Does beat perception rely on the covert use of the motor system?

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Abstract

Listening to music often drives people to move along to the beat of that music. Past research has suggested that motor resources are recruited not just to produce a beat, but also to perceive a beat. The present study extends this correlational work and examines whether the motor system plays a functional role in beat perception using a dual-task behavioral paradigm. Wßhile performance on a beat perception task was affected by a simultaneous motor task compared to a control task (Experiment 1), pitch perception was not affected (Experiment 2). Furthermore, this effect was mediated by whether or not participants had received formal musical trainingß. The results suggest that the motor system may play a functional role in beat perception, even when people are not overtly moving in time to the beat.

Keywords: beat perception; pitch perception; motor system; dual-task

Introduction

When listening to music, people often experience a compelling drive to move along to the beat. Moving along with music appears to be a human universal, appearing in very young children (Drake, Penel, & Bigand, 2000; Kirschner & Tomasello, 2009) and across the world's cultures (Brown, 2003; Nettl, 2000). Thus, perhaps it's not surprising that a variety of neuroscientific research suggests a tight link between the auditory and motor systems in rhythm processing (for a review see Zatorre, Chen, & Penhune, 2007). This body of work suggests that the motor system is activated not only during beat production, but also during beat *perception*, even when an overt movement is not produced. For instance, the perception and production of musical rhythm both activate brain areas implicated in motor processing, including the supplementary motor area (SMA), premotor cortex (PMC), the cerebellum, and the basal ganglia (Grahn & Brett, 2007; Grahn & Rowe, 2009; Grahn, 2009). Furthermore, based on MEG data, Iversen, Repp, and Patel (2009) have suggested that the motor system influences one's interpretation of the metricality of a sound, even when individuals are not required to move when perceiving a beat. Behavioral research also supports this idea. For example, Phillips-Silver and Trainor found in both infants (2005) and adults (2007) that moving in time with a particular musical beat influences one's perception of that music's rhythm.

However, although studies like these have revealed motor system activity during both production and perception of a musical beat, it is largely unknown whether or not the motor system plays a functional role in beat perception. Is activation in motor areas during beat perception simply the result of associating music with movement (that in some cases is simply not expressed muscularly)? Or does motor activation reflect calculations used to perceive a beat? For instance, perhaps individuals, upon hearing music, use motor planning areas to simulate moving to the beat. This motor activity might then allow an individual to decide whether the music is on or off beat, as put forth by the action simulation for auditory prediction (ASAP) hypothesis (Patel & Iversen, in press). The present pair of studies aims to address this issue using a dual-task behavioral paradigm.

In order to investigate the functional role of the motor system in beat perception, we prevented people from moving to the beat (or even thinking about moving to the beat, and presumably from engaging motor planning areas in action simulation) by tying up their motor system with an unrelated secondary motor task. This allowed us to ask whether beat perception is selectively impaired by a simultaneous motor task. If the motor system plays a functional role in beat perception then we would expect to see worse performance on beat perception during a motor task, but no such impairment on a different perceptual task that does not rely as extensively on the motor system.

Experiment 1

In Experiment 1, participants listened to clips of music and had to decide whether an overlaid beat track was on or off the beat of the music. Critically, they simultaneously performed one of two secondary tasks, a Motor task, which was designed to occupy the motor system, and a color change detection task that served as a Control.

To interfere with the motor system, the Motor task had participants continuously track a pseudo-randomly moving dot on a computer screen with a computer mouse (more details can be found in the methods section). Such visually-guided motor movement is thought to involve many of the areas also implicated in beat perception, including supplementary motor area (SMA) (e.g., in humans: Grafton, Mazziotta, Woods, & Phelps, 1992; in monkeys: Picard & Strick, 2003), premotor cortex (PMC) and the cerebellum (e.g., Miall, Reckess, & Imamizu, 2001).

In the Control task, participants tracked the same dot visually and kept track of whether or not it changed shade during the trial. Visual tracking of moving objects (smooth pursuit) largely recruits the middle temporal (MT) and medial superior temporal (MST) areas, as well as the frontal eye fields (see Krauzlis, 2004, for a review), which do not overlap with motor areas purportedly active during beat processing to the same extent as the Motor task.

If the motor system plays a functional role in beat perception, then participants should be worse at making beat perception judgments when their motor system is occupied with the unrelated Motor task (which occupies the motor areas putatively involved in beat perception) than when they are occupied with the unrelated Control task (which does not).

