Auditory temporal preparation induced by rhythmic cues during concurrent auditory working memory tasks

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Abstract

The present study investigated whether participants can develop temporal preparation driven by auditory isochronous rhythms when concurrently performing an auditory working memory task. In Experiment 1, participants had to respond to an auditory target presented after a regular or an irregular sequence of auditory stimuli while concurrently performing a Sternberg-type working memory task. Results showed that participants responded faster after regular compared to irregular rhythms and that this effect was not affected by working memory load; however, the lack of a significant main effect of working memory load made it difficult to draw any conclusion regarding the influence of the dual-task manipulation in Experiment 1. In order to enhance dual-task interference, Experiment 2 combined the auditory rhythm procedure with an auditory N-Back task, which required working memory updating (monitoring and coding of the information) and was presumably more demanding than the mere rehearsal of the working memory task used in Experiment 1. Results now clearly showed dual-task interference effects (slower RTs in the high vs. the low load condition). However, such interference did not affect temporal preparation induced by rhythms, with faster RTs after regular than after irregular sequences in the high load and low load conditions. These results revealed that secondary tasks demanding memory updating, relative to tasks just demanding rehearsal, produced larger interference effects on overall RTs in the auditory rhythm task. Nevertheless, rhythm regularity exerted a strong temporal preparation effect that survived the interference of the working memory task even when both tasks competed for processing resources within the auditory modality.

1. INTRODUCTION

Temporal preparation reflects the ability to generate expectations about when a relevant event is going to occur (Nobre, Correa, & Coull, 2007). These expectations are based on information provided by our environment, enabling us to respond at the appropriate moment in time. Temporal preparation can be induced by regular sequences of stimuli (e.g., rhythms). Regular sequences would implicitly orient our attention to a certain point in time corresponding to the temporal pattern of the sequence, resulting in an enhancement of response accuracy and speed (e.g., Jones, Moynihan, MacKenzie, & Puente, 2002; Sanabria, Capizzi, & Correa, 2011; Sanabria & Correa, 2013; Teki and Griffiths, 2014). This type of temporal preparation can be considered as exogenous or stimulus-driven, since temporal expectations would be based on the sequential pattern of the rhythm. The Dynamic Attending Theory (Jones, 1976; Large & Jones, 1999) suggests that internal attentional oscillations are synchronized with the temporal patterns formed by the recurrent onset of external events. Thus, if the target onset coincides with the peak of an attentional oscillation, its processing would be facilitated (anticipatory attending). Attention, then, seems to operate in a rhythmic mode when relevant stimuli are presented within a rhythmic structure. In these situations, neural oscillations are re-set so that attentional peaks occur at the onset of the relevant stimuli, amplifying these inputs and suppressing irrelevant ones (Schoroeder & Lakatos, 2009). For instance, Mathewson et al. (2012) conducted an EEG experiment to test whether neural oscillations remained phase-locked to rhythmic visual sequences. Results showed that target detection was enhanced when targets were presented during one phase of the alpha EEG oscillations and that target detection decreased during the opposite phase. Similar results were also found by Rohenkohl and Nobre (2011) for the visual modality, with enhancement of the alpha power in rhythmic condition. Synchronization processes can also be observed spontaneously, for example, when an audience applauds after a performance, people are progressively entrained to clap their hands following the same rhythm (Néda, Ravasz, Brechet, Vicsek, & Barabási, 2000). Other authors have theorized that a flexible internal clock is generated while listening to temporal structures and that this clock can adapt itself to the patterns in order to produce a more accurate perception and better responses (Povel & Essens, 1985).

It has been proposed that rhythmic stimuli induce exogenous temporal preparation (Triviño, Arnedo, Lupiañez, Chirivella, & Correa, 2011; de la Rosa, Sanabria, Capizzi, & Correa, 2012; Jones, Moynihan, MacKenzie, & Puente, 2002; Sanabria, Capizzi, & Correa, 2011; Sanabria & Correa, 2012), contrary to endogenous temporal orienting that involves predictive symbolic cues (Capizzi, Sanabria, & Correa, 2012, Coull & Nobre, 1998; Nobre, Correa, & Coull, 2007). For example, Rohenkohl and colleagues (Rohenkohl, Coull, & Nobre, 2011) showed that the presence of an isochronous rhythm enhanced participants' performance regardless of task instructions to focus on the temporal structure of the rhythm. In contrast, symbolic cues were only effective when participants were instructed to voluntarily orient their attention to the time predicted by the cue. However, a closer look to Rohenkohl et al.'s study reveals that the pace of the rhythm predicted the onset of the target (i.e., a fast rhythmic pace predicted that the target would appear early). Therefore, the effect of isochronous rhythms on participants' performance in their study could be attributable either to exogenous temporal preparation driven by the rhythms, to top-down processes sensitive to the a priori probability of target appearance, or both.

In light of the extant research, de la Rosa and colleagues (de la Rosa, Sanabria, Capizzi, & Correa, 2012) devised a study for further research to test the temporal preparation effect on rhythmically presented sequences under dual-task conditions. In the single-task condition of their study, participants had to perform an RT task in which the target onset was preceded by a regular or irregular auditory sequence. In the dual-task condition, participants performed the same RT task, together with a secondary working memory (WM) task presented in the visual modality. The results showed that participants' responses were faster after regular sequences than after irregular sequences, which converged with previous studies (Lange, 2010). Moreover, this effect was significant and of a similar magnitude in single-task and dual-task conditions, showing that the temporal preparation effect was resistant to the working memory task.

