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Unattended musical beats enhance visual processing

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ABSTRACT

The present study investigated whether and how a musical rhythm entrains a listener's visual attention. To this end, participants were presented with pictures of faces and houses and indicated whether picture orientation was upright or inverted. Participants performed this task in silence or with a musical rhythm playing in the background. In the latter condition, pictures could occur off-beat or on a rhythmically implied, silent beat. Pictures presented without the musical rhythm and off-beat were responded to more slowly than pictures presented on-beat. This effect was comparable for faces and houses. Together these results indicate that musical rhythm both synchronizes and facilitates concurrent stimulus processing.

1. Introduction

Have you ever listened to music and caught yourself tapping along? This apparently universal effect of music on listeners has been documented by many scholars (see e.g. McNeill, 1995). Moreover, it has informed current thinking of why humans, for over 36,000 years (Scothern, 1992), collectively create and experience music. According to this thinking, music evolved because it enabled a group of individuals to synchronize their activities thereby promoting the creation and maintenance of social bonds and group cohesion (Brown, 2000; McNeill, 1995; Peretz, 2006; Roederer, 1984).

One of the mechanisms by which music may synchronize human behaviour is described by 'dynamic attending theory' (DAT; Jones, 1976; Jones & Boltz, 1989; Large & Jones, 1999). This theory proposes that attention is not distributed evenly in time but varies periodically according to internal "dynamic oscillators". These oscillators determine an individual's attending rhythm and thus the rate at which the expectation for or processing of external events is at peak. Importantly, the harmonic structure and temporal course of external events may automatically entrain an individual's attending rhythm by forcing internal oscillators to synchronize with the external events. According to DAT it is this entrainment that enables listeners to predict upcoming beats of a musical piece and to prepare motor acts that fall on salient events marking the underlying musical meter (Drake, Jones, & Baruch, 2000; Large, 2000).

Support for DAT comes from investigations of tapping to music (e.g., Drake et al., 2000) as well as perceptual judgments. For example, Jones, Moynihan, MacKenzie, and Puente (2002) found that tones whose temporal position violates predictions based on a preceding isochronous tone sequence elicit poorer accuracy of pitch judgements than tones that fulfil temporal expectations. Additionally, there is evidence from research using scalp-recorded electroencephalography (EEG). Already in neonates, such recordings reveal a mismatch negativity in response to temporal violations in unattended rhythmic sequences, which points to innate processes that automatically reset internal oscillators based on changes in external rhythms (Winkler, Háden, Ladinig, Sziller, & Honing, 2009).

While existing research supports DAT, some of its assumptions still require investigation. For example, DAT assumes the entrainment of attention to be modality unspecific (Large & Jones, 1999). Aside from evidence of within modal auditory entrainment, researchers have observed that a visual rhythm can modulate temporal attention to visual targets (Correa & Nobre, 2008; Doherty, Rao, Mesulam, & Nobre, 2005). However, whether attentional entrainment in the auditory and visual modality is similar enough to enable cross-modal effects is still an open issue. Another aspect that is still unclear is whether musical rhythm enhances the processing of synchronous events or impairs the processing of non-synchronous events. This could not be tackled by prior, unimodal work, which failed to compare synchronous and non-synchronous processing with a no-rhythm baseline.

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Here we aimed to probe cross-modal rhythmic entrainment and to identify potential facilitatory and/or inhibitory effects. To this end, participants were presented with a series of photographs and indicated for each photograph whether it was upright or inverted. Participants performed this task in silence or with a task-irrelevant musical rhythm played in the background. Importantly, this rhythm contained a silent period for which the meter dictated a beat that was felt but not heard. This musical phenomenon, termed syncopation (Fitch & Rosenfeld, 2007; Longuet-Higgins & Lee, 1984), allowed us to study the effect of musical rhythm on visual processing without the confound of an audible cue.

Based on the literature reviewed above, we predicted that participants would perform better when the visual stimulus occurs in as compared to out of synchrony with the musical beat. According to DAT, such an effect could result from the entraining of internal oscillators by the musical rhythm and an ensuing facilitation of cross-modal attention. If true, this should be reflected in behavioural facilitation for synchronously presented stimuli relative to stimuli presented in silence. Alternatively, differences between in and out-of synchrony processing may arise from impaired visual processing due to a non-synchronous auditory beat. If true, we should observe behavioural inhibition for non-synchronously presented stimuli relative to stimuli presented in silence.