Methods

Participants A total of 66 UC San Diego undergraduates participated in the experiment for course credit. Their ages ranged from 18 to 24 years old (mean age = 20.6 years). Of these participants, 23 reported having no musical training.

Materials

Primary Task Stimuli The musical stimuli consisted of 135 unique sound files created from forty-five ten-second excerpts from songs spanning a wide variety of genres (e.g., "One Way or Another" by Blondie, "Tuxedo Junction" by Glenn Miller). All of the excerpts were instrumental (no lyrics were included) and were in either 4/4 or 3/4 time. As in Iversen and Patel (2008), a beep track (1 KHz pure tones, 100ms in duration) was overlaid on the excerpts after a five second delay. To create the beat track, ten rhythmically inclined volunteers listened to each excerpt three times while tapping in synchrony with the natural pulse of the music on a MIDI pad. A naturalistic beat track for each excerpt was created from successful synchronization trials by finding the median (across trials and tappers) tap time for each beat. This was the on-beat version. Two off-beat versions of each clip were then created by adjusting each intertap interval (ITI) to either 10% shorter or longer than the on-beat stimuli.

Participants heard each excerpt twice; once in each block. They never heard the same version of a single excerpt (for example, they never heard the on-beat version or the same version of the off-beat stimulus more than once over the course of the experiment).

Secondary Task Stimuli The two secondary tasks were designed to be performable above chance but sufficiently difficult to avoid ceiling effects. Both used a visual stimulus that consisted of a black dot that was roughly 1 cm (30 pixels) in diameter. To ensure that there were no rhythmic patterns in the secondary task, the dot moved along a curved path (see Figure 1) that was pseudorandomly generated frame-by-frame using a custom E-Prime script (Psychology Software Tools, Pittsbugh, PA, USA).

In Motor (dot following) blocks, cursor position was tracked on a frame-by-frame basis. The cursor was considered to be successfully tracking the dot if it was within the area of the dot or within a 25 pixel buffer around the dot. Accuracy was defined as the proportion of each trial in which the participant successfully tracked the dot.

In Control (color change) blocks, the dot changed color on 50% of the trials. Color changes consisted of a slow (2s) fade from black to dark gray to black during the second half of the trial. These changes were very subtle to encourage participants to pay close attention to the moving dot and to avoid ceiling effects. Detectability of the color change was verified for each participant.

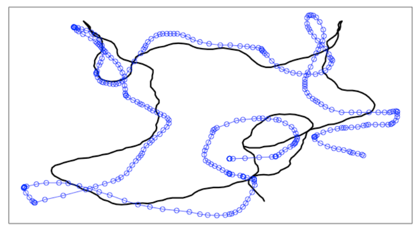

Figure 1: Example trajectory of the visual stimulus (black line) and the participant's mouse path (blue dots) in a single Motor task trial.

Procedure Participants were seated in a quiet room at a desktop computer. Each participant completed two blocks of trials. In both blocks, the participant's primary task was to determine whether a beat track superimposed on a musical clip was on or off beat. At the same time, they performed one of two secondary tasks: Motor (dot following) or Control (color change). The order of secondary tasks was counterbalanced across participants and all of the participants completed one block with each secondary task. To ensure participants were only moving during the Motor task, they were asked to minimize their physical movements, except for when it was required by the tasks (e.g. following the dot with the mouse). The experimenter remained in the room during the experiment to ensure participants complied with these instructions and reminded participants not to move if they started to move to the music. In each block, participants completed three practice trials followed by forty-five experimental trials. One-third of the trials required "on-beat" responses while the other two-thirds required "off-beat" responses.

During the Motor task block, in order to ensure that the motor system was engaged before hearing the beat track, participants started following the dot immediately at the start of the trial, along with the start of the musical excerpt, and the overlaid beat track began five seconds later. After the excerpts ended, the screen prompted participants to judge whether the beeps had been on-beat or off-beat. For both blocks, responses ("on" or "off") were reported verbally and were recorded online by the experimenter, who was seated away from the participant's view to avoid any unintentional cueing from the experimenter.

During the Control task block, after the excerpts ended, the screen prompted participants to judge whether the beeps had been on-beat or off-beat. Then, the screen prompted participants to judge whether or not the dot had changed color during the trial ("yes" or "no"). Both types of responses were reported verbally.

Once both blocks were completed, participants filled out a questionnaire with demographic information, self-reported rhythmic ability, and history of formal musical training.