In the present study, we report two experiments designed to further investigate the relationship between temporal preparation driven by rhythms and working memory processing. The temporal preparation task based on auditory rhythms was combined with an auditory WM task, in contrast to de la Rosa et al. (2012) who used a visual working memory task. That way we went a step further by combining two tasks that shared the sensory modality of stimulus presentation, increasing the degree of interference. Indeed, several neural regions have been associated with both auditory working memory and the processing of temporally regular sequences. Activation in the putamen and inferior frontal gyrus seems to be related to both temporal processing of rhythmic sequences (Grahn & Brett, 2007, frontal gyrus and putamen; Geiser et al., 2012, putamen) and working memory tasks dealing with auditory material (Schneiders et al., 2012, frontal gyrus; Protzner & McIntosh, 2007, putamen). Maintenance of auditory material in working memory as well as pitch memory and tonal working memory have been related to activity of the inferior frontal gyrus (Zatorre et al., 1994; Griffiths et al., 1999; Gaab et al., 2003). Thus, by using auditory stimuli in both the temporal preparation task and the working memory task, we expected to increase the interference between the primary and the secondary task in the dual-task procedure due to an overlap in neural structures involved in both tasks.

The aim of the current research was to determine whether simultaneous performance of a WM task sharing the same modality could interfere with the effect of rhythmic regularity on behavioural performance. We hypothesized that temporal preparation effect (faster RTs after regular sequences) would resist the dual-task interference even if a demanding secondary task (within the same modality of the rhythmic cue) increased the overall RTs. In Experiment 1, we adapted de la Rosa et al.'s (2012) working memory Sternberg-like task which demands memory rehearsal. In Experiment 2, we increased the working memory demands using an auditory N-back task demanding memory updating.

2. EXPERIMENT 1

In Experiment 1, temporal preparation was measured by means of participants' RTs in response to an auditory stimulus (target), which occurred after either a regular or an irregular auditory sequence. In order to measure response facilitation or interference of regular and irregular rhythms, respectively, we included a baseline condition in which only the first and the last tones of the sequence were presented (non-rhythm condition). We expected to find both facilitation of regular rhythms (i.e., faster RTs after regular rhythms) and interference of irregular rhythms (i.e., slower RTs after irregular rhythms), always in respect to the non-rhythm condition.

We presented the WM task in the auditory modality to enhance competition for resources by ensuring the involvement of the same sensory modality in both tasks. The concurrent WM task was adapted from Sternberg (1966) and the memory load was manipulated by the auditory presentation of either different letters (high-load condition) or the same letter (low-load condition) in the memory list. The temporal preparation task was performed during the retention interval, between the memory list and the presentation of the memory probe. In line with our previous work (de la Rosa et al., 2012), we predicted the regular rhythm to facilitate RTs when compared with irregular rhythm regardless of the memory load even if stimuli in the WM task were presented in the same sensory modality.

2.1. Method

2.1.1. Participants

Thirty-three students (three men) from the University of Granada aged between 18 and 46 years (mean age: 20.97; standard deviation: 4.83) voluntarily took part in Experiment 1 in exchange for course credits. Data from one participant in one of the experimental conditions was missing after the data collection (due to a technical issue), so we dropped that participant from the analyses. They did not report any history of neuropsychological impairments. The experiment was conducted according to the ethical standards laid down in the Declaration of Helsinki (1964) and approved by the ethics committee of the University of Granada.

The larger number of female participants in our study was due to the gender composition of the Psychology Department at the University of Granada, being similar to other Psychology Departments worldwide (Cynkar, 2007).

2.1.2. Apparatus and stimuli

Experiment 1 was run on an Intel Core 2 Duo PC connected to a 17’’ LCD monitor. The E-prime software (Schneider, Eschman, & Zuccolotto, 2002) was used for stimuli presentation and to record participants’ responses. The viewing distance was approximately 60 cm. All auditory stimuli were presented via headphones at 60 dB. In the temporal preparation task, participants had to respond to a target tone with a frequency of 400 Hz and 100 ms duration (5 ms smooth rising and falling time). This stimulus was preceded by an auditory sequence of six tones of 700-Hz for a period of 250 ms (5 ms smooth rising and falling time). In the memory task, the list consisted of six letters that were chosen randomly from a set of 20 alphabetic letters. All stimuli were presented orally by a male voice and had a duration of 500 ms. The letters were recorded and edited using Audacity 2.0.2 (The Audacity Team, 2012). All letters were consonants in order to keep the memory load constant through the trials and avoid syllable-grouping strategies. In the low-load condition, the same letter was presented in the memory list (e.g., “SSSSSS”). In the high-load condition, all letters were different (e.g., “SDCBMT”). For the memory probe a single letter was also orally presented. This letter was presented previously in the memory list in half of the trials. All auditory stimuli were presented at a clearly audible sound intensity.

