



When the rhythm disappears and the mind keeps dancing: sustained effects of attentional entrainment

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Abstract

Research has demonstrated that the human cognitive system allocates attention most efficiently to a stimulus that occurs in synchrony with an established rhythmic background. However, our environment is dynamic and constantly changing. What happens when rhythms to which our cognitive system adapted disappear? We addressed this question using a visual categorization task comprising emotional and neutral faces. The task was split into three blocks of which the first and the last were completed in silence. The second block was accompanied by an acoustic background rhythm that, for one group of participants, was synchronous with face presentations, and for another group was asynchronous. Irrespective of group, performance improved with background stimulation. Importantly, improved performance extended into the third silent block for the synchronous, but not for the asynchronous group. These data suggest that attentional entrainment resulting from rhythmic environmental regularities disintegrates only gradually after the regularities disappear.

Introduction

Humans and most living organisms constantly deal with changes in the environment that are either proactively established or passively endured. For example, a constantly flickering hallway light might suddenly disappear, a ticking clock may be intermittently blocked out by street noise, and a monotonous clattering of a shutter in the wind may be interrupted by the creak of an opening door. Many studies have demonstrated that rhythmic background activity can facilitate performance in various perceptual decision making tasks, even when the background rhythm is not attended to

explicitly (Correa & Nobre, 2008; Doherty, Rao, Mesulam, & Nobre, 2005; Jones et al., 2002).

How does a background rhythm facilitate performance? One hypothesis discussed in the literature is that the rhythm facilitates stimulus attention. Attention is known to enhance perceptual processing by improving the signal-to-noise ratio and contrast sensitivity, as well as by suppressing irrelevant information (Desimone & Duncan, 1995). Attention can be allocated based on spatial, feature, and object information (Posner, 1980; Serences et al., 2004). In addition, attention can be guided by temporal information, and this process taps into the same frontoparietal network as spatial attention, and activates motor areas in a preparatory fashion (Coull & Nobre, 1998).

Crucially, attention is a limited resource that requires parsimonious allocation (Kahneman, 1973; Wickens, 1991). It has been suggested that rhythmic activity provides temporal cues that help align the peaks and troughs of fluctuating attention with the external regularities. This idea was first put forward in the context of auditory processing and the auditory dynamic attending theory (Jones & Boltz, 1989; Jones, 1976) and has since been applied to visual and cross-modal perception more generally (Escoffier, Sheng, Schirmer, 2010; Henry & Obleser, 2012; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; Schroeder & Lakatos, 2009).

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Investigations of the brain's oscillatory activity (as measured with the electroencephalogram) revealed that the excitability or readiness of perceptual areas, indeed, entrains to the temporal structure of external events (Anderson, & Sheinberg, 2008; Besle et al., 2011; Escoffier, Herrmann, & Schirmer, 2015; for a review, see Schirmer, Meck, & Penney, 2016). Moreover, it seems such entrainment benefits higher-order cognitive functions. For example, variants of entrainment effects appear to also play a role in speech (Brocard et al., 2013), for which the tempo of spoken words as well as visually associated facial features naturally exhibit a specific rhythm, and perturbations of this rhythm reduce speech intelligibility (e.g., Smith, Delgutte, & Oxenham, 2002). This may even hold true for vocal gestures in animals. For example, Ghazanfar, Morrill, and Kayser (2013) demonstrated that monkeys have a preference for lip-smacking—a perceptual feature presumably linked to communicative signals—in natural as compared to perturbed rhythms.

Research to date has focused on cognitive effects concurrent with an external rhythm. Hence, it is not known whether these effects are tied to the external input, or whether they persist for some time after the input is removed. Such persistence would point to sustained entrainment of internal rhythms that allow prospective resource allocation independent of external stimulation. Revealing such effects would necessitate new avenues for theorizing on entrainment, e.g., how exactly the external rhythm modifies internal processing. Furthermore, discovering enduring facilitation by a previously presented external structure may also be useful for application purposes. To the best of our knowledge, there are no studies that would provide mechanistic explanations for such a putative effect, rendering the nature of this study exploratory. This study was designed to probe for sustained effects after facilitating exposure to rhythmic background activity.

