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Movement Enhances Perceived Timing in the Absence of Auditory Feedback

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Abstract

Moving (tapping) to a beat can objectively improve the perception of timing. Here we examine whether auditory feedback from tapping is a requirement for this improvement. In this experiment, two groups of participants heard a series of isochronous beats, and identified whether a probe tone after a short silence was consistent with the timing of the preceding sequence. On half of the trials, participants tapped along on an electronic drum pad up to and including the probe tone, and on half of the trials they listened without tapping. In the auditory feedback (AF) group sounds from tapping were available to participants and in the no auditory feedback (NAF) group these sounds were masked using white noise. In both groups, movement improved timing judgments of the probe tone, however this improvement was more pronounced when auditory feedback was present. Additionally, tapping was more accurate when auditory feedback was available. While previously we demonstrated an effect of movement on perceived timing, here we clarify that movement alone is sufficient to trigger this improvement (independent of the movement's auditory consequences). We identify the importance of auditory feedback as a cue for movement timing, which subsequently affects perceived timing of an external stimulus. Additionally we have demonstrated that movement alone can improve timing perception, independent of the auditory feedback caused by this movement.

Keywords

Timing perception, auditory feedback, motor timing, tapping, perception and action

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1. Introduction

The interplay between movement and sound shapes everyday tasks such as tapping along with a song on the radio or playing a musical instrument. Auditory information can influence ways in which we move; for example we can readily tap along to metronome or dance along with the beat in music. Conversely movement can modify the perception of temporal information (Phillips-Silver & Trainor, 2007; Su & Pöppel, 2012), in some cases leading to improvements in timing sensitivity (Iordanescu et al., 2013; Manning & Schutz, 2013). While these auditory–motor connections are not yet fully understood, we can explore these interactions by examining simple movement synchronization with predictable auditory stimuli.

Tapping is frequently used to study simple motor synchronization with an auditory pacing signal (reviewed in Repp, 2005), and typically involves integrating temporal information from a variety of sensory inputs. While audition is generally the most reliable modality for timing (Chen et al., 2002), particularly for movement synchronization (Kolers & Brewster, 1985), the addition of other modalities can improve accuracy (Maduell & Wing, 2007; Stenneken et al., 2006; Wing et al., 2010). For example, synchronization with a pacing signal is more precise when both auditory and tactile feedback are presented together, rather than individually (Wing et al., 2010).

Manipulating the temporal relationship between movement and its corresponding sound illustrates the complex cross-talk between the auditory and motor systems (Aschersleben & Prinz, 1995, 1997; Finney & Warren, 2002; Mates & Aschersleben, 2000; Mates et al., 1992; Pollok et al., 2004). Delaying auditory feedback impairs musical timing (Finney, 1997; Gates et al., 1974), and delaying a single note causes musicians to shorten the subsequent interval to maintain a steady tempo (Furuya & Soechting, 2010). Additionally, there is a systematic relationship between amount of delay and note-to-note variability in performance, where in general a larger delay in feedback leads to more variability (Pfordresher & Palmer, 2002). It is clear that delayed auditory feedback affects the timing of subsequent movements, presumably to compensate for the timing change (Furuya & Soechting, 2010; Wing, 1977). These studies illustrate how modifying auditory event timing affects concurrent movement. Here we extend this work by demonstrating how movement affects the perception of concurrent auditory events.

Measurements of the asynchrony between an isochronous stimulus and participant taps are useful in indexing tapping ability (smaller asynchronies indicate more accurate synchronization), with typical asynchronies preceding tones by tens of milliseconds (see Aschersleben, 2002). In research that manipulates auditory feedback, tap asynchronies are examined to determine how feedback affects synchronization abilities. Delayed auditory feedback has detrimental effects on tapping, increasing tap asynchrony (Aschersleben & Prinz, 1995, 1997; Mates et al., 1992), while auditory feedback occurring prior to movement has little effect on tapping (Mates & Aschersleben, 2000). The detrimental effects of delaying auditory feedback highlight its importance in movement timing.

