beginning of the foreperiod. The target appeared after a variable interval or foreperiod of either 200, 400, 900, 1400, or 1600 ms. A maximum of 2000 ms was allowed to respond. The inter-trial-interval was set to 500 ms. Visual feedback was provided on

anticipatory error, i.e., when participants responded prior to the presentation of the target.

 INSERT FIGURE 1

Design. Experiment 1 constituted a within-subjects design with the independent variables of Rhythm (fast pace– 450 ms or slow pace– 950 ms IOI) and Foreperiod (200, 400, 900, 1400, 1600). In the fast rhythmic pace condition the target appeared at the 400-ms foreperiod on 60% of the trials, and in the slow rhythmic pace condition the target appeared at the 900-ms foreperiod on 60% of the trials. The remaining 40% of trials were equally distributed among the other four foreperiods. Participants completed a practice block of trials and 12 experimental blocks of 20 trials each. A rest was allowed after each block of trials should the participant desired.

Results. Data from the practice block were not included in the analyses. Anticipations, misses, and trials with RT below 150 ms or above 1200 ms were also discarded from the analyses (2.7% rejected)³. A repeated-measures analysis of variance (ANOVA) was conducted on participants' mean RTs. The analysis revealed a significant main effect of Rhythmic pace, $F(1,26)=41.05, p<.001, \eta^2_p=0,61$, with participants responding faster after the fast rhythmic pace than after the slow rhythmic pace (see Table 1). The main effect of Foreperiod was also significant, $F(4,104)=13.62, p<.001, \eta^2_p=0,34$, showing the typical foreperiod effect obtained in variable foreperiod designs: RT reductions with increments of foreperiod duration.

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INSERT TABLE 1

As predicted, the interaction between Rhythmic pace and Foreperiod was significant, $F(4,104)=13.2$, $p<.001$, $\eta^2_p=0.33$ (see Figure 2). Subsequent a priori comparisons revealed that participants responded significantly faster in the fast compared to the slow rhythmic pace condition, at the 200 and 400 foreperiods, both $ps<.01$. The difference between the two rhythmic paces in the remaining three foreperiods did not reach statistical significance (all $ps>.1$).

INSERT FIGURE 2

Discussion

Experiment 1 confirmed that participants could use regular and predictive auditory rhythms to develop expectancies about the moment of target appearance, which speeded up their responses. These results replicate the findings by Lange (2009) and go further by describing the time course of the effect of predictive rhythmic paces on response speed. In fact, the effect of the fast rhythm was not restricted to the cued short foreperiod (400 ms) but it was also shown at the 200-ms foreperiod (see also Griffin, Miniussi, & Nobre, 2001). Two explanations might account for this result: On one hand, given that a main effect of rhythmic pace was obtained in Experiment 1, it could be argued that the effect at the 200-ms foreperiod following a fast rhythm mainly reflected an alerting effect. On the other hand, if one assumes that human time

estimation is not very accurate (Fraisse, 1963; Gibbon, Church, & Meck, 1984) and that preparation cannot occur backwards in time, preparing for around the shortest foreperiod and extending preparation to the following foreperiod after the fast rhythmic pace seems a valuable strategy. Note that, to date, only Griffin and collaborators (Griffin et al., 2001) had used a foreperiod shorter than the shortest cued foreperiod to investigate endogenous temporal orienting and found a similar anticipatory effect.

Experiment 1 demonstrated that a predictive fast rhythmic pace speeded participants' responses at short foreperiods compared to a slow rhythmic pace. No differences were obtained at long foreperiods. This latter result is consistent with findings using symbolic cues in variable foreperiod designs (e.g., Correa, Lupiáñez, Milliken, & Tudela, 2004). In these paradigms, the probability of target appearance increase with the passage of time, allowing participants to anticipate the target at long foreperiods even when the short foreperiod was cued (i.e., the conditional probability of target appearance increases as the FP increases).

An interim conclusion could be that temporal expectations based on regular and predictive rhythms can influence temporal expectations based on conditional probabilities (i.e., foreperiod effect). However, the design of Experiment 1 cannot disentangle whether the facilitation effect of the rhythmic pace was due to endogenous factors (top-down expectancies based on the *predictability* of the rhythmic pace) or to exogenous factors (bottom-up expectancies based on the *regularity* of the rhythm). In effect, the rhythmic paces used in Experiment 1 were both regular and predictive. Moreover, the potential flexibility of stimulus-driven temporal orienting was not demonstrated in Experiment 1 as no effect of the slow rhythmic pace (compared to the fast rhythmic pace) was found at long foreperiods.

EXPERIMENT 2

Experiment 2 tested whether two non-predictive auditory rhythmic paces could improve RT performance. If rhythms can orient attention automatically, regardless of predictive cuing, we should replicate the interaction between Rhythm pace and Foreperiod found in Experiment 1. Moreover, we investigated whether a slow non-predictive rhythmic pace (compared to a fast rhythmic pace) would enhance participants' RT at long foreperiods.

Methods

Participants. Twenty-eight (eighteen females; age range: 18-28 years old; mean age: 20 years old) undergraduate students from the Faculty of Psychology (University of Granada) took part in Experiment 2 in exchange of course credits. All reported normal hearing and normal or corrected-to-normal vision. None of them had taken part in Experiment 1.