To address this question, we adapted a previous entrainment paradigm using an auditory rhythm in the context of face and house processing (Escoffier, Sheng, Schirmer, 2010; Escoffier, Herrmann, & Schirmer, 2015). In the original paradigm, participants performed a simple visual perception task deciding whether a given image was upside or inverted. Here, we opted for a facial emotion recognition task to increase engagement with the stimulus and to explore entrainment effects on higher-order evaluative processes. Participants performed the facial emotion task in three consecutive blocks of which the first and last blocks were silent and the second block entailed a task-irrelevant auditory background rhythm. We predicted that this rhythm would facilitate task performance relative to the first block when played in synchrony with the faces and that this facilitation would sustain into the third block.

Materials and methods

Participants

Forty-six participants gave informed consent. They were recruited from the Western Sydney University. All participants reported normal hearing and had normal or corrected to normal vision. Eight participants had to be excluded because of technical difficulties (responses were not recorded during one or more blocks). One participant reported not hearing the background auditory rhythm during the experiment, and one participant failed to complete the Musical Ear Test (MET, Wallentin et al., 2010)—Subscale Rhythm, a listening task assessing rhythmic ability. Of the remaining 36 participants (mean age: 30.1 years, SD: 7.8, 18 females), 18 were randomly allocated to the in-synchrony group, and 18 were allocated the out-of-synchrony group. There was no significant difference between groups on the Musical Ear Test—Rhythm (mean in-synchrony: 39.1, SD = 3.9; mean out-of-synchrony: 37.9, SD = 5.6; *t* test $p = .474$).

Stimuli

We used 80 colored photos of Caucasian full-frontal faces (MPI for Human Development FACE data base, Ebner, Riediger, & Lindenberger, 2010). Forty faces (20 female) had a neutral expression and the remaining faces (20 female) had an angry facial expression. Presentation time of face stimuli was 250 ms.

We used the auditory background rhythm created by Escoffier, Sheng, and Schirmer (2010). The rhythm entailed bass and snare drum sounds arranged to produce a four-beat measure in which the fourth (final) beat was silent. Beats within the measure were spaced at an interval of 750 ms making a measure 3 s long. In the in-synchrony group, images were presented on the silent fourth beat, whereas in the out-of-synchrony group, they were presented 250 ms earlier (for details, see Escoffier, Sheng, & Schirmer, 2010).

Design

The experiment consisted of three blocks during which participants saw faces in random order and had to categorize them as neutral or emotional. Blocks were presented in a fixed order with the following background conditions. The first block was performed in silence and served as pre-rhythm baseline (Pre-beat); the second block was performed with the auditory background rhythm and face onsets were temporally aligned for the in-synchrony group and misaligned for the out-of-synchrony group (Beat); the third block was again performed in silence (Post-beat). Figure 1

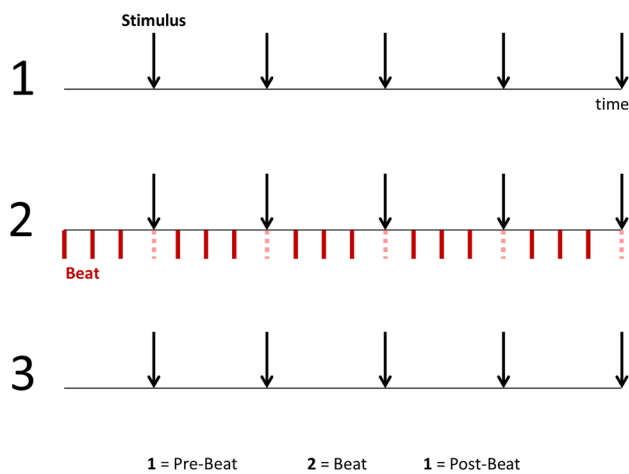


Fig. 1 Design. Experimental procedure illustrated for the group with synchronous beat presentations. **1** Face stimulus is presented at regular intervals (indicated by the arrow) and participants discriminate its emotional expression. **2** Stimulus presentation is synchronized to the fourth “silent” beat of a background rhythm (indicated in red). **3** Stimulus is presented again without background rhythm

illustrates the procedure for the in-synchrony group. Each block had 80 trials (40 with angry, and 40 with neutral faces). Each face was shown once to each participant in each block and repeated twice across blocks. Blocks were performed consecutively without breaks.

Task

Before the experiment, participants were informed that they would be exposed to a task-irrelevant background sound during the Beat block, and were asked to ignore it. Trials in each block started with the presentation of a white fixation cross at the center of the screen, followed by a face stimulus presented in the center for 250 ms and by the returning fixation cross. Participants were required to classify the facial expression as quickly and as accurately as possible by pressing one of two response buttons with their left or right index finger. They were allowed 1000 ms to respond, starting with the onset of the face stimulus. No feedback was given. Overall, each trial lasted 6 s, and an algorithm was implemented that waited for a trigger after exactly 6 s to start the next trial, during this waiting time participants also saw the fixation cross. The mapping between response buttons and hands was counterbalanced across participants.