While tap asynchronies exist even when auditory feedback is present and unaltered (Fraisse et al., 1958; Franěk et al., 1987; Hary & Moore, 1987; Mates et al., 1992), the absence of auditory feedback further increases tap asynchronies (Aschersleben & Prinz, 1995; Mates et al., 1992; Pollok et al., 2004). Similar findings are present when tactile feedback is disrupted using a local anaesthetic; removing tactile feedback increases tap asynchrony (Aschersleben et al., 2001). When both auditory and tactile cues are available, tap asynchrony is significantly lower than when one or neither timing cue is available, emphasizing the role of multiple sensory inputs in motor timing (Wing et al., 2010).

The present study examines the role of auditory feedback in the integration of auditory and motor information in a timing deviation task. Previously we observed that when participants judged the timing of a probe tone at the end of an isochronous sequence, performance improved when moving (tapping) prior to this judgment compared to when listening alone, specifically when the probe tone occurred later than expected (Manning & Schutz, 2013). Additionally we reported a relationship between tapping quality and timing judgments, where more consistent tapping correlated with better task performance. Here, our primary goal is to identify whether it is the presence of movement or the *auditory consequences* of movement that improve timing perception by comparing performance when the sound of tapping is present vs. masked. If movement improves performance even when tap sounds are masked this would suggest that movement itself is sufficient to elicit the improvement. This would be consistent with previous results showing that movement influences temporal encoding in subjective tasks, even when these movements produce no acoustic consequences (Phillips-Silver & Trainor, 2007; Su & Pöppel, 2012). However, finding that movement no longer improves performance in the absence of auditory feedback would indicate that that previously documented effects of movement in this paradigm might in fact be effects of the auditory consequences of movement. This work will inform research on the integration of auditory feedback and motor timing, as well as ways in which movement and other sensory information affect perceived timing of predictable temporal events.

2. Method

Two groups of participants completed this experiment. Both groups judged the timing of a probe tone at the end of an isochronous sequence while either tapping along with the sequence or listening without moving. The paradigm was adapted from Manning and Schutz (2013), using fewer conditions and more trials to allow for more fine-grained comparisons between accuracy scores and tapping data. The availability of auditory feedback differed between participant groups. In the auditory feedback (AF) group, the sound of tapping was available to participants throughout the sequence. In the no auditory feedback (NAF) group, we removed the availability of auditory feedback by masking the sound produced by tapping (see sections 2.2 and 2.3 for details).

2.1. Participants

The AF group consisted of thirty-seven undergraduate students (27 females) ranging in age from 18–26 years (*M* = 20.24, SD = 2.17). They had between 0 and 12 years (*M* = 3.35, SD = 3.24) of musical training. The NAF group consisted of thirty-eight different undergraduate participants (30 females) ranging in age from 17–24 years (*M* = 19.61, SD = 1.71). These participants had between 0 and 16 years (*M* = 5.18, SD = 4.34) of musical training. Both groups participated in exchange for course credit and all participants tapped using their dominant hand.

2.2. Stimuli and Materials

In each trial, an Apple iMac computer (OSX 10.6.8) presented a sequence of isochronous 'woodblock' tones (gmBank = 115) at an inter-onset interval (IOI) of 500 ms over Sennheiser HDA200 headphones (81 dB[A]). These tones were grouped together in patterns of four, where the first tone of each pattern was higher in pitch (C5; 523 Hz) than the following three (G4; 392 Hz) implying a 4/4 metric structure (see Fig. 1). In the fourth repetition of this pattern the lower pitch tones were replaced with silence. Following this silence a probe tone either occurred on time (50% of trials) with the sequence or 15% of the IOI (75ms) late (50% of trials). Trials were presented in blocks, which varied between instructions to listen alone (no-movement condition) or to tap while listening (movement condition) with the entire sequence using a drumstick (IP-1) on an electronic drum pad (Roland PDX-8) connected to an Alesis Trigger I/O Trigger-to-MIDI Interface. White noise (74 dB[A]) masked external sounds, including the sound of the drumstick hitting the drum pad for the NAF group (while the AF group heard their taps).