Apparatus, stimuli, procedure, and design. Everything was the same as in Experiment 1 except for the following: the rhythmic pace was not predictive of target appearance, that is, the auditory target appeared at the 200, 400, 900, 1400 or 1600-ms foreperiod with the same probability (0.2) in both fast and slow rhythmic pace conditions. Contrary to Experiment 1, participants were not informed regarding the relationship between the rhythmic pace and the moment of target appearance. They completed a practice block of 10 trials before going through 200 experimental trials divided in 10 blocks. A rest was

allowed between blocks of trials.

Results. Data from the practice block were not included in the analysis. Anticipations, misses, and trials with RT below 150 ms or above 1200 ms were also discarded from the analyses (4% rejected). The ANOVA on participants' mean RT revealed that the main effect of Rhythmic pace was not significant, $F(1,27)=2.42$, $p=.13$, $\eta^2_p=0,08$ (see Table 1). Once again, the main effect of Foreperiod was significant, $F(4,108)=30.36$, $p<.001$, $\eta^2_p=0,52$. In contrast to Experiment 1, the interaction between Rhythmic pace and Foreperiod did not reach statistical significance, $F(4,108)=1.98$, $p=.1$, $\eta^2_p=0,06$ (see Figure 3).

 INSERT FIGURE 3

Discussion

The results in Experiment 2 were not as clear-cut as in Experiment 1. The statistical analysis showed a non-significant interaction between Rhythmic pace and Foreperiod. This finding contrasts with previous research that has shown that a non-predictive rhythm clearly orients temporal attention, leading to enhanced perceptual accuracy in tasks demanding either estimation of interval duration or sound pitch discrimination (e.g., Jones et al., 2002). It might be then concluded that temporal orienting induced by rhythms is not a general mechanism of exogenous temporal orienting, but that it is restricted to perceptual accuracy tasks.

An important aspect of our study that differs from previous investigations (e.g.,

Jones et al., 2002) needs to be taken into account before drawing such a firm conclusion: we measured RT in a variable foreperiod design, instead of response accuracy under no time pressure. This design (both in Experiments 1 and 2) typically produces a robust foreperiod effect whereby the RT decreases as the foreperiod increases (see also Correa & Nobre, 2008). In contrast, the use of unspeeded tasks and narrow sets of foreperiods (see Elliot, 1973 on this issue; see also Steinborn et al., 2008) may have prevented the occurrence of foreperiod effects in previous studies using rhythms (e.g., Jones et al., 2002).

In Experiments 1 and 2 the probability of target appearance increased with the passage of time, which allowed participants to anticipate the onset of the target at long foreperiods even following a fast rhythmic pace (i.e., analogous to the occurrence of temporal re-orienting with symbolic cues). The modulation of RT performance at the short foreperiods in Experiment 1 was probably due to the predictive nature of the rhythmic pace, replicating previous studies using symbolic cues (see Nobre, 2001, for a review). The non-predictive rhythmic paces in Experiment 2 were not as efficient as the predictive rhythmic pace in Experiment 1 in modulating the foreperiod effect.

Research using symbolic cues has already confirmed the robustness of the foreperiod effect. In fact, it has been demonstrated that in order to obtain cuing effects at long foreperiods the foreperiod effect must be prevented by manipulating the conditional probabilities of target appearance with time (Correa et al., 2006). The question is therefore whether the foreperiod effect was somehow masking temporal orienting by rhythms in Experiment 2, as well as the effect of the slow rhythmic pace at long foreperiods in Experiment 1.

EXPERIMENT 3

Experiment 3 tested whether the effect of non-predictive rhythmic pace on participants' RT performance could be maximized and clearly revealed, once the foreperiod effect was controlled for by adding temporal uncertainty with the inclusion of catch trials (see Correa et al., 2006 on this issue). The prediction was straightforward: An interaction between Rhythmic pace and Foreperiod should now be found, with participants responding faster at short foreperiods following the fast as compared to the slow rhythmic pace, while responding faster at long foreperiods following the slow as compared to the fast rhythmic pace.

Methods

Participants. Fourteen naïve (one male; age range: 20-24 years old; mean age: 21 years old) undergraduate students from the Faculty of Psychology (University of Granada) took part in Experiment 3 in exchange of course credits. All reported normal hearing and normal or corrected-to-normal vision.

Apparatus, stimuli, procedure, and design. Everything was the same as in Experiment 2 except for the following: We included 1/3 of catch trials (i.e., the target was not presented) on each of the rhythmic pace conditions. A practice block of 30 trials and 12 experimental blocks of 30 trials constituted Experiment 3.