2.1.3. Procedure and task

Participants were tested in a silent and dimly illuminated room. They were first familiarized with the stimuli and tasks and were provided with both written and spoken instructions. They were informed that, before the auditory target, a sequence of tones irrelevant to the task would be presented. They could also listen to the target as many times as they wanted before performing the task. Each trial began with the presentation of a fixation point (plus sign, 1.5º x 1.5º) in the centre of the screen that remained on and steady until the target presentation at the end of every trial. After 500 ms the memory list was presented. Next, after 550 ms, the auditory sequence was presented. The interval time between the ending of the previous tone and the onset of the next one (inter-stimulus interval, ISI) was fixed to 550 ms in the regular sequence. In the irregular sequence, this interval could vary between five durations: 150, 350, 550, 750 and 950 ms, such that the order of these five intervals varied randomly across trials (see Figure 1). Both sequences included the same number of tones (6 tones) and the same total duration (4250 ms). In the non-rhythm condition only the first and the last tones of the sequence were presented to ensure that the interval time between the ending of the last tone and the target was the same in all conditions and, thus, temporal uncertainty was not larger in the non-rhythm condition. The target tone occurred after a fixed foreperiod of 1100 ms and, thus, it was consistent with the temporal structure of the regular sequence, since it was twice as long as the interval between each tone in this sequence (see Lange, 2010, and Jones et al., 2002, for a similar procedure). Participants should then respond as fast as possible to the auditory target by pressing the spacebar key with their right hand. After the response to the target stimulus (or after 1000 ms, in case of a missed response) the memory probe was displayed. Participants had to press the "a" key with their left hand if the letter was previously presented in the memory list or the "z" key if it was not presented.

Each participant completed 1 practice and 6 experimental blocks of 24 trials each, resulting in 24 trials per experimental condition. Irregular, regular and non-rhythm conditions in the temporal preparation task, as well as high-load and low-load conditions in the memory task, were randomly presented on each block of trials and with the same probability of occurrence.

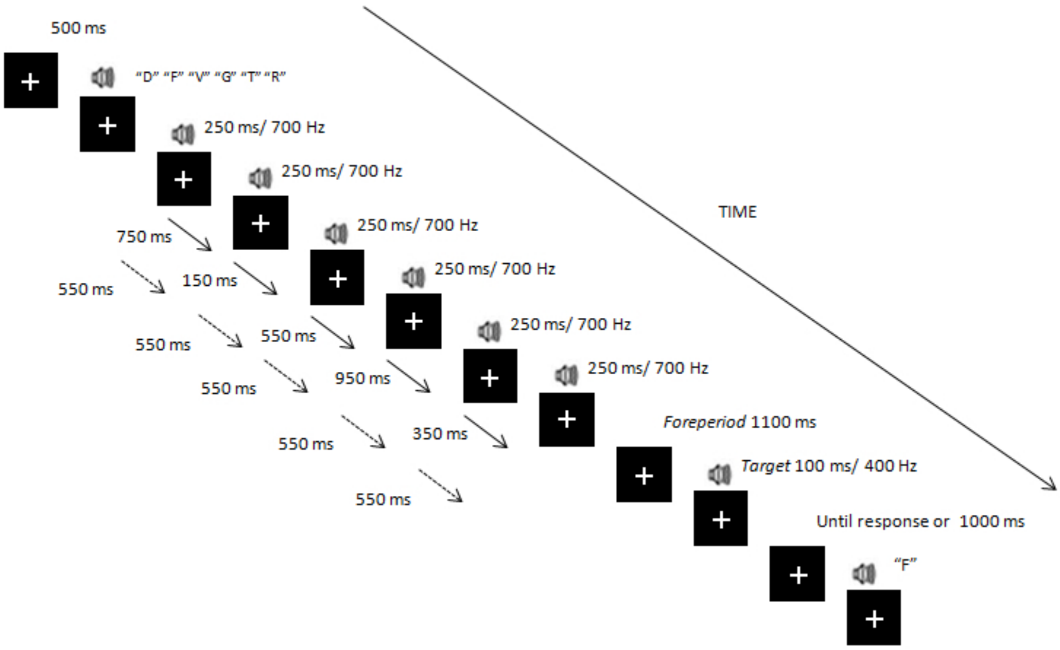

Figure 1. Schematic representation of events in a trial of Experiment 1. In the irregular condition the duration of each interval (150, 350, 550, 750 and 950 ms) was randomly presented.

2.1.4. Design and data analysis

The experiment constituted a 2x3 design with the independent variables of memory load (high-load and low-load) and rhythm (irregular, no-rhythm and regular) as within participant factors. The dependent variables were the mean RT to respond to the target in the temporal preparation task, and the mean percentage of correct responses to the probe in the WM task. They were analyzed by repeated-measures analyses of variance (ANOVAs). The individual memory load effect (RT in high load condition minus RT in the low load condition) was introduced as a continuous predictor in a subsequent analysis to investigate its effect on the relationship between rhythmic entrainment and memory load.

Data from the practice block, trials involving anticipated response, i.e., responses before target onset, or without response (4.19%) and trials involving premature responses (RT < 100 ms: 0.74%) were not included in the RT analysis. In order to make sure that participants were indeed engaged in the memory task, only trials involving correct responses in the memory task were included in the analysis of the temporal preparation task (10.12% rejected; standard deviation: 15.14%).