Auditory stimuli were delivered at a comfortable listening level over padded headphones. The task was programmed and presented using the Presentation software package (Neurobehavioral Systems, Albany, CA) and took place in a dimly illuminated room. The experiment lasted 12 min (4 min per block). Participants received a training block of three trials (without the auditory rhythm) before the

experiment started, which could be repeated if necessary. At the end of the session, participants completed the Musical Ear Test—Rhythm. The overall procedure lasted for approximately 20 min including briefing, training, experiment, and subsequent questionnaire.

Data analysis

Four specific time points were of particular interest, which will be referred to as Baseline (end of Pre-beat block), Entrainment (end of Beat block), Sustained (beginning of Post-beat block), and Decay (end of Post-beat block).

To analyze our time points of interest, we built two linear mixed-effects models (Bates et al., 2015). The first model included the natural logarithm of reaction times (log-RT, transformed because RTs did not have normal, but rather lognormal distribution) to all correctly responded trials as the dependent variable (DV) and group, block, and trial number (centered and scaled) with all interactions as fixed effects. As random effects, we included intercepts for participants and by-participant random slopes for block, trial number, and their interaction. Predicted log-RTs and confidence intervals obtained from the model were subsequently converted by exponentiation back to the millisecond scale. A second model was a binomial generalized linear mixed-effects model with raw accuracy as the DV (1 = correct, 0 = incorrect) and the same structure of fixed and random effects as the first model.

Missed trials were excluded from analysis. We coded group and block using treatment contrasts, with in-synchrony group and Beat block as baselines. *P* values for fixed effects were obtained using Satterthwaite approximation to degrees of freedom. Model assumptions were assessed via plots of residual to fitted values and residuals Q–Q plots. We used the models to estimate performance (RT and accuracy) at the time points of interest (i.e., at the first and last trial of each block) for each participant (i.e., based on random intercepts and random slopes).

In addition to these two mixed-effects models done on all trials, we conducted a few focused comparisons between the specified time points of interest within a group and between groups using two-tailed paired-samples *t* tests and Welch’s *t* tests, respectively. *P* values are reported both uncorrected and corrected using the Bonferroni–Holm procedure over all 12 planned *t* tests. Normality and equality of variances were assessed using the Shapiro–Wilk test and Levene’s test, respectively. Effect sizes are expressed as Hedges’ *g*, by which we mean an unbiased version of Cohen’s *d* (Cumming, 2012). All confidence intervals were obtained via bootstrapping (Kirby & Gerlanc, 2013). Bayes factors were computed using a non-informative prior allowing for a wide range of effect sizes, with a default scale of 0.707 (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