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Results. Data from the practice block were not included in the analyses. Anticipations, misses, false alarms (i.e., responses to catch trials) and trials with RT below 150 ms or above 1200 ms were also discarded from the analyses (1%). The remaining mean RT data were submitted to an ANOVA with the factors of Rhythmic pace and Foreperiod. The main effect of Rhythmic pace did not reach statistical significance, $F < 1$ (see Table 1). The catch trial manipulation was effective, leading to a significant reversed foreperiod effect, $F(4,52)=18.66, p < .001, \eta^2_p = 0.58$, with participants responding slower as the foreperiod increased. As predicted, we found a significant interaction between Rhythmic pace and Foreperiod, $F(4,52)=4.43, p < .01, \eta^2_p = 0.25$ (see Figure 4). This interaction was due to participants responding faster at the 200-ms foreperiod in the fast rhythmic pace condition than in the slow rhythmic pace condition ($p = .01$). Crucially, and in contrast to the results of Experiments 1 and 2, participants responded faster at the 900-ms and 1400-ms foreperiods in the slow rhythmic pace condition than in the fast rhythmic pace condition ($p = .001$ and $p = .01$, respectively). The difference between slow and fast rhythmic paces in the 400-ms and 1600-ms foreperiod conditions was not statistically significant ($ps > .5$).

INSERT FIGURE 4

Discussion

The results of Experiment 3 were straightforward: 1) non-predictive rhythmic paces oriented attention in the time domain enhancing participants' response speed, and 2) this attentional orienting driven by rhythms was flexible and depend on the rhythmic

pace; that is, a fast rhythmic pace drew attention to early moments and a slow rhythmic pace drew attention to late moments.

General Discussion

The results of the three experiments reported in this manuscript revealed that auditory rhythms can enhance participants' response speed and that this RT modulation depends on rhythmic pace. Experiment 1 replicated previous findings that have used rhythmic visual cues to modulate the foreperiod RT effect (Correa & Nobre, 2008). Experiment 2 showed a weak (statistically non significant) effect of non-predictive rhythmic paces on participants RT performance. The results in Experiment 3 confirmed the hypothesis that the robust foreperiod effect in Experiment 2 was masking the temporal orienting induced by non-predictive rhythmic paces.

The results reported here demonstrate that temporal orienting induced by rhythms can be considered as a general and flexible mechanism: fast rhythms can drive attention to early moments in time and slow rhythms can drive attention to late moments in time, producing benefits in response speed. It should be acknowledged, however, that our results might be constrained by the range of rhythmic paces, only two, used in the present study. Based on the research in endogenous temporal orienting we presume that our results would generalize to other situations, e.g., with more complex rhythms or different ranges of rhythmic paces and foreperiods. In any case, although further research is needed to tackle this issue, our findings extend previous research by showing that the mechanism is more flexible than previously demonstrated (cf. Barnes & Jones, 2000).

Finding an effect at the long foreperiod was crucial to rule out an explanation

based on general arousal and/or motor effects related to rhythmic pacing. The lack of a main effect of rhythm in Experiment 3, and the significant RT enhancement of slow versus fast rhythmic paces at the long foreperiods suggest that the effects were not a mere consequence of nonspecific alertness but the result of stimulus-driven temporal orienting. Moreover, ERP studies using rhythms cues in RT paradigms have shown modulation of brain activity related to both perception and response selection processes (e.g., Correa & Nobre, 2008), which suggests that our results support attentional, over purely motor, accounts.

In favour of an account of stimulus-driven temporal orienting as a flexible mechanism, the results in Experiment 3 showed that the two rhythmic paces exerted differential modulations of the time course of temporal preparation, i.e., the fast rhythmic pace induced RT facilitation that peaked early and vanished early whereas the slow rhythmic pace led to a more progressive attainment and later vanish of preparation. A closer look to the outcome of Experiment 3 suggests that the effect of the fast and slow rhythmic pace was not restricted to the exact matching foreperiod. In effect, a RT benefit of the fast rhythmic pace was also obtained at the shortest 200 ms foreperiod (no statistical difference was reported between the 200 ms and 400 ms foreperiod, $F < 1$), a result also showed in Experiment 1. Similarly, the slow rhythmic pace produced similar RTs at the 400 ms and 900 ms foreperiods ($p = .2$), together with an effect at the 900 ms and 1600 ms foreperiods with respect to the fast rhythmic pace condition. These results are consistent with previous accounts that have used accuracy tasks (e.g., Jones et al., 2002, Experiment 2) suggesting that the effect of a specific rhythmic pace can be extrapolated to other (temporally close) non-matching foreperiods also in RT tasks. These findings are also consistent with an EEG study (Correa et al., 2007) showing that

temporal orienting effects started the enhancement of neural activity up to 200 ms before the actual onset, which further supports the anticipatory nature of this mechanism. Further research, however, is needed to clarify the processes underlying the spreading of exogenous temporal preparation to non-matching foreperiods observed in our study and in studies using perceptual tasks.

The increase of the conditional probability of a catch trial with FP duration in Experiment 3 could also account for the effect of the slow rhythmic condition at the 400 ms foreperiod and the 900 ms foreperiod. In Experiment 3, catch trials were more likely to occur after the 900 ms foreperiod ($p=.33$) than after the 400 ms foreperiod ($p=.25$), producing a slowing in participants' RT. Note that this increase in RT with time is typically reported in studies using catch trial manipulations or in non-ageing procedures (e.g., Correa et al., 2004; Drazin, 1961). As suggested by numerous authors, catch trials involve temporal preparation since temporal preparation underlying foreperiod effects relies on temporal conditional probabilities, and catch trials involve a modulation of these temporal probabilities (e.g., Correa et al. 2004, 2006; Correa & Nobre, 2008; Drazin, 1961; Gabay & Henik, 2008, 2010; Näätänen, 1972; Nobre et al 2007; Trillenberg et al, 2000; Triviño et al. in press; Zahn and Rosenthal, 1966). Importantly, in our study, the slow rhythmic pace modulated this catch trial effect, producing faster RT at the 900 ms foreperiod (and at the 1600 ms foreperiod) than the fast rhythmic pace. In general, our results show that the time course of stimulus-driven temporal preparation depends on the previous rhythmic pace.