2.2. Results

The ANOVA with participants' mean RTs in the temporal preparation task showed a significant main effect of rhythm, $F(2, 62)= 20.9$, $p<.001$, $\eta^2=.40$. Planned comparisons revealed that participants were faster in the irregular rhythm condition (367 ms, $SD= 83.4$) than in the non-rhythm (408 ms, $SD= 98.2$), $t(31)= -3.43$, $p<.01$, faster in the regular (339 ms, $SD= 76.6$) than in the non-rhythm condition, $t(31)= -5.09$, $p<.001$, and also faster in the regular than in the irregular condition, $t(31)= 6.31$, $p<.001$. There was not a significant main effect of memory load on RTs, $F(1, 31)= 1.93$, $p<.18$, $\eta^2=.06$.

The interaction between memory load and rhythm was not significant, $F<1$ (see Figure 2). Most relevant was the effect of rhythm was significant for both high-load and low-load conditions. In the high-load condition, responses were significantly faster in the regular than in the irregular rhythm, $t(31)= -4.49$, $p<.001$, faster in the regular rhythm than in the non-rhythm, $t(31)= -5.43$, $p<.001$, and faster in the irregular rhythm than in the non-rhythm, $t(31)= -3.36$, $p<.01$. In the low-load condition, RTs were faster in the regular than in the irregular rhythm, $t(31)= -3.66$, $p<.001$, in the irregular than in the non-rhythm, $t(31)= -3.05$, $p<.01$, and also faster in the regular rhythm than in the non-rhythm, $t(31)= -4.32$, $p<.001$.

The analysis including the memory load effect as a continuous predictor also showed a main effect of rhythm, $F(2, 60)= 20.8$, $p<.001$, that did not depend on the memory load effect ($F<1$). Neither the interaction between rhythm and memory load, $F<1$, nor the interaction between rhythm, memory load, and the continuous predictor reached statistical significance, $F(2, 60) = 2.58$, $p=.08$.

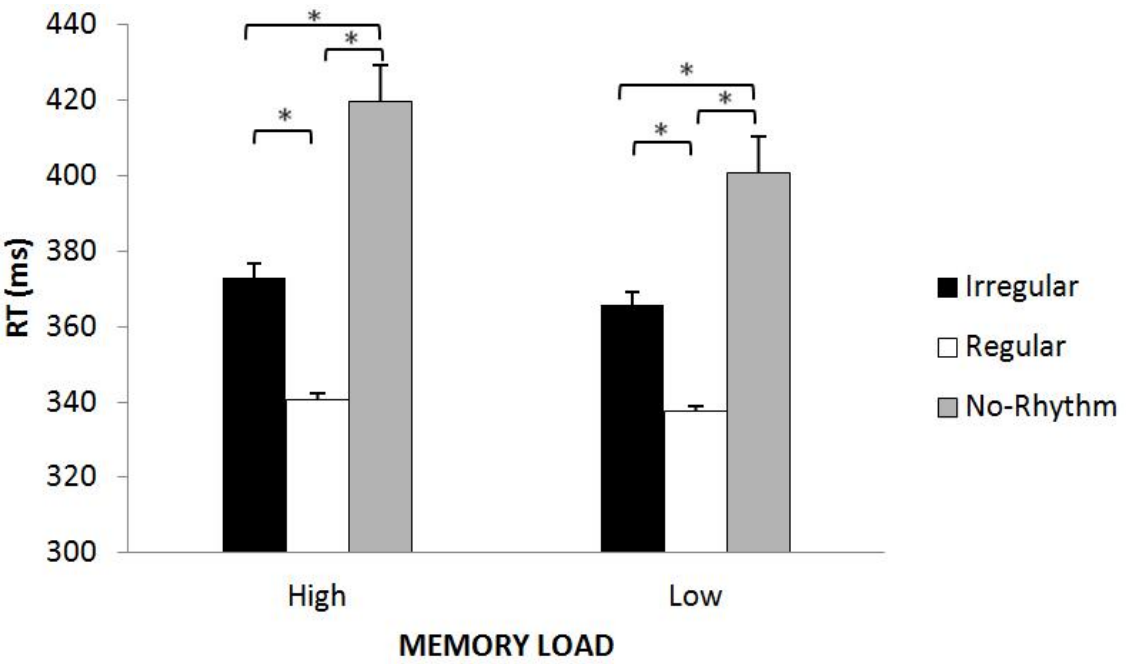

Figure 2. Mean RTs in temporal preparation task as a function of rhythm (irregular, regular, no-rhythm) and memory load (high, low) conditions in Experiment 1. Error bars represent the standard error of the mean.

Accuracy in the WM task was analyzed as a dependent variable in a Rhythm x Memory load ANOVA. Results showed a main effect of memory load, $F(1, 31) = 84.17$, $p < .001$, $\eta^2=.73$ (see Figure 3), revealing that participants' responses were more accurate in the low-load condition (97.8%) than in the high-load condition (84%). The main effect of rhythm, $F(2, 62) = 5.53$, $p < .01$, $\eta^2=.15$, and the interaction between rhythm and memory load, $F(2, 62) = 7.15$, $p < .005$, $\eta^2=.19$, also reached statistical significance. This interaction was mainly caused by low accuracy in the non-rhythm condition, since no significant differences in accuracy were found between regular and irregular rhythms, $t(31)= -1.22$, $p = 0.23$. Specifically, participants' accuracy was higher in the irregular condition than in the non-rhythm condition, $t(31)= 2.84$, $p<.01$, and also higher in the regular than in the non-rhythm condition, $t(31)= 2.76$, $p<.01$. In effect, the interaction between rhythm and memory load was not significant, F(1, 31)= 1.17, $p = .29$, when the non-rhythm condition was excluded from the analysis.

