TAPPING TO PITCHED AUDITORY FEEDBACK TONES: EFFECTS OF PITCH CONTOUR AND INTERVAL SIZE ON INTERTAP-INTERVAL AND TAP FORCE

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1. INTRODUCTION

Some auditory perception studies have reported an interaction between pitch contour (the pattern of pitch direction changes over time) and temporal judgment (Boltz, 1998; MacKenzie, 2007). For example, Boltz (1998) presented participants with pairs of isochronous melodies. Comparison melodies were judged to be slower than standards when they contained more contour changes and faster when they contained fewer pitch contour changes. This effect persisted even for melodic pairs in which tempo was actually held constant. These data imply that *contour-preserving* tones are perceived to be shorter in duration than *contour-violating* tones.

The *imputed velocity hypothesis* proposes that change of position between successive stimuli may be perceived as the trajectory of a single moving object (Jones & Huang, 1982). Thus, Boltz (1998) suggests that the effect of pitch contour on tempo perception might reflect the listener's experience with lawful trajectories of moving objects in the world. She cites the example of a land animal. When running a zigzagging (i.e., contour-violating) course, it must *decelerate* when changing directions in order to maintain balance; when running unidirectionally, it may *accelerate*.

We attempted to replicate this interaction in a finger-tapping task. Participants tapped a key at a steady pace. Auditory feedback was provided in the form of a tone that coincided with the end of each tap. Pitch contour of the feedback tones was continuously and randomly varied. We predicted that participants would dynamically respond to task-irrelevant pitch changes by shortening intertap-intervals (ITI) initiated by contour-preserving feedback tones relative to ITIs initiated by contour-violating tones.

In addition to ITI, we analyzed tap force in order to test a "strong" version of the imputed velocity hypothesis: that velocity implied by pitch contour will influence the velocity of participants' taps. Interference effects between stimulus magnitude along a task-irrelevant dimension and motor response magnitude have been previously reported (e.g., Andres et al., 2004). Thus, we predicted greater tap force for ITIs initiated by contour-preserving tones relative to ITIs initiated by contour-violating tones.

The magnitude of frequency separation between successive tones (Δf) was varied *between* trials. Previous studies have demonstrated that Δf is associated with spatial extent in the listener. For example, in a 2AFC speeded response task, Kadosh et al. (2008) found a response compatibility effect on reaction time between Δf and the spatial separation between response keys. We predicted that the magnitude of ITI acceleration would covary with Δf because, according to the imputed velocity hypothesis, at a steady pace greater contour-preserving Δf implies greater velocity.

2. METHOD

35 undergraduates (28 females) from Macquarie University participated for course credit. Average age was 22.0 (SD = 4.9). Number of years of individual music lessons ranged from 0 to 10 (M = 1.74; SD = 2.66).

Feedback tones were 250 ms sine tones. There were five conditions: monotone, 25, 50, 150, and 350 cents Δf. For the monotone control condition, the feedback tone was C5 (523.25 Hz). For each pitched condition, tones were a fixed Δf apart; tones 1 and 2 and tones 4 and 5 were above and below C5 (tone 3), respectively. Sequences began on any of the five tones and randomly ascended and descended stepwise (e.g., tone 2, 1, 2, 3, 4, 3, etc.). Pitch range of sequences covaried with Δf and was equal to four times Δf.

Participants heard feedback through headphones and tapped the highest key on a MIDI keyboard with their index finger. They were instructed to maintain contact between their fingertip and the key and to give an equal weight to all taps. It was stressed that the goal was to maintain a steady beat at the rate provided by the pacing signal and that any variation in pitch between feedback tones should be disregarded. Setting the output parameter to a fixed value eliminated variation in feedback tone intensity between taps. We used the continuation tapping task (Stevens, 1886). For each trial, participants synchronized their taps with the pacing signal (15 ms ticks with 500 ms IOI) for 20 taps after which the sound of the pacing signal stopped and was replaced by feedback tones. Participants continued to tap at the tempo set by the pacing signal until the end of the trial (30 additional taps). There were 35 trials in seven blocks, with each block consisting of one trial for each condition. Order of trials within a block was randomized. The task took approximately 30 minutes.

Only the final 25 continuation ITIs of each trial were subjected to analysis. These were defined as the time difference between MIDI "note on" events registered when the key contacted the key bottom. Tap force values were read from MIDI velocity data for each "note on" event in arbitrary units from 1 to 127. Preliminary analysis ruled out the *absolute* pitch height of feedback tones (which was not held constant between conditions) as a factor in mean ITI.