2.3. Procedure

In each trial, participants reported whether the probe tone was consistent with the preceding sequence, receiving feedback on the correctness of their responses. In the movement condition participants tapped along with the sequence (using their dominant hand) through the silence up to and including the probe tone. In the no-movement condition, participants listened to the sequence and remained still. After five warm-up trials, participants completed 12 blocks (8 trials/block) for a total

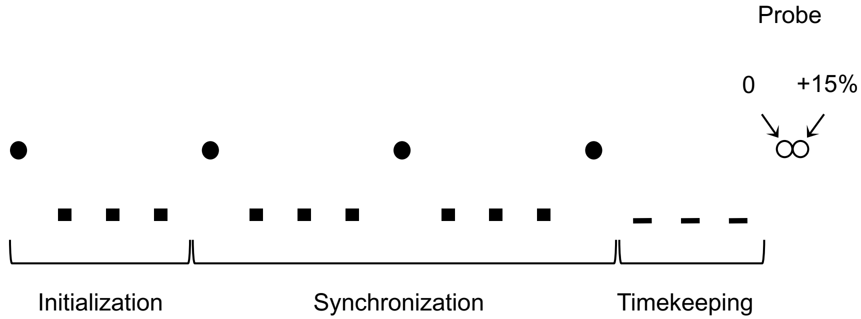

Figure 1. Circles represent accented tones while squares represent unaccented tones. The lines represent silent 'beats' and the unfilled circles depict possible probe tone positions. Trial segments are labelled.

of 96 trials. We randomized the order of movement/no-movement blocks in addition to the order of trials within each block for each participant. In an exit survey all participants in the AF group reported being able to hear tap feedback, and no participants in NAF group reported being able to hear their tapping for the duration of the experiment.

3. Results

3.1. Timing Judgments

We collected responses[1] and calculated the difference in the 'score' (i.e., the percentage of correct responses) in the movement vs. no-movement condition to quantify the 'effect of movement' on timing judgments for each participant and probe tone offset, with positive scores indicating better performance when moving (see Fig. 2). We conducted a 2 × 2 mixed-model ANOVA on the effect of movement using auditory feedback (group) as a between-subjects factor and offset as

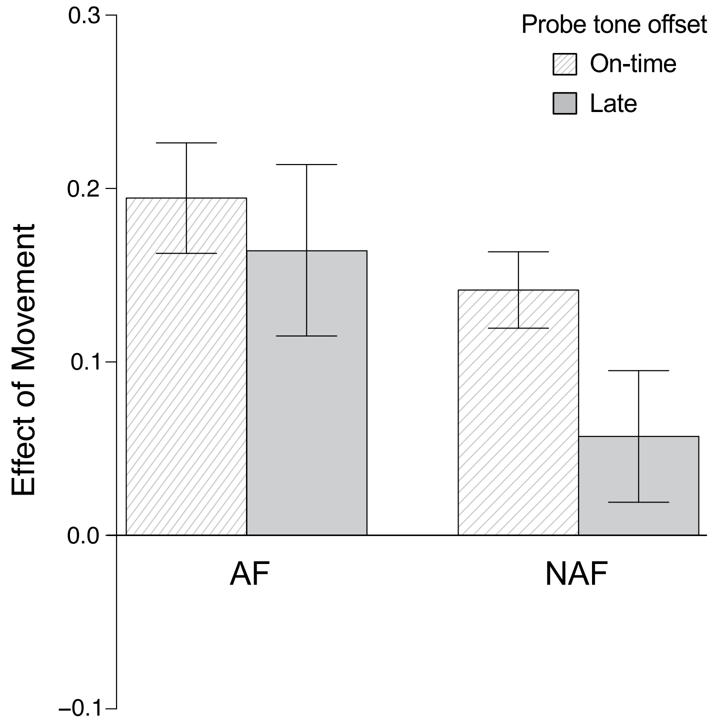

Figure 2. The effect of movement (movement–no-movement task score) on probe tone timing judgments for auditory feedback (AF) and no auditory feedback (NAF) groups. Error bars represent the standard error of the mean.

