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Hear it playing low and slow: How pitch level differentially influences time perception

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ABSTRACT

Variations in both pitch and time are important in conveying meaning through speech and music, however, research is scant on perceptual interactions between these two domains. Using an ordinal comparison procedure, we explored how different pitch levels of flanker tones influenced the perceived duration of empty interstimulus intervals (ISIs). Participants heard monotonic, isochronous tone sequences (ISIs of 300, 600, or 1200 ms) composed of either one or five standard ISIs flanked by 500 Hz tones, followed by a final interval (FI) flanked by tones of either the same (500 Hz), higher (625 Hz), or lower (400 Hz) pitch. The FI varied in duration around the standard ISI duration. Participants were asked to determine if the FI was longer or shorter in duration than the preceding intervals. We found that an increase in FI flanker tone pitch level led to the underestimation of FI durations while a decrease in FI flanker tone pitch led to the overestimation of FI durations. The magnitude of these pitch-level effects decreased as the duration of the standard interval was increased, suggesting that the effect was driven by differences in mode-switch latencies to start/stop timing. Temporal context (One vs. Five Standard ISIs) did not have a consistent effect on performance. We propose that the interaction between pitch and time may have important consequences in understanding the ways in which meaning and emotion are communicated.

1. Introduction

Our ability to perceive the passage of time is a cognitive process critical to our interactions with the environment and with others (Agostino, Peryer, & Meck, 2008; Bays, Foley, & Zabrucky, 2013; Buhusi & Meck, 2005; Conway, 2004; Meck, 2003, 2005; Meck, Doyère, & Gruart, 2012). Timing can be particularly important in conveying meaning and emotion in both speech (Cutler, Dahan, & van Donselaar, 1997; Juslin & Laukka, 2003; Murray & Arnott, 1993) and music (Juslin, 2000; Juslin & Laukka, 2003; Webster & Weir, 2005). Changes in pitch are also important in emphasizing meaning and conveying emotion (Juslin, 2005; Scherer, Johnstone, & Klasmeyer, 2003), however; the perceptions of time and pitch in music are generally studied independently (Allman, Teki, Griffiths, & Meck, 2014; Griffiths, 2012; Krumhansl, 2000). This may be due, in part, to double dissociations in performance on pitch and timing tasks within neuropsychological populations (Di Pietro, Laganaro, Leemann, & Schnider, 2004; Hyde & Peretz, 2004), as well as to neural dissociations in healthy participants (Jerde, Childs, Handy, Nagode, & Pardo, 2011). Such findings suggest that pitch and time perception rely on independent systems.

Nevertheless, the perceptions of pitch and time do interact behaviorally (Arvanti, 2009; Boltz, 1998; Henry & McAuley, 2009; Krumhansl, 2000; Lebrun-Guillaud & Tillmann, 2007; Schellenberg, Krysciak, & Campbell, 2000). For instance, higher pitched tones are overestimated in duration compared to lower pitched tones (Brigner, 1988; Cohen, Hansel, & Sylvester, 1954; Matthews, 2013). On the other hand, empty intervals are judged as *shorter* than a standard interval when the comparison intervals are flanked by at least one higher frequency tone and are judged as *longer* when flanked by at least one lower frequency tone (Pfeuty & Peretz, 2010). While such interactions between pitch and timing have been observed, studies have not identified the psychological mechanisms, according to standard models of time perception, that underlie these temporal distortions. As these interactions might enhance the communicative value of auditory signals, characterizing the mechanisms of resulting distortions and understanding if and how they might be modulated is of considerable interest.

The information-processing model of scalar timing theory outlines psychological processes underlying time perception and makes specific quantitative predictions for how distortions at each processing stage

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should affect temporal estimates. Scalar timing theory incorporates clock, memory, and decision stages into its information-processing architecture (Gibbon, Church, & Meck, 1984; Hinton & Meck, 1997; van Rijn, Gu, & Meck, in press). Briefly, this model proposes that at the onset of a stimulus to be timed a switch closes, allowing pulses to be emitted from a pacemaker at a certain rate and collected in an accumulator. At the offset of a signal, the switch opens and the number of pulses collected in the accumulator is compared to durations stored in memory to determine whether the timed duration is longer or shorter than remembered intervals. This model typically attributes within-trial distortions in time perception and timed performance to either changes in the rate of a pacemaker or the flow of pulses emitted by a pacemaker through a mode switch into an accumulator (Lejeune, 1998; Meck & Benson, 2002). These two components of the clock stage are, thus, of particular interest here.