Results

Accuracy

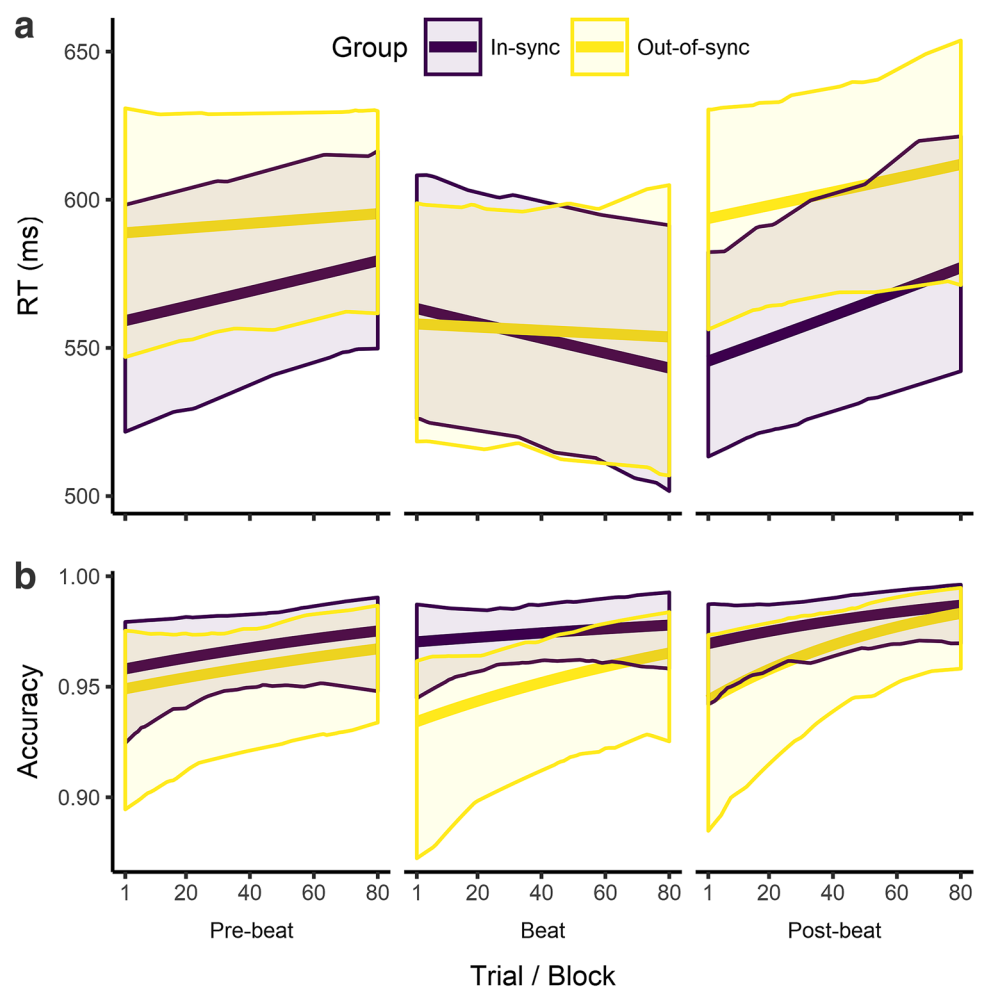
Discrimination accuracy was overall very high (mean = 94.9%, median = 96.4%; see Fig. 2b). The logistic mixed-effects model for accuracy revealed a marginal effect of group ($\beta = -0.65$, $z = -1.74$, $p = .081$), indicating that the in-synchrony group tended to be more accurate (mean = 96.4%, median = 97.0%) than the out-of-synchrony group (mean = 93.4%, median = 95.3%). All other effects were not significant ($ps > 0.1$).

Reaction time

Visual inspection of the development of RTs in time (see Fig. 2a) suggests that, indeed, for the in-synchrony group, RT performance improvement achieved in the Beat block was sustained at the beginning of the Post-beat block. At the end of the Post-beat block, performance was comparable to the Pre-beat block, i.e., indicating a return to baseline.

Overall, the mixed-effects model for RTs revealed a significant main effect of block ($F[2, 33.94] = 8.63$, $p < 0.001$) as well as an interaction of group and block ($F[2, 33.96] = 3.45$, $p = 0.043$) and, more specifically, of group and the Beat vs. Post-beat block contrast ($\beta = 0.067$, $t[33.94] = 2.63$, $p = .013$). On average, individual median RTs changed between Beat and Post-beat from 551 to 557 ms for the in-synchrony group, and from 562 to 598 ms for the out-of-synchrony group. This indicates that after the Beat block, response times increased more in the out-of-synchrony group than in the in-synchrony group. There was also a significant interaction of trial number and block and, more specifically, of trial number and the Beat vs. Pre-beat block contrast ($\beta = 0.021$, $t[33.02] = 2.05$, $p = .048$) as well as the Beat vs. Post-beat block contrast ($\beta = 0.027$, $t[31.51] = 2.79$, $p = .009$). This indicates that RT slopes changed significantly from the first block to the second block (slopes went from positive to negative) and from the second block to the third block (slopes went back from negative to positive), as can be seen in Fig. 2a. No other fixed effects were significant (all $ps > 0.12$).

Fig. 2 Results. Development of performance (**a** reaction times and **b** discrimination accuracy) in time, per group, derived from mixed-effects models. Shaded areas depict bootstrapped 95% confidence intervals obtained using the bootMer function from the lme4 R package (Bates, Maechler, Bolker, & Walker, 2015), using 200 simulations



As the next step, we analyzed the development of performance in time. Descriptive statistics for the time points are reported in Table 1. First, we explored group differences in performance development during the Pre-beat block, possibly pointing to a participant sampling bias. We compared the change in RTs from the beginning to end of this block between in- and out-of-synchrony groups. The difference was non-significant ($t[31.9]=1.23, p=.23$; Hedges' $g=0.40, 95\% CI=[-0.27, 1.07]$; $BF_{10}=0.58$).

