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Audiovisual beat induction in complex auditory rhythms: Point-light figure movement as an effective visual beat

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ABSTRACT

This study investigated whether explicit beat induction in the auditory, visual, and audiovisual (bimodal) modalities aided the perception of weakly metrical auditory rhythms, and whether it reinforced attentional entrainment to the beat of these rhythms. The visual beat-inducer was a periodically bouncing point-light figure, which aimed to examine whether an observed rhythmic human movement could induce a beat that would influence auditory rhythm perception. In two tasks, participants listened to three repetitions of an auditory rhythm that were preceded and accompanied by (1) an auditory beat, (2) a bouncing point-light figure, (3) a combination of (1) and (2) synchronously, or (4) a combination of (1) and (2), with the figure moving in anti-phase to the auditory beat. Participants reproduced the auditory rhythm subsequently (Experiment 1), or detected a possible temporal change in the third repetition (Experiment 2). While an explicit beat did not improve rhythm reproduction, possibly due to the syncopated rhythms when a beat was imposed, bimodal beat induction yielded greater sensitivity to a temporal deviant in on-beat than in off-beat positions. Moreover, the beat phase of the figure movement determined where on-beat accents were perceived during bimodal induction. Results are discussed with regard to constrained beat induction in complex auditory rhythms, visual modulation of auditory beat perception, and possible mechanisms underlying the preferred visual beat consisting of rhythmic human motions.

1. Introduction

1.1. Beat induction and rhythm perception

A fundamental feature of musical rhythm is the periodicity that emerges endogenously in the perception of a rhythm (Cooper & Meyer, 1963; Large, 2008). While several levels of periodicity may exist, the most salient level gives rise to the perceived *beat*. The patterns of recurrent, alternating salient and less salient events constitute the *meter* (Large, 2008; Lerdahl & Jackendoff, 1983), and events coinciding with the beat are metrically accented. The percept of a beat can emerge in several ways. A beat can be induced by increasing the loudness of a level of periodicity in the rhythm (Chen, Zatorre, & Penhune, 2006; Lerdahl & Jackendoff, 1983). A beat can also be instantiated by adding a metronomic sequence that precedes and/or accompanies the rhythm (Desain & Honing, 2003; Repp, Iversen, & Patel, 2008). Without physical accentuation of a rhythm, a beat can still be induced solely by the subjective accents arising as a result of grouping successive, physically identical events whose onsets are separated by different durations (Grahn, 2012; Grahn & Brett, 2007; Povel & Essens, 1985; Povel & Okkerman, 1981). The more regularly such temporal accents are perceived, the more strongly an underlying beat is suggested.

According to the clock model of beat induction (Povel & Essens, 1985), rhythms that yield regular temporal accents induce an internal clock (i.e., a beat) in the listener, which facilitates the perception of the rhythms. This model has received substantial empirical support: Rhythms with more regular temporal accents – and thus a more readily perceived beat – are more accurately reproduced (Grahn & Brett, 2007), are more easily discriminated against a change in the pattern (Grahn, 2012; Grahn & Brett, 2009; Grube & Griffiths, 2009), and lead to more stable synchronization to the perceived or imposed beat (Patel, Iversen, Chen, & Repp, 2005; Repp et al., 2008), compared to less beat-inducing rhythms. The present study was concerned with the perception of rhythms that, according to the Povel and Essens model, do *not* readily suggest a beat. These rhythms are henceforth referred to as 'weakly metrical rhythms' (Patel et al., 2005) to relate to the fact that metrical accents do not arise regularly in the perception of these rhythms.[1]

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[1] Temporal patterns that do and do not readily suggest a beat according to the Povel and Essens (1985) model have been termed 'strongly metrical' and 'weakly metrical' (Patel et al., 2005), 'metric simple' and 'metric complex' (Grahn, 2012; Grahn & Brett, 2007, 2009), and 'strongly beat-inducing' and 'weakly beat-inducing' (Repp et al., 2008), in each respective study. Although 'strongly/weakly beat-inducing' would describe these patterns very well (Repp et al., 2008), it was not adopted here in order not to be confused with the term 'beat-inducing stimulus' that was implemented on top of the rhythms in the present study.

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1.2. Beat induction in weakly metrical rhythms

Whereas the perceptual advantages of strongly metrical rhythms are well documented, the perception of weakly metrical rhythms, which are more temporally complex than the former (Grahn, 2012; Grahn & Brett, 2007), is less well understood. The present research was motivated by two issues. The first issue was concerned with the effect of beat induction in weakly metrical rhythms. Given that weakly metrical rhythms are less likely to induce a beat on their own by means of temporal (grouping) accents, can a beat underlying these rhythms be induced by an explicit induction sequence that unambiguously designates the positions of metrical accents in the rhythms? Although previous studies have investigated finger tapping synchronized to the prescribed beat of weakly metrical rhythms (Patel et al., 2005; Repp et al., 2008), it has not been shown how the *perception* of these rhythms is influenced by explicit beat induction. As such, the present study first asked whether the perception of weakly metrical rhythms could benefit from an explicit beat that precedes and accompanies the rhythms. A positive result was hypothesized, as explicit beat induction should impose a metrical structure that serves as temporal references in the rhythms (London, 2012; Povel & Essens, 1985; Repp, 2008). Namely, the explicit beat accompanying a weakly metrical rhythm was expected to function similarly as the beat arising from temporal accents in a strongly metrical rhythm, in aiding rhythm perception.