The non-predictive rhythmic paces in Experiment 2 did not modulate the time course of preparation as indexed by the participants' RT, in contrast with the results reported in Experiment 3. The key difference between both experimental designs was

the presence of the foreperiod effect in Experiment 2. Assuming that this foreperiod effect resulted from the action of an endogenous mechanism (Coull, 2009; Niemi & Näätänen, 1981; Vallesi, McIntosh, Shallice, Stuss, 2009; although see Los & Van den Heuvel, 2001) a dissociation between endogenous temporal preparation (i.e., driven by probability computation) and exogenous temporal preparation (i.e., driven by rhythms) could be drawn. In effect, only the endogenous manipulation of conditional probabilities of target appearance in Experiment 1 was efficient in modulating the endogenous foreperiod effect. Although this endogenous-exogenous dissociation should be considered with caution, it is important to acknowledge that our study represents the first attempt to investigate the relationship between the endogenous temporal preparation (i.e., driven by conditional probabilities) and exogenous temporal preparation (i.e., driven by non-predictive rhythms). To our knowledge, there is only one study comparing temporal orienting driven by predictive symbolic cues versus temporal orienting driven by predictive regular rhythms (Capizzi et al, 2007), which also suggested no interaction between the two processes.

Rhythms served to generate expectancies about the moment of target appearance. In Experiment 3 (and 2), the rhythmic pace did not predict the moment of target appearance. Participants could not use such information, like in Experiment 1, to prepare their response to the forthcoming target. In that case, we propose that the sequential and regular presentation of stimuli produced an online pacing and synchronization of attention with this regular stimulus pattern (see Large and Jones, 1999; Schroeder & Lakatos, 2009). Our results (see also Jones et al., 2002) suggest that this attentional entrainment by regular rhythms is proactive, that is, it is not restricted to the exact IOI that determine the rhythmic pace, but that it can be anticipated to earlier

intervals (and also extended to later moments). Interestingly, the time course of the effects of this attentional entrainment depends on the particular rhythmic pace to which participants are exposed.

Perceptual grouping processes might also account for the behavioural effects reported in this manuscript. In fact, Gestalt visual perceptual grouping laws (Wertheimer, 1928/1938; see also Kubovy & Berg, 2008) have their auditory counterpart (Bregman, 1990; Kubovy & Valkenburg, 2001). Thus, consecutive sounds sharing particular features (e.g., duration, pitch) would be grouped together and segmented from sounds with dissimilar features. It is then plausible to argue that the perceptual grouping of the target with the rhythmic sequence caused the benefit in RT shown in Experiments 1 and 3. Auditory stimuli presented outside the temporal sequence would have disrupted perceptual grouping and produced slower RT. The nature of the stimuli that formed the rhythm in our procedure makes this explanation unlikely. In fact, the last tone in the rhythm sequence was of a different frequency than the five precedent sounds. Frequency, together with time, has been defined as one of the two *indispensable attributes* that characterize an auditory object (Kubovy, 1981; see also Valkenburg & Kubovy, 2003). Therefore, it is likely that the last tone in the sequence already disrupted auditory perceptual grouping before the presentation of the target (that was also presented in a different frequency with respect to the other six auditory stimuli). On the other hand, it could be also argued that temporal grouping of the target with the rest of auditory stimuli would have made it less salient than targets presented outside the rhythmic pattern. However, according to a pure exogenous capture account of the effects (cf. Dalton & Lavie, 2004) one should have expected slower RT to less salient targets than to more salient targets. Therefore, it appears that the data

pattern presented here fits better with a stimulus-driven temporal orienting account rather than with an explanation based on perceptual grouping (cf. Barnes & Jones, 200; Jones et al., 1981) or capture by a single target stimulus.

In sum, our study goes beyond previous research demonstrating that temporal orienting driven by regular rhythms is a mechanism that modulates participants' response speed (and not only perceptual accuracy) in a flexible fashion. Simple regular rhythms are common in our everyday life experience, and research like the one presented here reinforces the idea that they are potent cues that orient our attention within the temporal layout.

