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"Lost in time" but still moving to the beat

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ABSTRACT

Motor synchronization to the beat of an auditory sequence (e.g., a metronome or music) is widespread in humans. However, some individuals show poor synchronization and impoverished beat perception. This condition, termed "beat deafness", has been linked to a perceptual deficit in beat tracking. Here we present single-case evidence (L.A. and L.C.) that poor beat tracking does not have to entail poor synchronization. In a first Experiment, L.A., L.C., and a third case (L.V.) were submitted to the Battery for The Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA), which includes both perceptual and sensorimotor tasks. Compared to a control group, L.A. and L.C. performed poorly on rhythm perception tasks, such as detecting time shifts in a regular sequence, or estimating whether a metronome is aligned to the beat of the music or not. Yet, they could tap to the beat of the same stimuli. L.V. showed impairments in both beat perception and tapping. In a second Experiment, we tested whether L.A., L.C., and L.V.'s perceptual deficits extend to an implicit timing task, in which they had to respond as fast as possible to a different target pitch after a sequence of standard tones. The three beat-deaf participants benefited similarly to controls from a regular temporal pattern in detecting the pitch target. The fact that synchronization to a beat can occur in the presence of poor perception shows that perception and action can dissociate in explicit timing tasks. Beat tracking afforded by implicit timing mechanisms is likely to support spared synchronization to the beat in some beat-deaf participants. This finding suggests that separate pathways may subserve beat perception depending on the explicit/implicit nature of a task in a sample of beat-deaf participants.

1. Introduction

One of the most compelling reactions to music is to move to its beat. Humans spontaneously or intentionally tend to clap their hands, sway their body, or tap their feet to the beat of music. Synchronizing movement to the beat (Repp, 2005; Repp and Su, 2013) involves the coordination of a discrete action with a sequence of rhythmic auditory events (e.g., tones of a metronome or musical beats). This complex activity is supported by a neuronal network, including areas devoted to tracking the musical beat (e.g., the basal ganglia; Grahn and Brett, 2007; Grahn and Rowe, 2009) and motor coordination (e.g., the cerebellum; Coull, Cheng, and Meck, 2011; Grube et al., 2010; Schwartze and Kotz, 2013). Motor synchronization to the beat is likely to be hard-wired as it appears spontaneously and early during development (Drake et al., 2000; Kirschner and Tomasello, 2009; Phillips-Silver and Trainor, 2005). Accordingly, this skill is highly widespread in the general population (Repp, 2010; Sowiński and Dalla Bella, 2013).

Even though the majority can move to the beat of music, some individuals, referred to as "beat-deaf" (Palmer et al., 2014) encounter particular difficulties in synchronizing to the beat (see also Sowiński and Dalla Bella, 2013). This condition is considered to be a congenital anomaly in the absence of brain damage (Phillips-Silver et al., 2011; Sowiński and Dalla Bella, 2013). An example of beat deafness is the

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case of Mathieu (Phillips-Silver et al., 2011), a young man who was unable to bounce accurately to the beat of music while showing good synchronization to a simple metronome. His poor synchronization is likely to result from poor perception, as he was inaccurate in estimating whether a dancer is on or off the beat in a music video. Notably, Mathieu's deficits cannot be ascribed to a general impairment of music processing (e.g., Peretz and Hyde, 2003; Stewart, 2008; see also Dalla Bella and Peretz, 2003). His pitch perception is spared as tested with the Montreal Battery of the Evaluation of Amusia (MBEA; Peretz et al., 2003).

The case of Mathieu points toward a perceptual explanation of poor synchronization to the beat. Inaccurate extraction of the beat from complex auditory signals (e.g., music), including several periodicities at different embedded temporal scales (meter; London, 2012), may bring about poor synchronization (Phillips-Silver et al., 2011). This deficit may not be apparent with a simpler isochronous sequence (e.g., a metronome) though. Beat tracking with a metronome is still possible, while beat extraction and synchronization with metrical rhythms are impaired (Launay et al., 2014). However, inaccurate beat perception is not mandatory to explain poor synchronization to the beat. In a large-scale study with around 100 students that were tested with a battery of rhythm perception and paced tapping tasks, we reported two cases (S1 and S5) who exhibited poor synchronization to the beat while showing spared rhythm perception (Dalla Bella and Sowiński, 2015; Sowiński and Dalla Bella, 2013). Additional evidence of sensorimotor deficits in beat deafness was provided more recently by Palmer and collaborators (Palmer et al., 2014). They showed that two beat-deaf participants, including Mathieu, had difficulties in adapting their tapping to perturbations in an isochronous sequence, next to poor beat perception. Finally, a recent study (Mathias et al., 2016) reports that Mathieu but not Marjorie, another beat-deaf participant, showed an abnormal P3 response to the omission of a beat in a musical sequence. Altogether these data suggest that there are different individual profiles of beat deafness, depending on the impairment of beat perception and/or production.