2. Method

2.1. Participants

Thirty-six Chinese undergraduates (18 females; mean age = 21.0, SD = 1.8), participated in this study in partial fulfilment of an introductory psychology course requirement. All participants reported normal hearing and normal or corrected-to-normal vision. Musical training ranged from 0 to 16 years (mean = 3.0, SD = 4.0).

2.2. Materials

2.2.1. Auditory stimulus

The task-irrelevant auditory stimulus consisted of a 12 s-long rhythmic sequence of 4 measures[1] at a tempo of 80 bpm (inter-beat interval of 750 ms). To avoid any pitch or tonal variations, the sequence was composed of bass drum and snare drum samples. The samples were drawn from the Ableton Live software sample library (Ableton, Germany). The bass drum sound was 224.5 ms long and the peak of its Fourier frequency spectrum was 31.8 Hz. The snare drum sound was 214.5 ms long and the peak of its Fourier frequency spectrum was 188.6 Hz. Each measure comprised four beats. The first beat was marked by the bass drum, the second by a snare drum and the third preceded and followed by a snare drum. The last beat fell in the 1098 ms long interval[2] between the offset of the last snare drum and the onset of the bass drum which marked the first beat of the next measure (Fig. 1).

Two main goals governed the construction of this rhythm. First, we aimed at creating a silent interval in which a visual stimulus could be presented without an auditory confound. This goal was achieved by keeping the last beat of each measure silent. Second, we aimed at creating measures that listeners perceived in their entirety. In particular, we were concerned that including a silent beat into a measure would change perception from the intended four-beat to a three-beat structure separated by breaks. To prevent the latter, we created a syncopation on the third beat to suggest a sense of continuity and to generate the

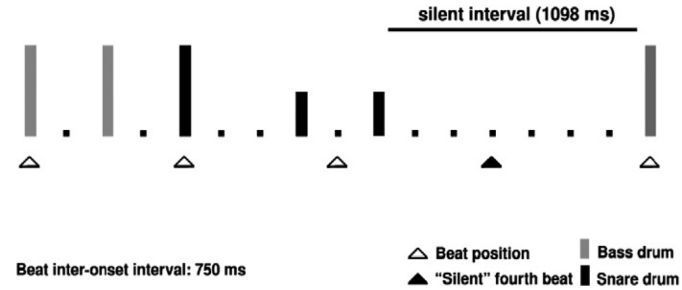

Fig. 1. Rhythmic sequence used in the experiment. The vertical bars represent sound onsets, their height represents relative amplitude. The dots mark one fourth of the beat inter-onset interval, 187.5 ms. One measure (4 beats, 3000 ms) and the first beat of the next measure are shown.

expectation for a beat during the silent interval. To limit the possibility that the two sounds marking the syncopation disrupted the meter established by the first two beats, we decreased their amplitude relative to those beats. This rendered the first two beats accented and potent to drive attending processes (see Jones & Boltz, 1989; Large & Kolen, 1999).

The rhythmic sequence was presented to 10 participants that were not included in the main experiment. These participants were asked to tap along to the sequence according to what they felt was the most natural position of beats. Ten rhythm loops were presented for a total duration of 120 s. Participants were asked to start tapping on the key of a computer keyboard whenever they felt comfortable doing so. On average participants started tapping 12.7 s (SD = 8.9) after the start of rhythm. A total of 1430 taps were recorded. Tapping asynchrony, defined as the time interval between a beat and a tap, was converted to a tapping phase with 0 (or 360) degrees representing a tap on the beat, phases up to 180° representing taps that followed the beat, and phases greater than 180° representing taps before the beat. To determine whether the participants perceived the beat and tapped regularly to the sequence, we tested the existence of periodicities in their tapping data using circular statistics (Fisher, 1993; see Kirschner & Tomasello, 2009, for an example of such an analysis). The analysis indicated that participants perceived a beat and were able to tap to it. Their average tapping phase did not differ from zero ($z = .001$, $p = .50$) and was thus close to the actual beat position (tap position = 1.92°, circular SD = 230°, equivalent mean beat-tap asynchrony = 4 ms, SD = 193.2 ms). Furthermore, a separate analysis of the taps surrounding the silent beats, revealed that their distribution mean did not differ from that of the whole sequence ($\chi^2(1) = .0008$, $p = .98$). The mean tapping asynchronies for each beat of the sequence were as follow: first beat: −30 ms (SD = 107), second beat: 93 ms (SD = 150), third beat: −56 ms (SD = 147) and silent fourth beat: 1 ms (SD = 165).