Analysis As musical training is known to affect music processing in a variety of ways (e.g., Elbert et al., 1995; Hund-Georgiadis & von Cramon, 1999; Jäncke, Shah & Peters, 2000; Chen, Penhune & Zatorre, 2007; Bangert et al, 2006), self-reported formal musical training was included as a factor in the analyses. All analyses were implemented in *R* (R Development Core Team, 2005). For the primary and secondary tasks, ANOVAs were conducted on beat judgment performance (percent correct) or secondary task performance (z-score of accuracy) with type of secondary task (Motor vs. Control) and musical training (Yes or No) as factors.

Furthermore, to investigate whether any trade-offs occurred between the primary and secondary tasks, the difference in z-scores from the Motor and Control secondary tasks was used as a measure of an individual's relative performance on the secondary tasks. The correlation between that measure and the difference between performance on the beat judgment task during the Motor task condition and during the Control task condition was then calculated. Any significant negative relationship between the two would provide evidence of a trade-off between the primary and secondary tasks.

Results

Performance on primary task Overall, performance on the primary, beat-perception task was affected by an interaction between musical training and secondary task, $F(1,64)=4.35$, $MSE=.006$, $p=.041$. While those with no musical training performed significantly worse ($M=.72$) on the beat perception task during motor interference than those with musical training ($M=.82$), there was no difference between the two groups during the control task (musical training: $M = .80$, no musical training: $M = .76$) (Figure 2). There was also a marginal main effect of musical training: those with musical training performed marginally better ($M=.81$) on the beat perception task than those without ($M=.74$), $F(1,64)=3.09$, $MSE=.049$, $p=.08$. There was no main effect of secondary task type, $p=.93$.

Performance on secondary tasks An analysis of the z-scores of the accuracy on the secondary tasks revealed no main effects (task: $p=.85$, music training: $p=.83$) nor an interaction ($p=.22$). However, the difference in beat judgment accuracy scores across the two secondary tasks significantly predicted the difference of the z-scores of the accuracy of the two secondary tasks for those with musical training, $b=.06$, $t(42)=5.42$, $p<.001$, but not for those without, $p=.17$. Those with musical training who did better on the beat judgment task during the control secondary task than during the motor task also did better on the control secondary task than the motor task.

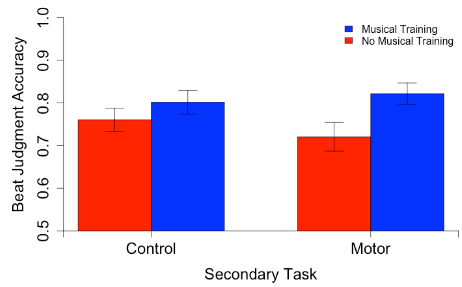

Figure 2: Average beat judgment accuracy during each of the secondary tasks, split by musical training. Error bars represent standard error.

Discussion

When occupied with the Control secondary task, participants with musical training performed as well on the beat perception task as those without musical training. However, during the Motor task, beat perception performance suffered for those without musical training as compared to those with musical training. Critically, this was not simply due to a trade-off between the primary and secondary tasks. Rather, there was a *positive* relationship between participants' beat perception scores during one secondary task and their respective scores on that secondary task.

Why did musical training affect the effectiveness of the manipulation? One possibility is that individuals with musical training, who are often trained specifically in beat perception, may process beat information more efficiently than those without such training. This efficiency might play out in musicians relying less on secondary motor areas than those without musical training for beat perception. Corroboratory evidence comes from beat *production,* in which the SMA is significantly less active in professional pianists than in non-musicians (Hund-Georgiadis & Von Cramon, 1999; similar results were also observed by Jäncke, Shah, & Peters, 2000). Whether this also extends to beat perception needs to be further explored.

Of course, because the motor task we used is known to recruit many components of the motor system, we cannot determine what specific motor areas might be differentially recruited for beat perception as a function of musical training. This remains a potentially fruitful direction for future work to investigate.

More urgently, however, the results from Experiment 1 have an alternative explanation to the one that's offered above. It's possible that the Motor task is simply more difficult than the Control task. If so, then the decrease in performance in the primary beat perception task during the Motor secondary task might not result from the specific recruitment of the motor system. To ensure that the results weren't due to this deflationary possibility, we conducted a second experiment, with a different primary task.

Experiment 2

Experiment 2 was designed to control for the possibility that the Motor task is more demanding than the Control secondary task. Rather than making beat perception judgments for their primary task, participants made judgments about the pitch of musical tones, which involves auditory processing regions of the brain, but is not thought to involve the motor system in the same manner as beat perception (see Peretz & Zatorre, 2005, for a review). If participants with and without musical training are differentially affected across the two secondary tasks, as in Experiment 1, then we cannot reject the possibility that the results of Experiment 1 are due to differences in the two secondary tasks independent of motor interference. However, if participants with and without musical training in Experiment 2 perform equally well on pitch judgments during both secondary tasks, this suggests that the Motor task is not simply more demanding than the Control task.