[1] Timing judgments for each group are plotted in online Supplementary Fig. S1.

a within-subjects factor. We found a main effect of auditory feedback [$F(1, 73) = 7.26$, $p = 0.009$], indicating a difference between the AF group and NAF group on task performance. There was no main effect of offset [$F(1, 73) = 1.98$, $p = 0.164$], and no interaction between group (AF/NAF) and offset [$F(1, 73) = 0.49$, $p = 0.487$]. Movement affected both the NAF [$t(37) = 4.48$, $p < 0.0001$] and AF [$t(36) = 6.40$, $p < 0.0001$] groups, however, movement's effect was lower in the NAF group [$t(73) = 2.27$, $p < 0.05$]. These results demonstrate that while auditory feedback may be used as a cue for timing (Kolers & Brewster, 1985; Maduell & Wing, 2007; Wing et al., 2010), movement alone can significantly improve timing perception. We conducted a correlation between performance in the movement condition and years of musical experience for each group and found a significant relationship in the NAF group [$r(37) = 0.41$, $p = 0.011$], but not in the AF group [$r(36) = 0.24$, $p = 0.146$]. This suggests that participants with more musical experience performed better in the movement condition than do participants with little or no musical experience when auditory feedback is lacking, however explicit examination of this idea is needed for further discussion.

3.2. Tapping

The first four taps in each trial were disregarded, allowing participants to stabilize tapping. We computed a coefficient of variation (standard deviation of IOI/mean IOI) as a measure of variability for taps in the synchronization segment. We also calculated the signed asynchrony between the onset of each tone and each remaining tap[2] in the synchronization and probe tone segments of the trials (Fig. 1). The coefficient of variation was no different between groups [$t(73) = 0.21$, $p = 0.833$], indicating auditory feedback did not affect tapping consistency (Fig. 3a). However, the presence of auditory feedback lowered measures of synchronization variability, where the SD of tap asynchronies in the synchronization segment were lower in the AF group compared to the NAF group [$t(73) = 3.20$, $p = 0.002$], a trend that approached significance for the SD of tap asynchronies at the expected probe tone [$t(73) = 1.89$, $p = 0.063$]. The presence of auditory feedback lowered mean asynchronies (Fig. 3b) both for taps in the synchronization segment [$t(73) = 3.22$, $p < 0.005$] and those concurrent with the expected probe tone [$t(73) = 3.07$, $p < 0.005$]. We found a significant correlation between probe tone tap asynchrony and movement condition score for the AF group [$r(35) = -0.32$, $p = 0.050$], and a trend that did not reach significance for the NAF group [$r(36) = -0.27$, $p = 0.099$], suggesting participants with smaller probe tone tap asynchronies performed better on the timing detection task.[3] This illustrates an interaction between tapping accuracy and timing judgments.

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2 Reported measures of tapping are corrected for a constant latency in the experimental setup.

3 Additional correlations between task performance and other measures of tapping are presented in the online Supplementary Table S1.

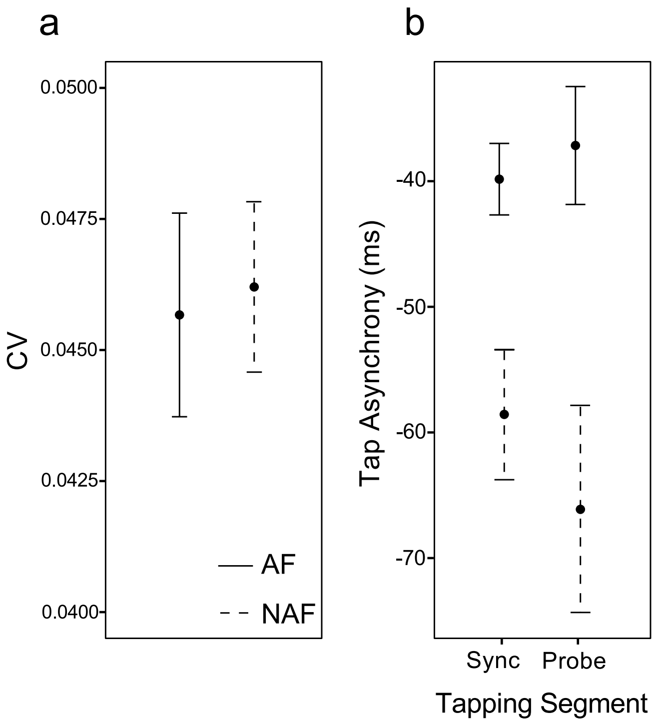

Figure 3. The coefficient of variation (a) and tap asynchronies (b) plotted for AF and NAF groups. Error bars represent the standard error of the mean.