To allow presentation of the visual stimuli on-beat and off-beat, we defined two positions in the sequence. The on-beat position was defined as the silent fourth beat position while the off-beat position was set 250 ms earlier. We chose this interval because it did not coincide with any of the binary subdivisions of the rhythm's metric structure. On and off-beat stimuli were presented in separate blocks referred to as in-synchrony block and out-of-synchrony block, respectively. In addition, we included a silence block, where visual stimuli were presented without the rhythmic sequence. Blocked presentation allowed us to keep the temporal relationship between pictures and between pictures and rhythm constant. Thus, we avoided potential confounds associated with variations in picture inter-onset interval (Niemi & Näätänen, 1981) or temporal preparation (Niemi & Näätänen, 1981; Woodrow, 1914; see Discussion section for further details). Auditory stimuli were delivered at a comfortable hearing level over padded headphones (Sennheiser HD 250) using a Sound Blaster SB X-Fi audio card (44100 Hz, 16 bit).

2.2.2. Visual stimuli

Two sets of visual stimuli – social and non-social – were selected. Based on the presumed social function of music (Gregory, 1997;

[1] A measure is the repeating time unit of the music defined as a given number of beats. It is commonly delimited by lines in a music score.

[2] The length of the silent interval was computed by taking the time between the onset of the snare drum following the third beat and the onset of the following bass drum (1500–187.5 = 1312.5) and subtracting the duration of the snare drum sound (1312.5–214.5 = 1098).

Roederer, 1984), we were interested in determining whether entrainment of visual processing would vary depending on the social nature of a visual stimulus. Social stimuli included 72 greyscale photographs of emotionally-neutral, full-frontal Asian faces (36 females and 36 males) taken from the CAS-PEAL Facial Image Database Release 1 (Gao et al., 2004). Non-social stimuli consisted of 72 greyscale photographs of semi-detached and terrace houses (see Fig. 2). Social and non-social stimuli were mixed, with an equal number appearing in each condition.

2.3. Procedure

Participants performed a speeded-response visual discrimination task. They were required to judge as quickly and accurately as possible whether a picture was upright or inverted by pressing one of two keys on a response box (Cedrus RB-730). Participants were informed that the pictures could be presented simultaneously with music, which they were asked to ignore. Participants then completed twenty practice trials presented without the auditory stimulus and with images not used in the main experiment. During practice only, they received visual feedback on response accuracy after each response. Presentation software (www.neurobs.com) was used to present audio and visual stimuli and record reaction times. The delay of stimulus presentation by the video display (maximum 12.5 ms, 1/refresh rate) was comparable to that of the sound card (10.4 ms latency) thus ensuring an acceptable synchronization between audio and video stimuli.

The task was divided into six blocks of 48 trials each, two blocks for each synchrony condition (in synchrony, out-of-synchrony, silence). For every block, half of the faces and half of the houses were presented upright and the remaining stimuli were inverted. The occurrence of upright and inverted faces and houses was random and each stimulus was presented twice within each block. A mandatory break of 10 s was inserted between blocks and participants initiated the block whenever ready by pressing a button. The presentation of a picture (visual angle 9° 2′ × 6° 59′, refresh rate 85 Hz) lasted for 250 ms, and was followed by a fixation cross lasting 2750 ms (Fig. 2). The order of consecutive in synchrony, out-of-synchrony and silence blocks was fully counterbalanced.

The experiment concluded with a questionnaire assessing the participant's age, sex, handedness, length of formal musical training and weekly music listening.