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REFERENCES

- Barnes, R., & Jones, M. (2000). Expectancy, attention, and time. *Cognitive Psychology*, *41*, 254–311.
- Capizzi, M., Correa, A., Coull, J., & Nobre, A. (2007). Anticipation of moving objects by implicit and explicit temporal expectations. In Rovereto Attention Workshop on Attentional Processing and Control. Trento (Italy).
- Correa, Á., Kane, R., Lupiáñez, J., & Nobre, A. (2007). Temporal orienting facilitates perception: Electrophysiological evidence based on steady-state visual evoked potentials. Presented at the *XV Conference of the European Society for Cognitive Psychology*. Marseille (France)
- Correa, Á., Lupiáñez, J., Milliken, B., & Tudela, P. (2004). Endogenous temporal orienting of attention in detection and discrimination tasks. *Perception and Psychophysics*, *66*(2), 264-278.
- Correa, Á., Lupiáñez, J., & Tudela, P. (2006). The attentional mechanism of temporal orienting: Determinants and attributes. *Experimental Brain Research*, *169*(1), 58-68.
- Correa, Á., & Nobre, A. (2008). Neural modulation by regularity and passage of time. *Journal of Neurophysiology*, *100*(3), 1649-1655.
- Correa, Á., Sanabria, D., Spence, C., Tudela, P., & Lupiáñez, J. (2006). Selective temporal attention enhances the temporal resolution of visual perception: Evidence from a temporal order judgment task. *Brain Research*, *1070*(1), 202-205.
- Coull, J. T. (2009). Neural substrates of mounting temporal expectation. *PLoS Biology*, *7*, e1000166. doi: 10.1371/journal.pbio.1000166.
- Coull, J., Frith, C., Buchel, C., & Nobre, A. (2000). Orienting attention in time: Behavioural and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia*, *38*(6), 808-819.
- Dalton, P., & Lavie, N. (2004). Auditory attentional capture: effects of singleton distractor sounds. *Journal of Experimental Psychology. Human Perception and Performance*, *30*(1), 180-193.
- Doherty, J., Rao, A., Mesulam, M., & Nobre, A. (2005). Synergistic effect of combined

RHYTHMS THAT SPEED YOU UP

- temporal and spatial expectations on visual attention. *The Journal of Neuroscience*, 25, 8259-8266.
- Drazin, D. (1961). Effects of foreperiod, foreperiod variability, and probability of stimulus occurrence on simple reaction time. *Journal of Experimental Psychology*, 62, 43-50.
- Elliott, R. (1973). Some confounding factors in the study of preparatory set in reaction time. *Memory and Cognition*, 1, 13-18.
- Fraisse, P. (1963). *The psychology of time*. Westport, CT: Greenwood Press.
- Gabay, S., & Henik, A. (2008). The effects of expectancy on inhibition of return. *Cognition*, 3, 1478-1486.
- Gabay, S., & Henik, A. (2010). Temporal expectancy modulates inhibition of return in a discrimination task. *Psychonomic Bulletin & Review*, 17, 47-51.
- Gibbon, J., Church, R., & Meck, W. (1984). Scalar timing in memory. En *Timing and time perception* (págs. 52-77). New York: Annals of the New York Academy of Sciences.
- Griffin, I., Miniussi, C., & Nobre, A. (2001). Orienting attention in time. *Frontiers in Bioscience*, 6, 660-671.
- James, W. (1890). *The principles of psychology*. New York: Henry Holt.
- Jones et al. 1981 Evidence for rhythmic attention. *Journal of Experimental Psychology: Human Perception & Performance*, 7, 1059-1073.
- Jones, M. (1976). Time, our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Review*, 83, 323-335.
- Jones, M., Moynihan, H., MacKenzie, N., & Puente, J. (2002). Temporal aspects of stimulus-driven attending in dynamic arrays. *Psychological Science*, 13(4), 313-319.
- Kubovy, M. (1981). Concurrent-pitch segregation and the theory of indispensable attributes. In *Perceptual organization* (p. 55-98). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Kubovy, M., & Berg, M. V. D. (2008). The Whole Is Equal to the Sum of Its Parts: A Probabilistic Model of Grouping by Proximity and Similarity in Regular Patterns. *Psychological Review*, 115(1), 131-154.
- Kubovy, M., & Valkenburg, D. V. (2001). Auditory and visual objects. *Cognition*, 80(1-2), 97-126.
- Lange, K. (2009). Brain correlates of early auditory processing are attenuated by expectations for time and pitch. *Brain and Cognition*, 69(1), 127-137.
- Large, E., & Jones, M. (1999). The dynamics of attending: How we track time varying events.