The dissociation between beat perception and tapping to the beat that we reported in two poor synchronizers (Sowiński and Dalla Bella, 2013) is particularly intriguing. It suggests that perception and action in the rhythm domain may be partly independent. However, task factors such as difficulty, attention, and memory demands may explain these differences. For example, synchronization requires both tracking the beat and generating a motor response. Thus, it may be more demanding than a simple perceptual task. As the opposite dissociation - impaired beat perception with spared synchronization - has not been described so far, it is difficult to conclude whether there are two independent mechanisms involved. However, a functional separation of perception and action is not unusual, and is supported by a double dissociation in pitch processing (for reviews, see Dalla Bella et al., 2011; Berkowska and Dalla Bella, 2009; Dalla Bella, 2016). A similar functional architecture may apply to rhythm. Beat perception and synchronization to the beat involve multiple components, which may be difficult to dissociate in the healthy brain, as motor and perceptual processes are usually strongly coupled (Grahn, 2012; Kotz et al., 2016; Repp, 2005; Repp and Su, 2013). Yet, first evidence that these processes can be disrupted separately as a result of brain damage or a developmental disorder (Fries and Swihart, 1990; Provasi et al., 2014; Sowiński and Dalla Bella, 2013) suggests some degree of functional separability.

Our goal is to present two cases of beat deafness (L.A. and L.C.) and to show that poor beat perception can occur while synchronization to the beat is spared. A third case, L.V. displays impairment of both beat perception and synchronization. With these data we also confirm the sensitivity of a battery of timing tests to detect both perceptual and synchronization deficits. In a first Experiment, participants' beat perception and synchronization to the beat were assessed with the Battery for The Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA; Dalla Bella et al., 2016; see also Benoit et al., 2014; Falk et al., 2015). An additional question was whether deficits in beat tracking observed in explicit timing tasks (e.g., Fujii and Schlaug, 2013; Phillips-Silver et al., 2011; Repp and Su, 2013; Repp, 2005; Sowiński and Dalla Bella, 2013) extend to implicit timing processes. In general, explicit timing is associated with tasks requiring either voluntary motor production (e.g., synchronized tapping tasks; Repp, 2005), or perceptual discrimination of a timed duration (e.g., anisochrony detection, Ehrlé and Samson, 2005; Hyde and Peretz, 2004). In contrast, implicit timing is involved in tasks that do not explicitly test timing (e.g., detecting a deviant pitch in a temporally regular or irregular sequence), but in which temporal prediction affects performance (Coull, 2009; Coull and Nobre, 2008; Nobre et al., 2007; Sanabria et al., 2011). In particular, temporal prediction fostered by a regular temporal pattern of sensory stimuli improves performance in these tasks (e.g., reduces reaction times; Lange, 2010; Sanabria et al., 2011; Sanabria and Correa, 2013). Explicit and implicit timing are associated with distinct neuronal substrates, involving cortico-striato-cortical networks and inferior parietal-premotor networks with projections from the cerebellum, respectively (Coull and Nobre, 2008; Coull et al., 2011; Kotz and Schwartze, 2010; Nobre and Coull, 2010; Schwartze and Kotz, 2013; Zelaznik et al., 2002). Here we hypothesize that beat perception deficits characteristic of beat deafness as observed in explicit tasks may not carry over to implicit timing tasks. This hypothesis was tested in a second Experiment, in which L.A., L.C., and L.V. were asked to respond as quickly as possible to a target sound presented either after five sounds embedded in a temporally regular or an irregular sequence. Better performance following the regular sequence of sounds compared to the irregular sequence would be indicative of spared implicit timing processing.

2. Experiment 1

2.1. Participants

2.1.1. Cases histories

L.A., L.C., and L.V. were 21-year-old female university students recruited at the University of Montpellier. L.A. and L.V. had not received any musical training. L.C., in spite of the fact that she received 5 years of non-formal piano lessons, considers herself a non-musician. She practiced less than 1 h a week during her musical training, and has rarely played the piano in the last 7 years. L.V. complained about difficulties in finding the beat in music, especially while dancing, singing, or tapping the foot to the beat. In contrast, L.C. and L.A. reported no difficulties with beat tracking. Neither participant suffered from a brain injury nor had undergone brain surgery. None of them reported previous neurological or psychiatric problems or an auditory deficit.

2.1.2. Control group

Seven female university students recruited at the University of Montpellier, matched to the three beat-deaf participants took part in the study. They were between 18 and 30 years old (M=23.29 years; SD=4.54), and were self-reported non-musicians (mean number of years of musical training=1.29; SD=1.89). They did not have any previous neurological or psychiatric problems. All participants provided informed consent for participating in the study.

2.2. Material and method

The participants were submitted to BAASTA (Dalla Bella et al., 2016) as a way to assess their explicit perceptual and sensorimotor timing abilities. In addition, they performed the pitch-related tasks of the MBEA (Contour, Interval, and Scale subtests; Peretz et al., 2003) to assess their pitch perception.

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