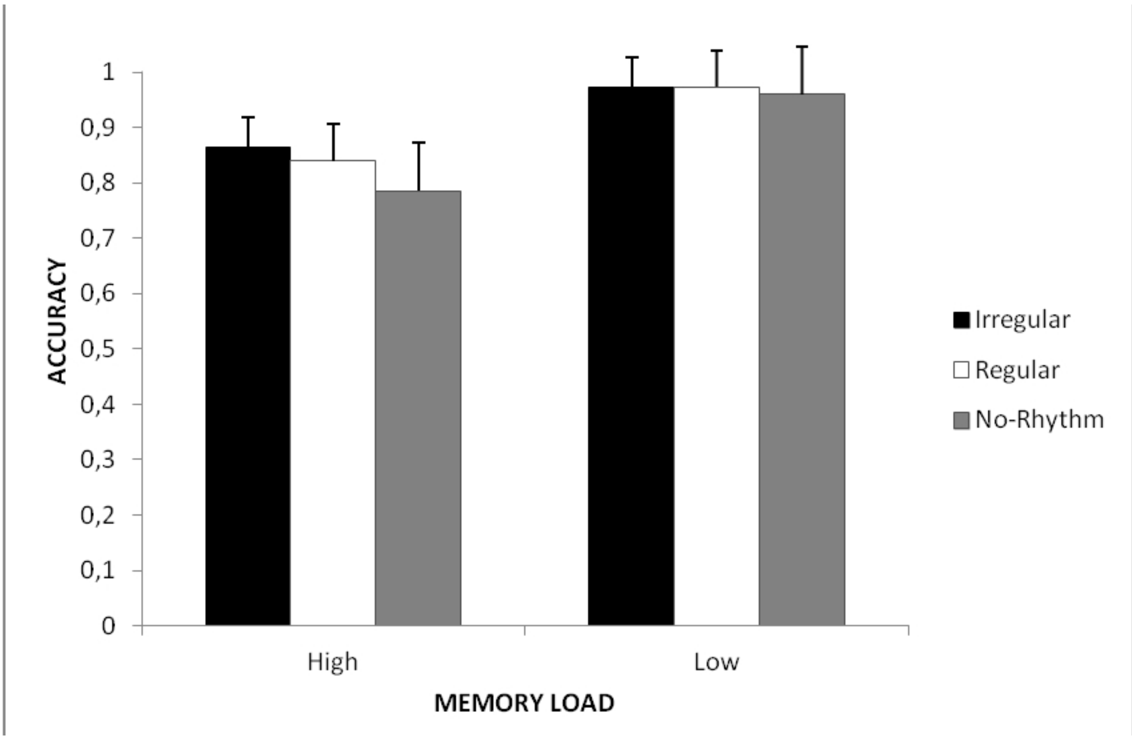

Figure 3. Mean accuracy (correct proportion) in the working memory task as a function of rhythm (irregular, regular, no-rhythm) and memory load (high, low) conditions in Experiment 1. Error bars represent the standard error of the mean.

2.3. Discussion

The analysis of Experiment 1 confirmed that participants were faster after regular rhythms as compared to the irregular rhythm and non-rhythm conditions. Firstly, the finding of slower RTs in the non-rhythm than in the irregular condition did not confirm our prediction of interference by irregular rhythms compared to the non-rhythm condition. Accuracy in the WM task was also lowest in the non-rhythm condition. Compared to the regular and irregular rhythms, the non-rhythm condition did not provide any stimulus between the first and the last tone of the sequence and it seems, thus, that the sequence of stimuli in the regular and irregular rhythm conditions could have helped participants to keep focus on the task, enhancing their performance. This result is in keeping with the outcome of a recent study conducted by Mathewson et al. (2012) in which participants had to respond to a target presented after either a rhythmic sequence (regular), a variable sequence (irregular) or a control condition (non-rhythm). As in our Experiment 1, only the first and the last stimulus of the sequence were presented in the control condition before the target onset. Results showed that detection was lower in the control condition with respect not only to the rhythmic condition but also to the variable condition. Nevertheless, the main purpose in this experiment was to test whether participants would be faster after regular than after irregular rhythms regardless of the Memory load condition. This hypothesis was confirmed by the finding of a rhythm effect in both low load and high load WM conditions.

The memory load manipulation proved to be effective only partially. Although participants' accuracy in the WM task was impaired with increasing memory load, this load effect did not transfer to the primary temporal preparation task. Thus, it could still be argued that the lack of interference effects in Experiment 1 was due to low WM demands even in the high load condition. This seemed to be the case of a subgroup of participants (N=7), who did not show interference effects, thus increasing variability in our data. However, further analyses revealed that both the effect of rhythm and the lack of interaction with memory load were not dependent on whether participants showed the overall memory load effect or not.