Then, we examined whether the Beat block entrained performance by comparing Baseline (end of Pre-beat block) and Entrainment (end of Beat block) time points. For the in-synchrony group, Entrainment RTs were significantly faster than Baseline RTs (mean difference = -34, 95% CI = [-46, -17] ms; $t[17]=-4.49, p<.001, p_{holm}=0.003$; Hedges' $g=-1.01, 95\% CI=[-1.74, -0.50]$; $BF_{10}=99.7$). For the out-of-synchrony group, this effect was observed before but not after p value correction, and the Bayes factor favors its presence ($M_{diff}=-34, 95\% CI=[-58, -8]$ ms; $t[17]=-2.64, p=.017, p_{holm}=0.11$; Hedges' $g=-0.59, 95\% CI=[-1.17, -0.08]$; $BF_{10}=3.38$). This effect (decrease in RTs) was not significantly different between the groups ($t[27.2]=0.047, p=.96, p_{holm}=1.0$; Hedges' $g=0.02, 95\% CI=[-0.62, 0.66]$; $BF_{10}=0.32$). Possibly, both groups benefited from the auditory background rhythm, regardless of synchrony.

To answer our main research question, i.e., whether performance gain was sustained after removal of the auditory background, we compared the periods Entrainment and Sustained (beginning of Post-beat block). While there was no significant difference between these two periods for the in-synchrony group ($M_{diff}=1, 95\% CI=[-14, 15]$ ms; $t[17]=0.10, p=.92, p_{holm}=1.0$; Hedges' $g=0.02, 95\% CI=[-0.46, 0.50]$; $BF_{10}=0.24$), the out-of-synchrony group significantly increased their RTs ($M_{diff}=35, 95\% CI=[13, 55]$ ms; $t[17]=3.14, p=.006, p_{holm}=0.048$; Hedges' $g=0.71, 95\% CI=[0.19, 1.27]$; $BF_{10}=8.13$). This group difference was marginally supported by a t test and corroborated the Bayes factor ($t[29.79]=-2.55, p=.016, p_{holm}=0.11$; Hedges' $g=-0.83, 95\% CI=[-1.56, -0.11]$; $BF_{10}=3.60$).

Table 1 Reaction times

	In-synchrony	Out-of-synchrony
Baseline	582 [555, 609]	599 [566, 629]
Entrainment	549 [513, 585]	565 [514, 614]
Sustained	549 [521, 582]	600 [559, 635]
Decay	581 [551, 611]	618 [580, 659]

Mean reaction times in milliseconds and bootstrapped 95% CIs for the mean for each group and time point

To further test whether auditory performance was sustained in the in-synchrony but not the out-of-synchrony group, we compared Sustained RTs with Baseline RTs. The difference was significant in the in-synchrony group ($M_{diff}=-33, 95\% CI=[-47, -20]$ ms; $t[17]=-4.59, p<0.001, p_{holm}=0.003$; Hedges' $g=-1.03, 95\% CI=[-1.57, -0.57]$; $BF_{10}=121.6$). In contrast, for the out-of-synchrony group, performance in Sustained was not distinguishable from Baseline ($M_{diff}=0, 95\% CI=[-11, 10]$ ms; $t[17]=0.067, p=.95, p_{holm}=1.0$; Hedges' $g=0.02, 95\% CI=[-0.48, 0.53]$; $BF_{10}=0.24$), and the change was significantly different between the groups ($t[31.4]=-3.72, p<.001, p_{holm}=0.007$; Hedges' $g=-1.21, 95\% CI=[-1.94, -0.51]$; $BF_{10}=41.3$).

Finally, we tested whether performance decreased from Sustained to Decay (end of Post-beat block). This was clearly the case for the in-synchrony group ($M_{diff}=31, 95\% CI=[20, 45]$ ms; $t[17]=4.68, p<.001, p_{holm}=0.003$; Hedges' $g=1.06, 95\% CI=[0.60, 1.60]$; $BF_{10}=144.4$), but was inconclusive for the out-of-synchrony group ($M_{diff}=18, 95\% CI=[0, 41]$; $t[17]=1.74, p=.10, p_{holm}=0.50$; Hedges' $g=0.39, 95\% CI=[-0.12, 0.84]$; $BF_{10}=0.85$). The difference between the groups were also inconclusive ($t[29.0]=1.06, p=.30, p_{holm}=1.0$; Hedges' $g=0.35, 95\% CI=[-0.33, 1.07]$; $BF_{10}=0.50$).