4. Discussion

This experiment investigated how auditory feedback as a consequence of movement influences the perceived timing of an external stimulus. We found that movement improved timing perception, even in the absence of auditory feedback from those movements. This extends our previous findings (Manning & Schutz, 2013) by showing that *movement itself* (independent of a movement's acoustic consequences) is capable of improving timing perception. Moreover, the fact that auditory feedback further enhances a movement's effect on perception complements previous research demonstrating that inputs from multiple sensory modalities enhance timing perception (Maduell & Wing, 2007; Stenneken et al., 2006; Wing et al., 2010).

The tap asynchrony data in this study illustrate that tapping is more accurate with auditory feedback, consistent with previous findings examining motor timing with and without sensory feedback (Aschersleben & Prinz, 1995; Aschersleben et al., 2001; Mates et al., 1992). In contrast, the absence of auditory feedback does not adversely affect tapping variability (see Fig. 3a). This suggests auditory feedback may not help with the mere production of periodic movement, but is important for aligning that movement with an external stimulus. These data complement previous findings showing that temporally congruent auditory feedback leads to more accurate movement timing (Keller et al., 2010) and can affect motor planning (Hatfield et al., 2010). This may be particularly true in the timekeeping segment of trials in the present study, where movement planning is especially critical as the pacing signal is absent.

The correlation between the tap asynchrony (at the probe tone) and judgment correctness further reflects auditory–motor coupling. Since tapping occurs prior to the timing judgment, it is possible that participants are relying to some extent on the timing of their final movement to make a judgment about the timing of the probe tone. For example, smaller tap asynchronies lead to better performance on timing judgment task. Less accurate movement (denoted by a larger tap asynchrony) negatively impacts timing judgments, suggesting that any feedback from movement (either auditory or tactile) may improve perceived timing.

Taken together, these results show that despite the auditory system's capacity for precise temporal processing, movement can further improve judgments about auditory event timing. While auditory feedback from tapping provides a helpful cue, these data suggest it is not essential for improving timing perception. In showing that movement shapes timing perception and now further demonstrating how the auditory information from that movement improves movement quality, we emphasize the bidirectional interactions between auditory and motor systems. Overall the current study sheds light on the interplay between perceived and produced timing, and complements the literature on links between perception and action (Hommel et al., 2001; Prinz, 1997). This study emphasizes the role of movement and specifically motor timing in perception and clearly demonstrates that while auditory feedback may be a useful cue for timing, movement alone can improve timing perception.

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References

Aschersleben, G. (2002). Temporal control of movements in sensorimotor synchronization. *Brain Cogn.*, *48*, 66–79.

Aschersleben, G., & Prinz, W. (1995). Synchronizing actions with events: The role of sensory information. *Percept. Psychophys.*, *57*, 305–317.

Aschersleben, G., & Prinz, W. (1997). Delayed auditory feedback in synchronization. *J. Mot. Behav.*, *29*, 35–46.

Aschersleben, G., Gehrke, J., & Prinz, W. (2001). Tapping with peripheral nerve block: A role for tactile feedback in the timing of movements. *Exp. Brain Res.*, *136*, 331–339.

Chen, Y., Repp, B. H., & Patel, A. D. (2002). Spectral decomposition of variability in synchronization and continuation tapping: Comparisons between auditory and visual pacing and feedback conditions. *Hum. Mov. Sci.*, *21*, 515–532.

Finney, S. A. (1997). Auditory feedback and musical keyboard performance. *Music Percept.*, *15*, 153–174.

Finney, S. A., & Warren, W. H. (2002). Delayed auditory feedback and rhythmic tapping: Evidence for a critical interval shift. *Percept. Psychophys.*, *64*, 896–908.