The working memory task in Experiment 1 only required working memory maintenance and rehearsal. However, an important distinction has been made in the literature between information maintenance-rehearsal and updating contents in WM (monitoring and coding information in the working memory so that new items can replace old irrelevant information; Morris and Jones, 1990). Memory updating has been widely proposed as an executive process (Salmon et al., 1996; Miyake et al., 2000). For instance, Rammsayer and Ulrich (2011) found interference in temporal processing of intervals when updating was involved in a secondary task, but not when this task only involved the mere maintenance of information. Thus, the memory task used in Experiment 1 might not have been demanding enough to interfere with the temporal preparation task. Experiment 2 was designed to address this issue.

3. EXPERIMENT 2

In Experiment 2 we used the N-back procedure requiring memory updating (Smith and Jonides, 1997; Jonides et al, 1997). This task allowed us to test whether a secondary task involving memory updating would interfere with the temporal preparation.

3.1. Method

3.1.1. Participants

Twelve students (two men) from the University of Granada with ages between 18 and 28 (mean age: 22; standard deviation: 3.13) took part in Experiment 2 in exchange for course credits. None of these participants took part in Experiment 1.

3.1.2. Apparatus and stimuli

As in Experiment 1, the temporal preparation task consisted of a rhythmic sequence of six 700-Hz and 250-ms tones followed by a target of 400 Hz and a duration of 100 ms. A N-back procedure was used for the working memory task so only one spoken letter was presented in each trial. Four letters (M, R, S and V) were chosen from the same set of letters used in Experiment 1. All visual stimuli were presented in silver background, 18-point Courier New, black colour font, in the centre of the screen. All auditory stimuli were presented at the same intensity as in Experiment 1.

3.1.3. Procedure and task

The procedure and task were the same as in Experiment 1 except for the following. The non-rhythm condition was not presented in Experiment 2 for the sake of simplicity. Each trial began with the presentation of a fixation point (plus sign, 1.5º x 1.5º) in the centre of the screen with a duration of 500 ms. After this, a single letter was orally presented. The memory load was manipulated (block-wise) by asking participants to remember the first letter presented within each block (0-back, low-load condition) or the letter presented two trials before the current one (2-back, high-load condition). Next, the sequence (regular or irregular) was presented followed by the target as in Experiment 1. After the participants' response to the auditory target or after 1000 ms, a question mark appeared at the centre of the screen for 3000 ms or until participants' response. Participants had to press the "a" key with their left hand if the letter was the same one presented in the first trial of the block (0-back) or two trials ago (2-back) and the "z" key if it was different. Feedback on the WM performance was provided for 550 ms at the end of each trial. The inter-trial interval was set to 550 ms. In order to make sure that participants were equally engaged in both tasks, feedback (550 ms) was also provided after the temporal preparation task informing participants of their RTs as well as omissions or anticipations.

Each participant completed 1 practice and 3 experimental blocks of 24 trials each in both WM conditions. The order of presentation of 0-back and 2-back blocks was counterbalanced across participants. Regular and irregular conditions in the temporal preparation task were randomly presented on each block of trials and with the same probability of occurrence.

3.1.4. Design and data analysis

The experiment constituted a 2x2 design with the independent variables of memory load (high-load and low-load) and rhythm (regular and irregular) as within-participants factors. Dependent variables were mean RT to the target in the temporal preparation task and accuracy percentage in the WM task.

As in Experiment 1, data from the practice block, anticipations (2.55%) and omissions (1.68%) as well as premature responses (RT < 100 ms: 4.08%) were not included in the analysis.

Trials involving incorrect responses in the WM task were rejected. Mean accuracy in this task was 93.38% (standard deviation: 9.09%). Mean RTs in the temporal preparation task were submitted to a repeated-measures ANOVA.

3.2. Results

The ANOVA on the RTs in the temporal preparation task showed a significant main effect of rhythm, F (1, 11) = 54.95, p <.001, η^2=.83, revealing that participants were faster after regular (265 ms, *SD*= 68.3) than after irregular rhythms (310 ms, *SD*= 69.2). A significant main effect of the memory load was also found, F (1, 11) = 8.48, p =.014, η^2=.44, with faster RTs in the low-load condition (269 ms) than in the high-load condition (305 ms).

The interaction between memory load and rhythm was not significant $F < 1$ (see Figure 4). The effect of rhythm was significant for both high-load and low-load conditions, with faster RTs after regular rhythms than after irregular rhythms in the low-load condition, t(11)= 5.66, p<.001, as well as in the high-load condition, t(11)= 3.87, p<.01.

As in Experiment 1, we included memory load effect (RT in the high-load condition – RT in the low-load condition) as a continuous predictor in a subsequent analysis. Once again, the main effect of Rhythm, F (1, 10) = 39 p <.001 was significant, and did not interact with the continuous predictor, F<1. The interaction between Rhythm and Memory load and between rhythm, memory load, and the continuous predictor did not reach statistical significance either, both F<1.