Methods

Participants A total of 70 UC San Diego undergraduates that did not participate in Experiment 1 completed the experiment for course credit. Their ages ranged from 18 to 28 years old (mean age = 20.9 years). Of these participants, 32 reported having no musical training.

Materials

Primary Task Stimuli The musical stimuli consisted of 90 unique 10-second excerpts containing two sets of three notes each, played individually. There were two types of excerpts created: one where the first and second sets of notes contained the same notes as each other, regardless of order (Same stimuli) and one where the second set of notes contained different notes than the first, regardless of order (Different stimuli). There were twice as many Different stimuli as Same stimuli. The first set of notes was either a major triad or a diminished triad (arpeggiated, not necessarily in ascending order). For Same stimuli, the second set of notes was the same triad with the order of notes changed. For Different stimuli, the second set of notes was a different triad.

For each Different stimulus, the new triad was different from the first triad by one note. If the first set of notes was a major triad, the root (tonic) note was moved down a whole step to create a diminished triad as the second set of notes (with the major third of the major triad serving as the new root of the diminished triad). If the first set of notes was a diminished triad, the fifth was moved up a whole step to create a major triad (with the changed note serving as the new root of the major triad). A second version of each of the Different stimuli was also created by lowering the changed note by an octave. Stimuli were created in GarageBand (Apple, Inc.) using a default MIDI piano sound. All the notes were uniform in intensity and duration.

Secondary Task Stimuli The secondary task stimuli were the same as in Experiment 1.

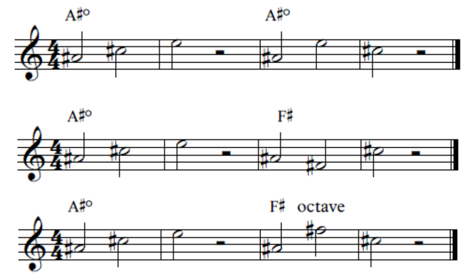

Figure 4: Examples of pitch judgment stimuli. The correct answer for the top example would be "same", and the correct response for the bottom two would be "different".

Procedure The procedure and structure of the experiment were identical to Experiment 1, differing only in the primary task. Throughout both the Motor and Control blocks, participants listened to the musical (pitch) stimuli and were then prompted to determine whether or not the second set of notes contained the same notes as the first ("same" or "different"). Then they either proceeded to the next trial or made a color change judgment ("yes" or "no"), depending on which block they were currently completing. As in Experiment 1, participants completed 48 trials per block (3 practice, 45 experimental), with one-third of the trials requiring a "same" pitch response and the remaining trials requiring a "different" pitch response.

Analyses The data were analyzed in the same manner as in Experiment 1, except that pitch judgment accuracy was used as the dependent variable for the primary task.

Results

Performance on primary task Those with musical training (M=.73) significantly out-performed those without training (M=.64) on the pitch judgment task, $F(1, 68)=13.94$, $MSE=.019$, $p<.001$. In addition, there was a main effect of secondary task: participants made more accurate pitch judgments following the motor task (M=.70) than following the control task (M=.67), $F(1,68)=5.11$, $MSE=.004$, $p=.027$. No interaction was observed, $p=.99$ (see Figure 4).

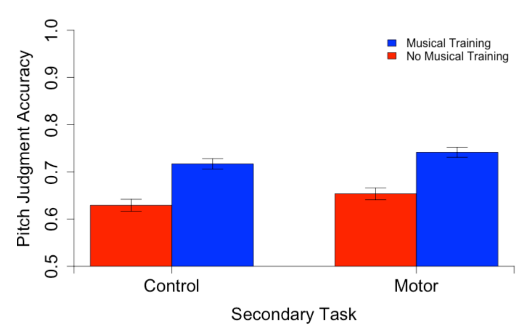

Figure 4: Average pitch judgment accuracy during each of the secondary tasks, split by musical training. Error bars represent standard error.

Performance on secondary tasks As in Experiment 1, an analysis of the z-scored accuracy of the secondary tasks revealed no main effects (task: p=1, musical training: p=.34) nor an interaction (p=.85). Furthermore, the difference in pitch judgment accuracy scores across the two secondary tasks did not predict the difference of the z-scores of the accuracy of the two secondary tasks for neither those with musical training (p=.48) nor those without (p=.15).