3. RESULTS

As there were no learning effects, ITIs from each trial were pooled by Condition (7 trials x 25 ITIs per trial = 150 ITIs per participant for each of the 4 pitched conditions). ITI_n values were classified according to the pitch direction of the feedback tones initiating both ITI_{n-1} (Previous Tone Direction) and ITI_n (Current Tone Direction). For example, AA means ascending contour-preservation; AD means a descending contour-violation at the onset of ITI_n.

Mean ITI values according to Condition, Previous Tone Direction, and Current Tone Direction were entered into a 4 x 2 x 2 repeated measures ANCOVA with Years of Training as covariate. A main effect of Current Tone Direction, $F(1,33) = 5.89$, $p < .02$, was qualified by a Current Tone Direction x Previous Tone Direction interaction, $F(1,33) = 8.22$, $p < .01$. Post hoc analysis revealed that, as expected, contour-preserving ITIs were accelerated relative to contour-violating ITIs (AA < AD, $p < .02$; DD < DA, $p < .01$; AD = DA, $p < .17$, N.S). When analyzed separately by condition, this interaction did not remain significant at 25 cents Δf In addition, descending contour-preserving ITIs were unexpectedly accelerated relative to ascending contour-violating ITIs (DD < AA, $p < .02$). There was also a main effect of Condition, $F(3,99) = 6.50$, $p < .001$. Post hoc analysis revealed a significant linear contrast, $F(1,34) = 18.25$, $p < .001$, indicating mean ITI negatively covaried with Δf There were no significant interactions with Years of Training. Mean ITI values by contour and condition are displayed in Figure 1.

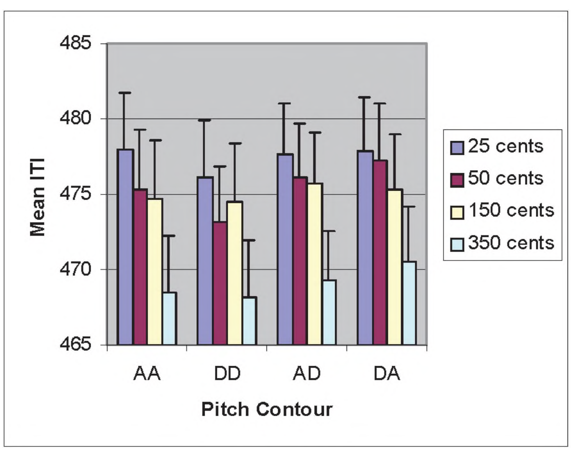

Figure 1. Mean ITI values by pitch contour and condition.

Mean tap force values according to Condition, Previous Tone Direction, and Next-to-Previous Tone Direction were entered into a 4 x 2 x 2 repeated measures ANCOVA with Years of Training as covariate. Only the Previous Tone Direction x Next-to-Previous Tone Direction interaction was significant, $F(1,33) = 12.684$, $p < .01$. Post hoc analysis revealed that, as expected, taps had greater force following a contour-preserving tone (AA < AD, $p < .04$; DD < DA, $p < .001$; DD = AA, $p < .28$, N.S; AD = DA, $p < .19$, N.S). At 25 cents Δf, this interaction did not remain significant. We speculate that the inconsistencies between mean ITI and tap force findings for 1) linear effect of Δf and 2) directional asymmetry for contour-preserved tones might reflect smaller tap force effect sizes and the limited sensitivity of the apparatus to detect tap force variation.

Finally, we investigated whether the accumulation of accelerating ITIs would result in an accelerating tempo over the course of a trial. The slope of the linear regression of ITI against tap number was calculated for each participant's 35 trials. Slope values averaged across the seven trials of each condition significantly deviated from zero except in the monotone condition. Means for pitched feedback conditions were all negative, indicating accelerated ITI with increasing tap number. Slope values were entered into a repeated measures ANOVA and revealed a significant main effect of Condition, $F(4,132) = 15.25$, $p <.001$. Acceleration over the course of a trial increased with Δf, $F(1,33) = 38.3$, $p < .001$.

4. DISCUSSION

As predicted, when initiated by contour-preserving tones, intertap-intervals (ITI) were accelerated and of greater tap force relative to ITIs initiated by contour-violating tones. Contour-preserving ITI acceleration 1) was initiated rapidly (within ~500 ms); 2) did not vary with years of music training; 3) persisted with Δf of 50 cents or greater; 4) increased in magnitude with greater Δf, and 5) persisted over the course of a trial, the cumulative effect being an increase in tempo. An unexpected finding was that descending contour-preserving ITIs were significantly accelerated relative to ascending contour-preserving ITIs. These data support a strong version of the imputed velocity hypothesis, suggesting that participants were unable to disambiguate increases in velocity implied by pitch contour from the velocity of their finger trajectory.

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