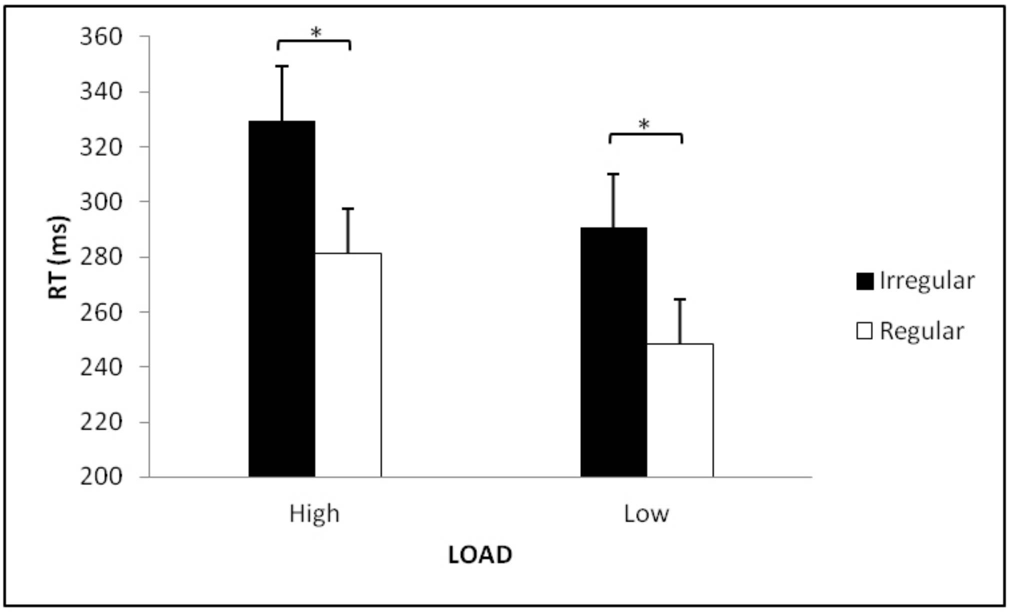

Figure 4. Mean RTs in temporal preparation task as a function of Rhythm (irregular, regular) and Memory load (high, low) conditions in Experiment 2. Error bars represent the standard error of the mean.

The ANOVA on the accuracy in the WM task showed no significant effects of Rhythm or interaction (both ps>.45). There was a significant main effect of the Memory load, F (1, 11) = 10.03, p < .01, η^2=.48, which confirmed that participants were more accurate in the low load (98.1%) than in the high load (88.4%) condition (see Figure 5).

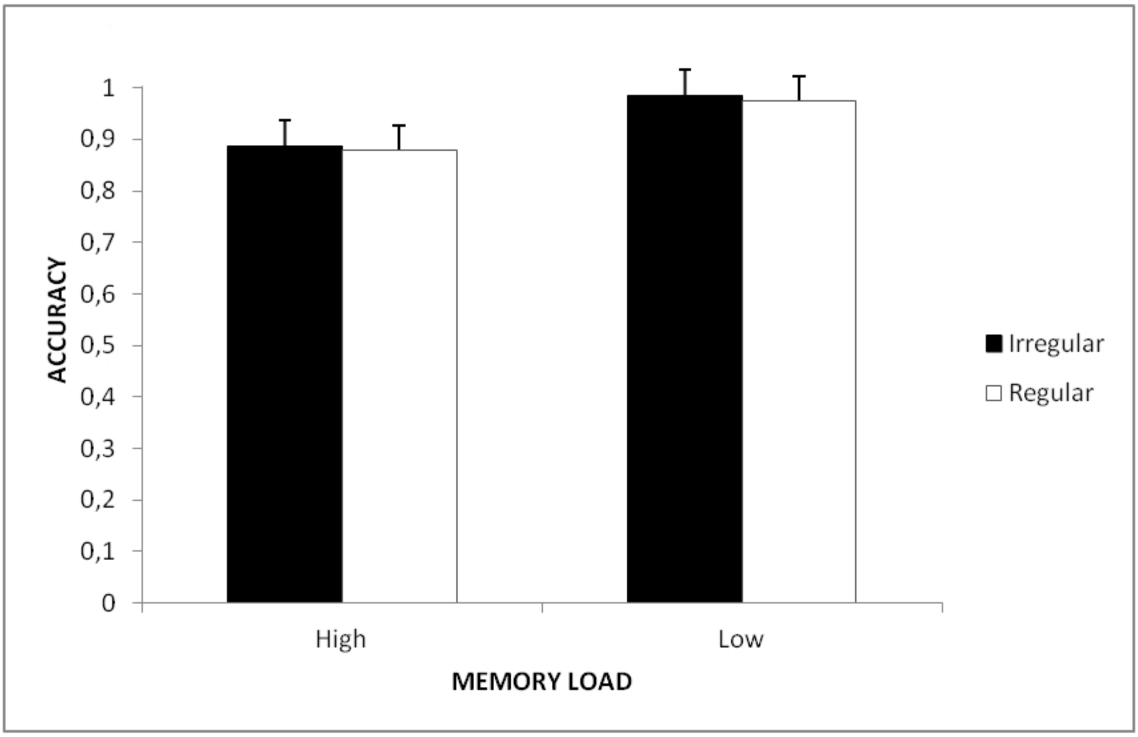

Figure 5. Mean accuracy (correct proportion) in the working memory task as a function of rhythm (irregular, regular, non-rhythm) and memory load (high, low) conditions in Experiment 2. Error bars represent the standard error of the mean.