Fraisse, P., Oléron, G., & Paillard, J. (1958). Sur les repères sensoriels qui permettent de contrôler les mouvements d'accompagnement de stimuli périodiques [On the sensory reference points that allow for controlling movements accompanying periodic stimuli]. *Année Psychol.*, *58*, 332–338.

Franěk, M., Radil, T., Indra, M., & Lánský, P. (1987). Following complex rhythmical acoustical patterns by tapping. *Int. J. Psychophysiol.*, *5*, 187–192.

Furuya, S., & Soechting, J. F. (2010). Role of auditory feedback in the control of successive keystrokes during piano playing. *Exp. Brain Res.*, *204*, 223–237.

Gates, A., Bradshaw, J. L., & Nettleton, N. C. (1974). Effect of different delayed auditory feedback intervals on a music performance task. *Percept. Psychophys.*, *15*, 21–25.

Hary, D., & Moore, G. (1987). Synchronizing human movement with an external clock source. *Biol. Cybern.*, *311*, 305–311.

Hatfield, B. C., Wyatt, W. R., & Shea, J. B. (2010). Effects of auditory feedback on movement time in a Fitts task. *J. Mot. Behav.*, *42*, 289–293.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behav. Brain Sci.*, *24*, 849–937.

Iordanescu, L., Grabowecky, M., & Suzuki, S. (2013). Action enhances auditory but not visual temporal sensitivity. *Psychon. Bull. Rev.*, *20*, 108–114.

Keller, P. E., Dalla Bella, S., & Koch, I. (2010). Auditory imagery shapes movement timing and kinematics: Evidence from a musical task. *J. Exp. Psychol. Hum. Percept. Perform.*, *36*, 508–513.

Kolers, P. A., & Brewster, J. M. (1985). Rhythms and responses. *J. Exp. Psychol. Hum. Percept. Perform.*, *11*, 150–167.

Maduell, M., & Wing, A. M. (2007). The dynamics of ensemble: The case for flamenco. *Psychol. Music*, *35*, 591–627.

Manning, F., & Schutz, M. (2013). "Moving to the beat" improves timing perception. *Psychon. Bull. Rev.*, *20*, 1133–1139.

Mates, J., & Aschersleben, G. (2000). Sensorimotor synchronization: The impact of temporally displaced auditory feedback. *Acta Psychol.*, *104*, 29–44.

Mates, J., Radil, T., & Pöppel, E. (1992). Cooperative tapping: time control under different feedback conditions. *Percept. Psychophys.*, *52*, 691–704.

Pfordresher, P. Q., & Palmer, C. (2002). Effects of delayed auditory feedback on timing of music performance. *Psychol. Res.*, *66*, 71–79.

Phillips-Silver, J., & Trainor, L. J. (2007). Hearing what the body feels: Auditory encoding of rhythmic movement. *Cognition*, *105*, 533–546.

Pollok, B., Müller, K., Aschersleben, G., Schnitzler, A., & Prinz, W. (2004). The role of the primary somatosensory cortex in an auditorily paced finger tapping task. *Exp. Brain Res.*, *156*, 111–117.

Prinz, W. (1997). Perception and action planning. *Eur. J. Cogn. Psychol.*, *9*, 129–154.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychon. Bull. Rev.*, *12*, 969–992.

Stenneken, P., Prinz, W., Cole, J., Paillard, J., & Aschersleben, G. (2006). The effect of sensory feedback on the timing of movements: Evidence from deafferented patients. *Brain Res.*, *1084*, 123–131.

Su, Y.-H., & Pöppel, E. (2012). Body movement enhances the extraction of temporal structures in auditory sequences. *Psychol. Res.*, *76*, 373–382.

Wing, A. M. (1977). Perturbations of auditory feedback delay and the timing of movement. *J. Exp. Psychol. Hum. Percept. Perform.*, *3*, 175–186.

Wing, A. M., Doumas, M., & Welchman, A. E. (2010). Combining multisensory temporal information for movement synchronisation. *Exp. Brain Res.*, *200*, 277–282.