3. Results

Correct response times and accuracy (percent correct) were subjected to separate ANOVAs with Rhythmic Synchrony (in-synchrony, out-of-synchrony, silence), Stimulus Type (faces, houses) and Stimulus Orientation (upright, inverted) as repeated measures factors. For reaction times, the significant main effects of Stimulus Orientation, $F(1, 35) = 17.22$, $p < .001$, $\eta^2 = .330$, and Stimulus Type, $F(1, 35) = 133.58$, $p < .001$, $\eta^2 = .792$, indicated that participants responded faster to upright as compared to inverted stimuli and to faces as compared to houses. More importantly, however, the Rhythmic Synchrony effect was significant, $F(2, 34) = 8.62$, $p < .001$, $\eta^2 = .198$ (Fig. 3). Follow-up analyses indicated that visual stimuli presented in synchrony with the unattended musical rhythm were responded to faster than stimuli presented in silence, $t(35) = -4.01$, $p < .001$, or stimuli presented out-of-synchrony, $t(35) = -2.79$, $p = .008$. Visual stimuli presented out-of-synchrony elicited response latencies tendentially faster than stimuli presented in silence ($p = .118$). The absence of a Rhythmic Synchrony by Stimulus Type interaction ($p = .739$) furthermore indicated that these effects were comparable for social and non-social stimuli. No other interaction effects were significant (all $ps > .15$).

For accuracy, all effects were non-significant (all $ps > .10$). Participants performed well across conditions (in-synchrony: 94.8, SD = 1.5; out-of-synchrony: 94.9, SD = 1.5; silence: 95.7, SD = 1.4).

4. Discussion

The present study set out to investigate the effect of musical background rhythm on visual processing. First, of interest was whether the postulated rhythmic entrainment is modality specific or is evident for cross-modal processing. To provide evidence for the latter position, the present study compared behavioural responses to visual stimuli presented in and out of synchrony with a musical rhythm. This comparison revealed faster perceptual judgments for in-synchrony stimuli indicating that musical rhythm modulates attention in at least one modality besides audition. This accords with previous evidence of auditory cues modulating visual processing (Noesselt, Bergmann, Hake, Heinze, & Fendrich, 2008; Turatto, Mazza, & Umiltà, 2005). Additionally, it extends existing work on the effect of music on visual processing. As mentioned in the Introduction, DAT proposes harmonic and temporal markers to entrain listener attention. Entrainment from harmonic markers was used recently by Escoffier and Tillmann (2008) to explain performance in a visual

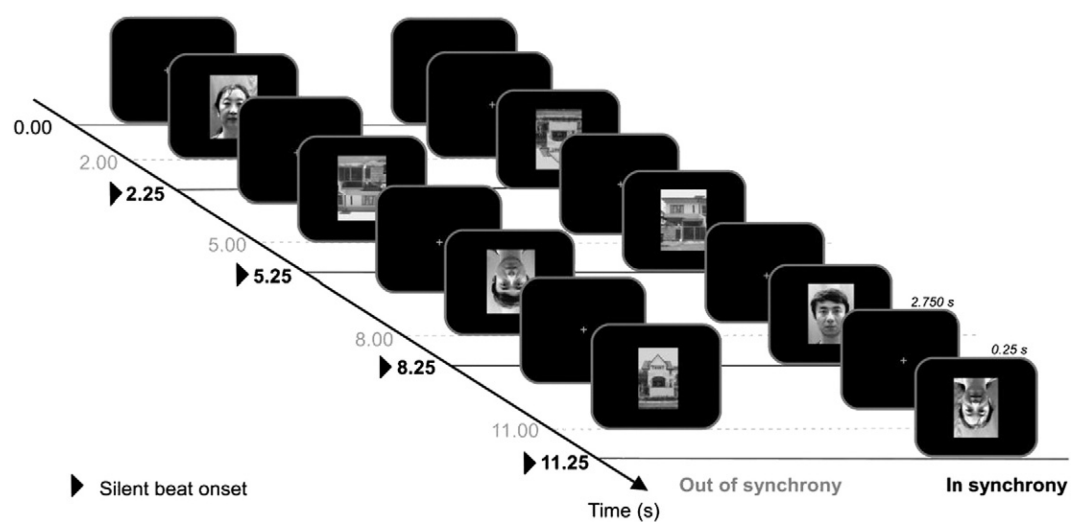

Fig. 2. Orientation discrimination task and stimulus presentation timing. The relative onset times are indicated in black for the in-synchrony condition and in grey for the out-of-synchrony condition. Stimulus duration (in italic) and inter-stimulus intervals were identical for all three conditions including the silence condition.