Taken together, both groups benefited from the auditory rhythm, but differed in the temporal course of rhythm effects. Whereas the in-synchrony group showed sustained performance after rhythm removal and a gradual performance decrement in the Post-beat block, the out-of-synchrony group showed a step-like performance decrement immediately after rhythm removal, returning back to the Pre-beat baseline. In addition to the interaction of mean block RTs and group in the overall model, these effects are supported by the Bayes factor, which quantifies the strength of evidence, rather than just indicating significance by testing against a null model.

Discussion

Our brain is able to adapt its processing to rhythmic patterns in the environment, and several studies have demonstrated that such an adaptation leads to faster and more accurate performance (Correa & Nobre, 2008; Escoffier, Scheng, & Schirmer, 2010; Doherty et al., 2005; Jones et al., 2002). In this study, we investigated how the withdrawal of an established rhythmic pattern influences performance—would it drop back to baseline, or remain sustained over a certain period of time? To this end, we implemented three consecutive blocks, in which participants saw faces, and their task was to classify the expression (emotional or neutral). The second block exposed

participants to an acoustic background rhythm, and the face stimulus was either presented in or out-of-synchrony with that rhythm. The first and third blocks were done in silence.

Our first finding is a replication of previously reported entrainment effects, i.e., a reduction of reaction time under a background rhythm. Interestingly, we found no significant difference between in and out-of-synchrony conditions. While Escoffier, Sheng, and Schirmer (2010) have shown a difference between in- and out-of-synchrony conditions, facilitated performance has been demonstrated for out-of-synchrony conditions (as compared to silent conditions) as well. One reason may be that the rhythmic background increases arousal, which is discussed as a potential mechanism that contributes to facilitated performance in the context of entrainment (Husain, Thompson, & Schellenberg, 2002). This effect may be exaggerated when using emotional faces as in the present study, and thus overshadow an entrainment effect that differentiates in- and out-of-synchrony conditions. Another reason may be that in both conditions, the rhythm allowed to temporarily predict the onset of the visual stimulus. The visual stimulus was either presented in synchrony with the beat or slightly too early, but it was always predictable and triggered by an acoustic event. This auditory temporal cuing may have facilitated performance in both groups. While temporal predictability triggered by the acoustic stimulation may account for the lack of difference between in- and out-of-synchrony during the Beat block, it cannot explain the differential effects found in the Post-Beat block. Note that (1) stimuli in all three blocks had a predictable onset, i.e., we did not use jittered intervals or varied the length of stimulus presentation (see Fig. 1). In addition, (2) during the Beat block, acoustic background stimulation increased predictability for all events, even if, as in the out-of-synchrony condition, the event was always presented 250 ms earlier than the onset of the fourth silent beat. In other words, differences between in- and out-of-synchrony conditions in the Post-beat block cannot be explained by (1) general temporal predictability effects, or by (2) acoustic predictability effects, or by a disruption of any of these processes.

Our second and main finding is that the in-synchrony condition yielded sustained effects during the Post-beat block. This effect is intriguing particularly because it does not occur for the out-of-synchrony condition, which suggests that rhythmic entrainment, rather than the mere presence of arousal or temporal cues, guides the allocation of attention in a prospective manner. Note that our data clearly speak against general learning effects over time in the Post-beat block, because a general learning effect would result in overall decreased reaction times, i.e., without a drop back to baseline as observed for out-of-synchrony conditions during the Post-beat block.

Certainly, understanding the mechanisms underlying rhythm effects requires further investigation. For example, time–frequency analyses of the EEG and event-related potential correlates might help to elucidate the neural mechanisms underlying these sustained effects, and enable us to find predictors for its temporal course. So far, we can conclude that rhythms affect our performance beyond their physical presence. This key finding seems relevant for a range of contexts in which rhythmic activity is used to enhance performance. Some examples include physical exercise (Karageorghis, & Priest, 2011), musically contingent stepping-in-place training in Parkinson’s disease (Chomiak et al., 2017), training phonological awareness in preschoolers (Degé & Schwarzer, 2011), or improving learning in more general educational settings (Hallam, Price, & Katsarou, 2002).

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Compliance with ethical standards

Conflict of interest All authors declare no conflict of interest.

Research involving human and animal participants All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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