- Psychological Review*, 106, 119-159.
- Los, S. A., & Van den Heuvel, C. E. (2001). Intentional and unintentional contributions to nonspecific preparation during reaction time foreperiods. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 370-386.
- Miniussi, C., Wilding, E., Coull, J., & Nobre, A. (1999). Orienting attention in time: Modulation of brain potentials. *Brain*, 122, 1507-1518.
- Näätänen, R. (1972). Time uncertainty and occurrence uncertainty of the stimulus in a simple reaction time task. *Acta Psychologica*, 36, 492-503.
- Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin*, 89, 133-162.
- Nobre, A. (2001). Orienting attention to instants in time. *Neuropsychologia*, 39, 1317-1328.
- Nobre, A., Correa, A., & Coull, J. (2007). The hazards of time. *Current Opinion in Neurobiology*, 17, 1-6.
- Posner, M., Cohen, Y., & Rafal, R. D. (1982). Neural systems control of spatial orienting. *Philosophical Transactions of the Royal Society of London B*, 298(1089), 187-198.
- Ruz, M., & Lupiáñez, J. (2002). A review of attentional capture. *Psicológica*, 23, 283-309.
- Schroeder, C., & Lakatos, P. (2009). Low-frequency neuronal oscillations as instruments of sensory selection. *Trends in Neurosciences*, 32(1), 9-18.
- Spence, C., & Driver, J. (1997). Audiovisual links in exogenous covert spatial orienting. *Perception & Psychophysics*, 59(1), 1-22.
- Steinborn, M. B., Rolke, B., Bratzke, D., & Ulrich, R. (2008). Sequential effects within a short foreperiod context: evidence for the conditioning account of temporal preparation. *Acta Psychologica*, 129, 297-307.
- Triviño, M., Correa, A., Arnedo, M., & Lupiáñez, J. (in press). Temporal orienting deficit after prefrontal damage. *Brain*.
- Trillenberg, P., Verleger, R., Wascher, E., Wauschkuhn, B., & Wessel, K. (2000). CNV and temporal uncertainty with 'ageing' and 'non-ageing' S1-S2 intervals. *Clinical Neurophysiology*, 111, 1216-1226.
- Vallesi, A., McIntosh, A. R., Shallice, T., & Stuss, D. T. (2009). When time shapes behaviour: fMRI evidence of brain correlates of temporal monitoring. *Journal of Cognitive Neuroscience*, 21, 1116-1126.
- Valkenburg, D. V., & Kubovy, M. (2003). In defense of the theory of indispensable attributes.

RHYTHMS THAT SPEED YOU UP

Cognition, 87(3), 225-233.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *J Exp Psychol Hum Percept Perform*, 16(1), 121-134.

Zahn, T. P., & Rosenthal, D. (1966). Simple reaction time as a function of the relative frequency of the preparatory interval. *Journal of Experimental Psychology*, 72, 15-19

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1. In the present study, “predictability” refers to the relationship between the rhythmic pace and the target onset time; that is, a regular rhythm is predictive when the target has a larger probability to appear at an interval matching the pace of the rhythm than at any other interval. Note that the use of non-predictive regular rhythm may appear paradoxical as it contrasts with the fact that every stimulus conforming a rhythmic regular sequence predicts the temporal onset of the subsequent element of that sequence. For example, the typical 100-meters race countdown is a non-predictive regular rhythm, as the rhythmic regular pace does not predict the start shot (i.e., the interval duration between countdown and start shot is always jittered in order to prevent sportsmen’s anticipations). The colour sequence in traffic lights would be an example of a predictive rhythmic pace as the IOI between the green and the yellow light predicts the onset of the red light (the stop signal).

2. Note that the IOI of 450 ms matched the 400 foreperiod (i.e., which corresponded to the 450 ms critical IOI). The mixed use of the two nomenclatures, IOI and foreperiod ($FP = IOI + 50 \text{ ms}$) intended to link for the first time the literatures about rhythm and foreperiod. Moreover, according to Jones and colleagues' (2002) finding that rhythmic entrainment persists for IOIs of double duration, we tried to avoid the 800 and the 1800 foreperiod because they were multiple of the rhythms we used. The distribution of foreperiods was symmetrical including increments of 500 and 700 ms for the foreperiods surrounding the middle foreperiod.

3. In order to address the concern regarding the typically skewed RT distribution leading to non-normal distributions, we performed a logarithmic transformation on

participants' data in Experiments 1-3 to accomplish the normality assumption to perform the ANOVA. The ANOVAs were conducted using the antilogarithm of the means (again leading to millisecond units of data) for each participant and experimental condition.

4. In principle, the rhythms used by Correa and Nobre can be considered as non-predictive because there was .50 of a priori probability for both valid and invalid conditions. However, at the short FP, it might be an advantage for the fast pace-valid condition (probability of .50) as compared to the slow pace-invalid condition (e.g., for a medium pace the invalid condition would have $p=.25$ of invalid targets appearing at short FPs and $p=.25$ appearing at long FPs). This issue may question the claim that the rhythms used by Correa and Nobre were purely non-predictive. In contrast, the present study followed a design more similar to Jones et al.'s than to Correa and Nobre's, by presenting pure non-predictive rhythms.

FIGURE CAPTIONS

Figure 1. Schematic representation of a trial in Experiments 1-3. The only variation between the three experiments was the inclusion of predictive rhythms in Experiment 1 and the inclusion of catch trials in Experiment 3. Note that the duration of the foreperiod is the IOI (inter onsets interval) + 50 ms.

Figure 2. Mean RT as a function of Rhythmic pace and Foreperiod in Experiment 1 (vertical bars represent mean standard error).

Figure 3. Mean RT as a function of Rhythmic pace and Foreperiod in Experiment 2 (vertical bars represent mean standard error).

Figure 4. Mean RT as a function of Rhythmic pace and Foreperiod in Experiment 3 (vertical bars represent mean standard error).

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Figure 1.