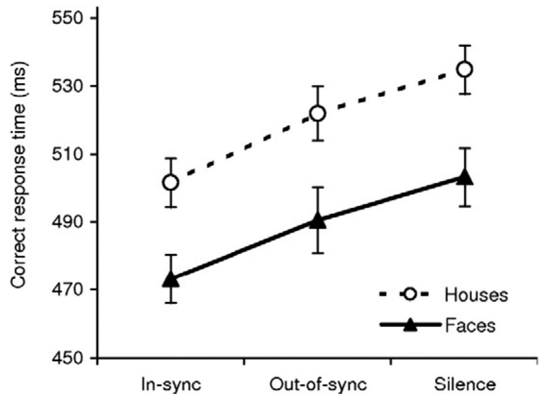

Fig. 3. Mean RTs as a function of background synchrony and stimulus type. Error bars represent within-participant standard error of the mean (Cousineau, 2005; Morey, 2008).

target discrimination task that participants performed with chord sequences playing in the background. Visual targets were responded to faster when presented in the context of harmonically expected as compared to less-expected chords. In accordance with DAT, the authors argued that harmonic markers predict future musical events and speculated that these events integrate with temporally coinciding information to facilitate multisensory processing. Processing was proposed to be optimal when harmonic predictions are fulfilled. The present study points to a comparable phenomenon for predictions derived from rhythm. More importantly, however, it demonstrates that a beat need not be marked by an auditory event to impact visual processing.

One possible challenge for interpreting rhythm effects, such as the one observed here, is the involvement of temporal preparation related to foreperiod effects (Woodrow, 1914; for a review see Niemi & Näätänen, 1981). The foreperiod is the empty interval between a cue and an imperative target. Changes in foreperiod duration affect temporal preparation and modulate reaction time to the target (Niemi & Näätänen, 1981). When the foreperiod is variable within a block, reaction times are faster for longer foreperiods. On the other hand, when the foreperiod is kept constant within a block and greater than 70 ms, the effect is reversed in that reaction times are faster for shorter foreperiods (Bertelson & Tisseyre, 1969; Sperling & Dosher, 1986). In the present study, the silent interval between the last sound of the musical rhythm and the following visual target can be considered a foreperiod. It invariably differed between in and out-of-synchrony conditions and thus represents a potential confound. In order to overcome this confound, we presented the conditions blocked and used a shorter foreperiod for out-of-synchrony presentations (98 ms) relative to in-synchrony presentations (348 ms).[3] Thus, a foreperiod effect should have resulted in faster responses to the former relative to the latter. As the longer foreperiod in the in-synchrony condition was associated with shorter response times, temporal preparation cannot explain the present results. Instead, they must reflect an effect of musical rhythm that was strong enough to override local cue influences.

Aside from testing rhythmic entrainment cross-modally, we were interested in whether behavioural differences between the in- and out-of-synchrony conditions reflect facilitatory and/or inhibitory processes. A comparison of the in-synchrony condition with a silent baseline revealed evidence for facilitation. Perceptual judgments were faster in the former relative to the latter condition. Importantly, perceptual judgments in the out-of-synchrony condition did not differ significantly from silence, suggesting an absence of inhibition. This absence of inhibition is consistent with previous findings (Escoffier & Tillmann, 2008) and compatible with the DAT framework, which does not predict a decrease of attentional resources below a no-rhythm baseline (Jones & Boltz, 1989; Large & Jones, 1999).