Apart from the Povel and Essen model, another theoretical framework is relevant when discussing beat induction: that of temporal entrainment as proposed by the dynamic attending theory (DAT, Large & Jones, 1999). DAT postulates that attention as an internal oscillatory energy is entrained by the periodicity of a sensory rhythm, enabling listeners to generate expectations for the upcoming events. As a result, stimulus processing is enhanced at points in time that are synchronized to the salient period of the stimulus rhythm (Jones, Moynihan, MacKenzie, & Puente, 2002). In line with this theory, the metrical structure of a sensory rhythm is proposed to orient attention, such that increased attention is allocated to the metrically accented events (Large & Snyder, 2009; London, 2012). This has been empirically shown as increased sensitivity to pitch, intensity, and temporal deviants in metrically accented positions of an auditory rhythm (Jones et al., 2002; Repp, 2010). In light of these findings, as explicit beat induction is expected to impose metrical accents to a weakly metrical rhythm, perceptual sensitivity should be enhanced for events in the rhythm coinciding with the (induced) beat.

1.3. Beat induction within and across modalities

The second issue addressed in the present research – also in the context of weakly metrical rhythms – was the effect of beat induction within and across modalities. Thus far, explicit beat induction has only been examined in a within-modality manner: An auditory/visual beat-inducing sequence is used to cue an auditory/visual rhythm, respectively (Desain & Honing, 2003; Jongsma, Desain, & Honing, 2004; Patel et al., 2005; Repp et al., 2008). However, real-world experiences of musical rhythms are often multimodal in nature, and they often involve both auditory and visual information: e.g., watching a dancer moving along with the music, or observing the musicians' movements as they play the instruments. The question thus emerges as to whether a visual rhythm can induce a beat that will influence the perception of an auditory rhythm, as does an auditory beat. It has been shown that the perceived beat of auditory rhythms improves subsequent beat perception of comparable visual rhythms, whereas a visually induced beat does not affect subsequent auditory beat perception (Grahn, Henry, & McAuley, 2011). In that study, the visual rhythms were presented as repetitive flashes. Recent studies have demonstrated that, as opposed to static visual stimuli, visual rhythms derived from apparent motion of an object or effector, e.g., a moving bar (Grahn, 2012; Hove, Fairhurst, Kotz, & Keller, 2013), a tapping finger (Hove & Keller, 2010; Hove, Spivey, & Krumhansl, 2010), or a bouncing ball (Hove, Iversen, Zhang, & Repp, 2013), have a greater potential to induce a beat and to engage the observers rhythmically (for a summary, see Section 1.4.2 in Repp & Su, 2013). As such, it is of interest whether a visual beat communicated by an observed movement can affect beat perception of an auditory rhythm.

The present study took one step further and tested a new visual stimulus – a modified version of a human point-light figure (PLF, Johansson, 1973; see Blake & Shiffrar, 2007, for a review of point-light motion perception) that bounced periodically – regarding its capacity for beat induction and temporal entrainment. The bouncing movement here consisted of repetitive knee-bending, without the feet leaving the ground (as in Miura, Kudo, Ohtsuki, & Kanehisa, 2011). The choice of a PLF movement as a visual beat inducer was encouraged by studies showing that a beat can be located in the trajectories of point-light human motion, such as a music conductor's beating gesture (Luck & Sloboda, 2008, 2009; Wöllner, Deconinck, Parkinson, Hove, & Keller, 2012). Besides, a bouncing PLF similar to the one adopted here has recently been employed in an audiovisual synchrony judgment task, and it was found to convey sufficient visual rhythmicity to be temporally matched to an auditory rhythm (Su, 2014). As rhythm and beat perception is tightly coupled to body movements (Phillips-Silver & Trainor, 2005, 2007; Su & Pöppel, 2012) and internal motor representation of the rhythm (Section 4.1.2 in Repp & Su, 2013), it was hypothesized that an observed rhythmic human movement should induce a beat, which can mark the beat of a concurrent auditory rhythm. Of particular interest was the comparison of the effect of beat induction between such a visual PLF movement and an auditory beat.

Finally, the effect of uni-modal versus bimodal beat induction was also examined in the present research. The benefit of a bimodal (e.g., adding a visual beat to the auditory beat) relative to a unimodal beat has been evidenced by a greater bimodal beat strength for sensorimotor coupling in the finger-tapping literature (Elliott, Wing, & Welchman, 2010, 2011; Wing, Doumas, & Welchman, 2010). Accordingly, a bimodal beat was expected to exert a stronger effect of beat induction in the present scenario. However, with a periodic human movement as the visual beat-inducer, the effect of a bimodal beat may depend on the phase correspondence between the auditory beat and the visual movement. Given that a paced human bouncing movement is more stable when the flexion (downward) rather than the extension (upward) phase is synchronized to an auditory metronome (Miura et al., 2011), the observed downward – and not upward – movement should be perceived as phase congruent with a concurrent auditory beat (cf. Su, 2014). Thus, if a bouncing PLF can induce a visual beat, then phase congruency between the PLF movement and an auditory beat should modulate the bimodal beat strength. Namely, the effect of bimodal beat induction should be reduced if the upward (i.e., antiphase) instead of the downward movement phase is synchronized to the auditory beat.

1.4. The present study

The questions raised in the present study can be summarized as the following: (1) Does explicit beat induction facilitate the perception of weakly metrical auditory rhythms? (2) Can explicit beat induction lead to enhanced temporal sensitivity for events in an auditory rhythm coinciding with the beat? (3) Is a visual beat communicated by a periodic humanlike movement comparable to an auditory beat, in modulating the perception of complex auditory rhythms? (4) Is there a benefit of bimodal beat induction and, if so, is the effect dependent upon the phase of the visual movement? The last two questions converged to examine the idea that a visual beat can modulate auditory rhythm and beat perception, at least when effective visual stimuli are employed (Grahn, 2012; Hove, Fairhurst, et al., 2013; Hove, Iversen, et al., 2013). Two experiments were conducted to answer these questions. The weakly metrical auditory rhythms were to be