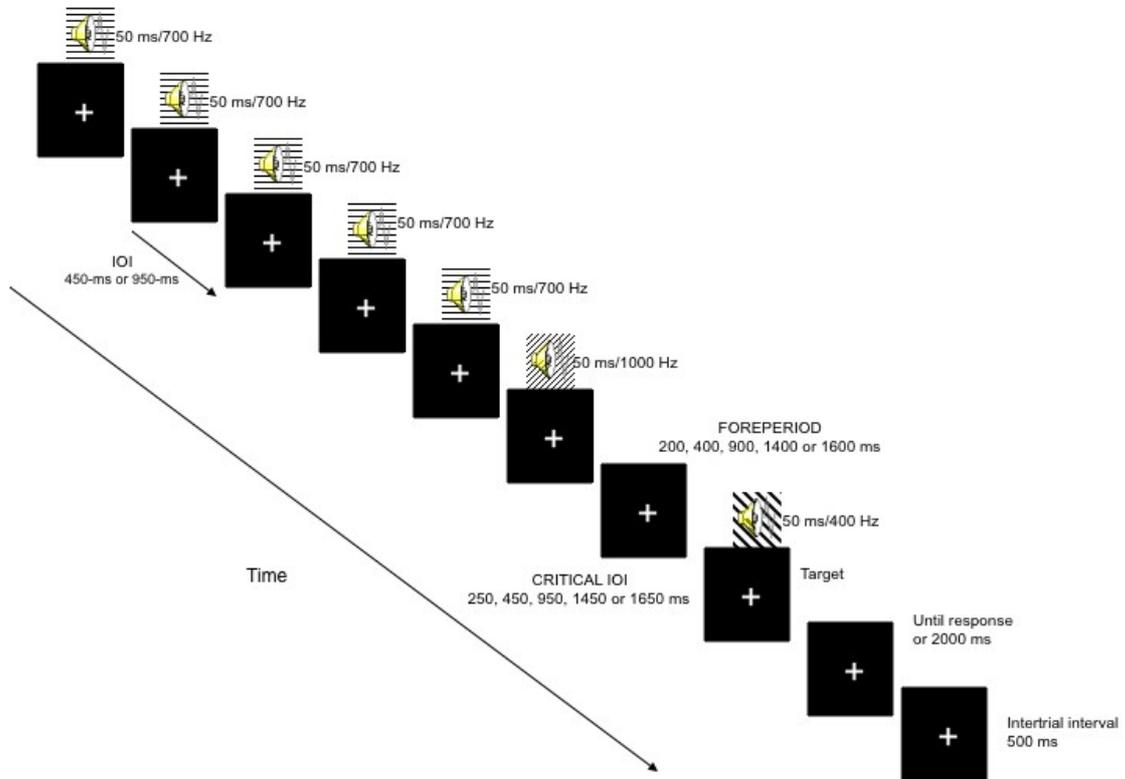


Figure 2

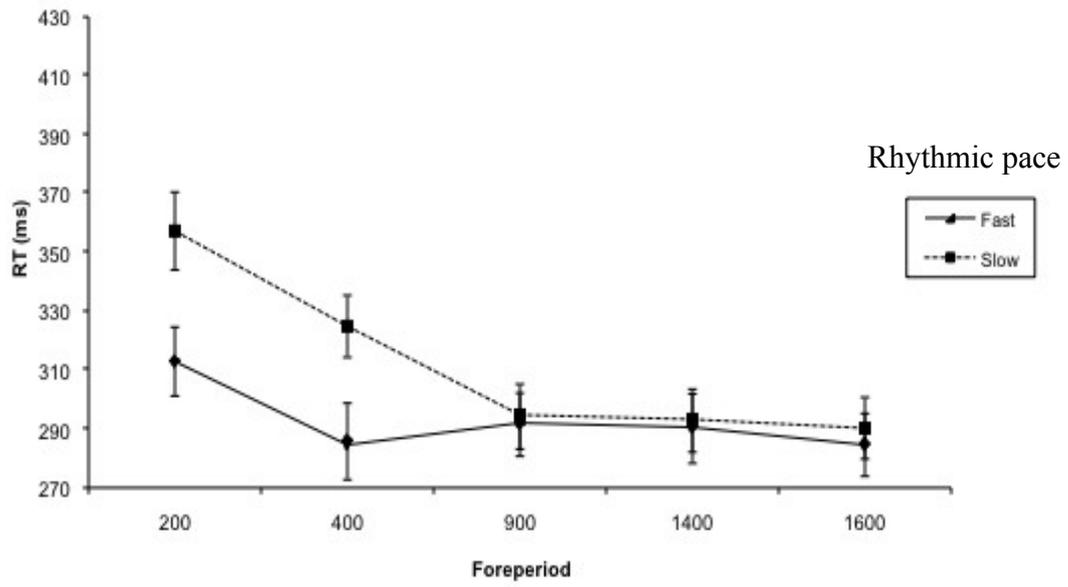


Figure 3

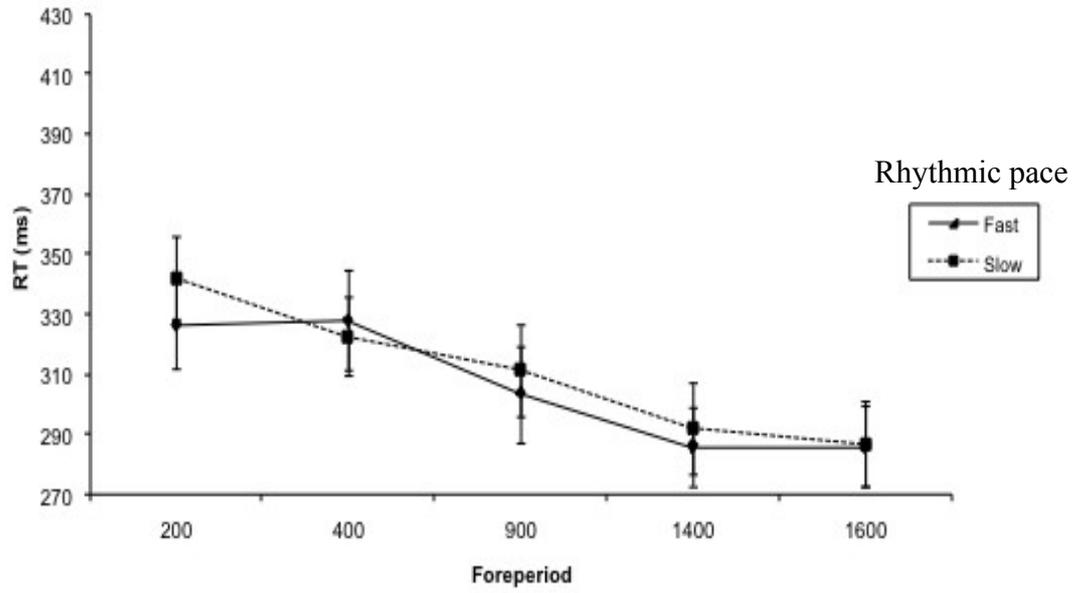
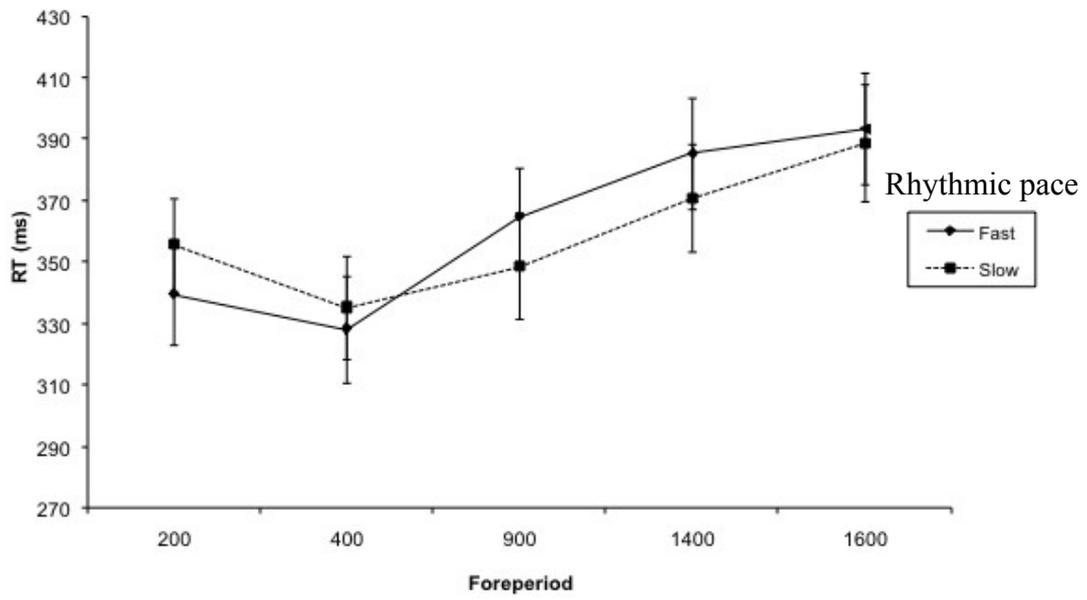


Figure 4



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Table 1. Mean RT for each Foreperiod and Rhythmic pace conditions in Experiments 1-

3. Values in parentheses are mean standard error. The percentage of errors (e.g., anticipations plus misses) are presented between brackets

Rhythm	Fast rhythmic pace (400 ms)					Slow rhythmic pace (900 ms)				
	200	400	900	1400	1600	200	400	900	1400	1600
Experiment 1	312.9 (11.7) [0.61]	285.76 (12.99) [1.18]	291.45 (10.73) [8.02]	290.11 (11.80) [7.71]	284.58 (10.66) [7.09]	357.26 (13.20) [0]	324.84 (10.52) [0.30]	294.19 (11.02) [2.16]	292.82 (10.70) [7.71]	290.26 (10.47) [5.86]
Experiment 2	326.34 (14.65) [0.71]	327.93 (16.66) [2.85]	303.03 (16.06) [3.57]	285.60 (13.18) [6.25]	285.90 (13.44) [8.03]	342.03 (13.77) [0.71]	322.54 (13.10) [1.60]	311.09 (15.32) [3.75]	291.77 (15.25) [6.60]	286.69 (14.23) [5.35]
Experiment 3	339.19 (16.26) [0.29]	327.93 (17.37) [0.29]	364.41 (16.17) [1.19]	385.28 (18.11) [0.59]	393.39 (18.17) [1.02]	355.57 (15.07) [0.59]	335.05 (16.79) [1.19]	348.69 (17.31) [0.29]	370.81 (17.53) [1.48]	388.77 (19.05) [0.68]