Facilitation of visual processing by an auditory rhythm may be explained in two ways. First, it may arise from changes in arousal. Prior work suggests that auditory rhythms can enhance physiological arousal (Husain, Thompson, & Schellenberg, 2002), which, in turn, enhances attention (Yerkes & Dodson, 1908). Moreover, one may speculate that synchronous auditory/visual rhythms may be more arousing than non-synchronous auditory/visual rhythms, enabling better performance in the former relative to the latter condition. However, given that in the current experiment, performance was comparable between the non-synchronous condition and the silent baseline, one may question whether the rhythms used here were effective in manipulating participant arousal.

A second, and more parsimonious explanation of our results is that rhythmic entrainment triggered changes in attention allocation policies. According to Kahneman (1973), attentional resources can be derived from a general, but limited, resource pool. Resources allocated to one task can be enhanced or reduced depending on other concurrent resource demands. In the context of this model, modulations of attention by entrainment can be expressed as changes in the allocation of resources over time. More attention is allocated when it is needed (i.e., an event is expected to occur) as opposed to when it is not needed (i.e., an event is not expected to occur). Support for this explanation comes from electrophysiological studies investigating the relationship between neuronal oscillations and attention. These studies have linked attentional control to oscillatory activity in the beta band (Gross et al., 2004) and demonstrated that this activity can be entrained by an auditory sequence (Fujioka, Trainor, Large, & Ross, 2009). Furthermore, auditory events within a sequence were found to elicit stronger beta responses when listeners imagined them to be in a beat position as compared to a no-beat position (Iversen, Repp, & Patel, 2009). Interestingly, visual rhythms also modulate activity in the beta band. The time–course of beta oscillations has been shown to synchronize with the pace of a visual stimulus stream (Praamstra, Kourtis, Fei Kwok, & Oostenveld, 2006), thereby facilitating visual perception (Gross et al., 2004). Additionally, there is crossmodal evidence. Unattended stimuli in one modality can drive oscillatory activity in another (Lakatos, Chen, O'Connell, Mills, & Schroeder, 2007). In a crossmodal auditory-visual paradigm, increased beta activity was associated with reduced response times when auditory and visual targets occurred in synchrony (Senkowski, Molholm, Gomez-Ramirez, & Foxe, 2006). Together this evidence links audio and visual rhythmic entrainment to beta oscillations and thus points to their implication in the effects observed here. Moreover, based on this evidence one may speculate that the present behavioural facilitation for images presented in synchrony with a background rhythm likely arose from entrainment of neuronal activity in visual processing areas by auditory processing areas (Lakatos et al., 2007).

Before coming to a close, we would like to address a final question that was implicit in the selection of images for this study. Specifically, we asked whether potential benefits arising from musical synchrony would be more pronounced for socially relevant images (i.e., faces) relative to socially irrelevant images (i.e., houses). This prediction was derived from the notion that music evolved to facilitate social processes (Bispham, 2006; Peretz, 2006). Moreover, based on evidence that humans preferably attend to social over non-social stimuli (Vuilleumier, 2000), we asked whether this attentional bias would be stronger in the context of music. In line with previous evidence, we found faster responses to faces as compared to houses. However, contrary to prediction, this difference was not modulated by the auditory background. Thus, whereas the presence of others may

[3] These foreperiods were defined as the silent intervals between the offset of the last sound before the target picture and the onset of the target picture itself, in either the out-of synchrony or in-synchrony condition.

enhance rhythmic entrainment (Kirschner & Tomasello, 2009), rhythmic entrainment does not specifically enhance the perception of others, at least not when these others are represented through photographs on a computer screen. Then, rhythmic synchrony enhances processing to a similar degree for socially relevant and socially irrelevant images.

To conclude, we found that musical rhythm modulates ongoing cognitive processes even when it is not attended. Specifically, it seems to entrain attention such that information processing in synchrony with the rhythm is facilitated. This facilitation is seen across modalities, suggesting that the effect of musical rhythm on cognition is amodal. As such, musical rhythm appears to be a powerful modulator of human cognitive processes, enhancing their efficiency and allowing synchronization across a group of individuals (McNeill, 1995; Roederer, 1984). Through this synchronization, individuals collectively experience their environment and are able to feel, think, and act as one (McNeill, 1995; Roederer, 1984).

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