3.3. Discussion

In Experiment 2 we used an N-Back task compelling participants to update the working memory content on a trial-by-trial basis. Strengthening the results obtained in Experiment 1, we now found a significant main effect of Memory load on RTs from the primary task, with participants being faster in the low load condition than in the high load condition. Most important, the temporal preparation effect did not rely on the Memory load condition, since we replicated a robust rhythm effect, with participants responding faster after regular than after irregular rhythms, regardless of memory load.

4. GENERAL DISCUSSION

Previous studies of temporal preparation had shown that people can orient their attention as a function of rhythmic sequences of stimuli (Jones, Moynihan, MacKenzie, & Puente, 2002; Sanabria, Capizzi, & Correa, 2011; Triviño, Arnedo, Lupiañez, Chirivella, & Correa, 2011; Sanabria & Correa, 2012). Several of the previous research suggests that temporal preparation effects driven by rhythmic cues are so strong that they should be present under dual task conditions (Jones et al, 2002; Rohenkohl et al, 2011; De la Rosa et al, 2012). However, other studies found the opposite results. In particular, Schwartze and colleagues (2011) found a larger P3b for deviant tones within the regular sequences compared to the irregular sequences in the attentive session (participants were told to concentrate on the tonal sequence) but not in the pre-attentive session (participants were told to ignore the sequence and to concentrate on a silent video clip). These results, contrarily to our hypothesis, suggest the participation of top-down (attention-dependent) mechanisms in the temporal preparation induced by rhythms. De la Rosa and colleagues (2012) designed an experiment to test the automaticity of temporal preparation driven by auditory rhythms and found that temporal preparation was not affected by the concurrent performance of a secondary visual working memory task. In our Experiment 1, we went a step further by presenting auditory instead of visual stimuli in the working memory task. Moreover, in Experiment 2, we used an N-back task in order to increase WM load further by demanding memory updating. The N-back task has been classically used in literature to compel participants to encode incoming information and update working memory contents. Working memory updating has been related to executive processes (Salmon et al., 1996; Miyake et al., 2000), and, moreover, previous studies found that temporal processing of intervals is affected when concurrently performed with a secondary task involving updating of information, but not when only passive storage is required (Rammsayer and Ulrich, 2011). Temporal preparation driven by symbolic predictive cues, i.e. temporal orienting, is also impaired by updating WM tasks (Capizzi, Correa, & Sanabria, 2013; Capizzi et al., 2012). Crucially, the experiments reported here revealed faster RTs after regular rather than irregular rhythms regardless of WM load. Temporal preparation induced by rhythms also resisted different demands of WM, maintenance and rehearsal in Experiment 1, and updating in Experiment 2. These results therefore provide strong support of the involvement of bottom-up processing in temporal preparation exogenously driven by auditory rhythms.

Our results seem to be in line with previous studies (de la Rosa et al., 2012; Rohenkohl, Coull, & Nobre, 2011; Triviño, Arnedo, Lupiañez, Chirivella, & Correa, 2011; Bolger, Trost, & Schön, 2013). For example, Triviño et al. found that patients with right prefrontal lesions did not show impairments in temporal preparation driven by rhythms, whereas they showed difficulties when temporal orienting, symbolic cues were used. In this vein, a recent transcranial magnetic stimulation (TMS) study has confirmed this dissociation by showing that TMS on the dorsolateral prefrontal cortex selectively influenced temporal orienting driven by endogenous cuing, while the preparatory effects of regular rhythms remained intact (Correa et al., 2014). Since these prefrontal structures are related to controlled attentional processes, these findings suggest that temporal preparation driven by rhythms should be associated with more bottom-up processing not related to these areas. In the same line, other studies have found that the perception of regular sequences can induce adjustments in spontaneous motor behavior in infants. For example, Bobin-Bègue and colleagues (Bobin-Bègue, Provasi, Marks, & Pouthas, 2006) recorded infants' sucking while they were listening to a rhythmic sequence. The results showed that two-month-old infants adapt their sucking rhythm to an external auditory pattern when these rhythmic sequences were faster than their spontaneous rhythm. These results suggest that processing and responses to auditory rhythms are mediated by exogenous/bottom up processing, in contrast to endogenous temporal orienting.

Our data seems to point to an independence between temporal preparation induced by rhythmic cues and WM at the behavioural and, presumably, at the neural level, even if previous research has pointed to overlapping brain areas (i.e., putamen and inferior frontal gyrus; Griffiths et al., 1999; Gaab et al., 2003; Protzner & McIntosh, 2007; Granh & Brett, 2007; Geiser et al., 2012). However, any argument in that sense remains speculative since brain activity was not measured in the current study. Further studies measuring brain activity should be conducted in order to clarify this issue.

To sum up, the current research has provided two novel findings revealing the power of regular rhythms to enhance temporal preparation irrespective of whether a concurrent working memory task was performed. Firstly, auditory regular rhythms can enhance preparation under strong dual task competition for resources within the same modality. Secondly, rhythm preparatory effects survive WM interference not only under competition with a rehearsal Sternberg task, but also when a more demanding task involving memory updating, the N-back, is used. Future research might unveil whether other tasks (e.g. involving rhythmic stimulation) could interfere with temporal preparation driven by rhythms.

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