Discussion

In Experiment 2, participants made judgments about whether two sequences of musical notes contained notes of the same or different pitches while they performed one of two secondary tasks. Contrary to Experiment 1, there was no interaction between musical training and secondary task on pitch judgment accuracy. Furthermore, there was no evidence that individuals performed worse as a result of the Motor task as compared to the Control task. Rather, we found the opposite: participants were worse at making pitch perception judgments following the Control task than the Motor task.

General Discussion

In Experiment 1, we demonstrated that tying up the motor system resulted in deficits in beat perception in the musically untrained compared to the musically trained. This was not due to the motor task being more difficult than the control task. Indeed, in Experiment 2, participants actually performed worse on a pitch perception task during the control task, suggesting that if anything, the control task was more demanding than the motor task. Together, these studies suggest that the motor system plays an important role in beat perception.

What role might the motor system be playing in beat perception? One answer is that its connection to beat perception is merely associative. On this account, the motor system is active when listening to music only because we often move to music (for instance, in dancing). In this case motor system activity is a downstream process that does not play any functional role in a person's ability to perceive the beat. However, this account does not square with the results reported above. It would predict that beat perception should be equally affected by the two secondary tasks. This is not what we found.

Rather, our results are consistent with the predictions of an alternative account: the action simulation for auditory prediction (ASAP) hypothesis (see Patel & Iversen, in press, for a detailed description). According to the ASAP hypothesis, when listening to music, motor planning regions are used simulate body movement (particularly the periodicity of the movement) that becomes entrained to the beat, which in turn is used to generate a prediction about the timing of an upcoming beat. This motor entrainment could then provide feedback as to whether the music is on or off the beat (independent of actual movement). When the motor system is tied up, however, as in the Motor condition in Experiment 1, it would be unable to provide such feedback, making it more difficult for an individual to make beat judgments.

Interestingly, the covert involvement of the motor system has been observed in other domains, such as language. For example, a study using theta burst TMS found that individuals were faster to respond to action verbs that typically involve the right hand following stimulation of the left premotor cortex compared to right premotor cortex, suggesting a functional role of the PMC in language comprehension (Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011).

While we have argued that the present results are due to motor interference in the beat perception task (but not the pitch perception task), we cannot completely rule out the possibility that, due to the nature of this dual-task paradigm, differences in difficulty and type of the primary tasks are responsible for the observed patterns of results. However, if there were large discrepancies in the difficulties of the two primary tasks, one would expect this to be revealed in the secondary task performance. For instance, if pitch judgments were much more difficult for participants, performance on both secondary tasks would suffer as compared to the performance on the same secondary tasks when beat judgments were the primary task. To address this possibility, we compared performance on the secondary tasks across experiments. A 2 (type of judgment: beat or pitch) x 2 (type of secondary task: control or motor) x 2 (musical experience: yes or no) ANOVA was conducted using the z-scores of secondary task accuracy as the dependent variable. Neither an interaction nor any main effects were observed (all p-values > .35), which suggests that performance on the secondary tasks was equal across experiments and thus cannot explain the differences observed across experiments. Future studies could explore a similar question using complementary paradigms to examine whether the same pattern of results are observed.

One other wrinkle still to be addressed is the difference between participants with and without formal musical training. We've argued that individuals with musical training may be less affected by a motor manipulation due to more efficient processing of beat information (e.g., Jäncke, Shah, & Peters, 2000). While the present data is consistent with this idea, this hypothesis remains speculative.

We intend to investigate this moving forward. As discussed in Experiment 1, musical training can change how individuals process music on many levels. While we found that those with musical training performed better on both beat and pitch perception tasks, we had only limited information about the musical training of the participants (e.g., we did not obtain details the nature of their training, how often they practiced, whether they were instrumental or vocal musicians, etc.). By investigating varying levels and types of musical training, the interpretation of the effects observed in the present study may become clearer. Training non-musicians to use various strategies of internalizing the beat may similarly provide insight into the role that the motor system plays in beat perception and how it changes with musical training.

In conclusion, these studies suggest that moving (or even using the motor system to covertly simulate moving) to the beat may not merely be a side effect of listening to music. Rather, it may be critical in determining the beat of the music, especially for those who have no formal musical training.

Acknowledgments

We would like to thank Chitra Subrahmanyam, Erik Evangelista, Courtney Moltzen, and Omar Masarweh for help with data collection and stimulus generation.

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