Changes in the rate of the pacemaker shift psychometric timing functions either to the left (a relative increase in clock speed) or to the right (a relative decrease in clock speed), with a magnitude proportional to the standard interval being timed (Coull, Cheng, & Meck, 2011; Lake & Meck, 2013; Meck, 1983, 1986, 1996, 2006). Alternatively, distortions influencing the behavior of the mode switch, which controls the flow of pulses from the pacemaker to an accumulator by alternating between an open and a closed state, can result in proportional or additive distortions across durations, depending on the nature of the change in switch activity. Attention is thought to modulate mode-switch activity (Buhusi & Meck, 2009; Fortin et al., 2009; Lake & Meck, 2013; Meck, 1984; Penney, Holder, & Meck, 1996). If attentional resources are divided throughout the timing of a stimulus, the mode switch is said to 'flicker' between an opened and a closed state (Lui, Penney, & Schirmer, 2011; Lustig & Meck, 2001, 2011; Penney, Allan, Meck, & Gibbon, 1998; Penney, Gibbon, & Meck, 2000). Flickering of the mode switch would result in temporal distortions that, like changes in pacemaker rate, are proportional to the duration of the stimulus being timed. On the other hand, the *latency* with which the mode switch closes, allowing pulses to pass through to the accumulator to start the timing process, as well as the latency with which the mode switch opens to stop the accumulation process, can be modulated. Latency effects are independent of stimulus duration, resulting in distortions of temporal estimates that are additive, rather than proportional, across stimulus durations (Gibbon & Church, 1984). In other words, functions are shifted by a relatively fixed value regardless of the stimulus duration being timed. It should be noted that while differences in start/stop latencies bias temporal estimates, these differences should not affect temporal sensitivity (Gibbon & Church, 1984).

In order to determine whether pitch levels influence time perception as a result of changes in pacemaker rate/'flickering' switch activity or mode-switch start/stop latencies, the nature of the temporal task employed must be taken into consideration. In an ordinal comparison procedure (Gu & Meck, 2011), participants compare a comparison stimulus, which varies in duration across trials, to a standard stimulus, which generally has a fixed duration equal to the geometric or arithmetic mean of the distribution of comparison durations. On each trial, participants judge whether the comparison stimulus is 'longer' or 'shorter' in duration than the standard stimulus. Using this procedure often results in timing functions with floor and ceiling effects at anchor comparison durations, as these comparisons are often simple discriminations. As such, assessing whether shifts in timing functions across comparison durations are additive or proportional within a single duration range is usually difficult. In this study, we consider the magnitude of temporal distortion at the point of subjective equality (PSE) across multiple duration ranges to test for underlying mechanisms of temporal distortion (Droit-Volet, Meck, & Penney, 2007; Grommet et al., 2011; Merchant, Harrington, & Meck, 2013).

In the current study, we were also interested in whether or not the magnitude of pitch level-induced temporal distortions could be modulated. Specifically, we hypothesized that the features of the preceding temporal sequence might influence pitch-related distortions in time perception, which would suggest that pitch-related distortions of time are flexibly shaped by their temporal context. Information-processing models of interval timing suggest that repeated presentations of a single duration build up a stronger memory representation of that duration and result in higher temporal sensitivity (Drake & Botte, 1993; Pashler, 2001). We suggest that increased temporal sensitivity might be accompanied by enhanced attention to timing at the expense of non-temporal features of an auditory sequence (Buhusi & Meck, 2009; Buhusi, Sasaki, & Meck, 2002). If attention to pitch is reduced by temporal repetition, latencies to start/stop timing empty intervals flanked by tones of differing pitch might normalize toward the latencies of the repeated interval. If start/stop latencies are responsible for pitch-related distortions of time perception, then temporal repetition might reduce such distortions.

The goals of the present study were to 1) characterize the influence of different pitch levels on temporal estimates, 2) to assess the underlying psychological mechanisms for resulting temporal distortions based on quantitative predictions made by interval timing models for how pacemaker/accumulator versus mode-switch latency distortions should manifest across multiple standard ISI durations and 3) to determine whether temporal repetition might modulate the magnitude of such pitch-induced temporal distortions. We expected our results to support previous evidence of a differential effect of higher versus lower pitches on the perception of interval durations (Pfeuty & Peretz, 2010). Of specific interest here was how the *magnitude* of this effect would change across multiple ISI durations. A proportional effect across increasing standard ISI durations would lend support to a pacemaker/accumulator mechanism that varied in the rate of temporal integration (Meck, 1983, 1996), while a decrease in the magnitude of the effect with increasing standard ISI durations would support a mode-switch latency effect (Buhusi & Meck, 2006; Lejeune, 1998; Meck, 1984). We further predicted that the magnitude of the pitch-level effect would be modulated by temporal repetition, i.e., the number of standard ISIs preceding the final interval (FI), such that temporal repetition would reduce pitch-related biases in temporal estimates. We addressed these hypotheses across two experiments. In Experiment 1, we tested the effect of two different standard ISI durations (300 vs. 600 ms) and the influence of temporal repetition (One vs. Five Standard ISIs). To more conclusively determine the mechanism of distortion, as well as to assess the generalizability of the pitch-level effect across sub-second and supra-second duration ranges, we tested a separate group of participants on a third standard ISI (1200 ms) condition in Experiment 2.

2. Experiment 1

In Experiment 1, we examined whether or not higher and lower flanker tone pitch levels would differentially influence the perceived duration of a FI. We were specifically interested in whether the magnitude of such an effect would remain constant across standard ISI durations or would be proportional to the duration of the standard ISIs being tested. The former would support a mode-switch latency effect while the latter would imply a pacemaker-like mechanism (Lustig & Meck, 2011; Meck & Church, 1983; Meck, Church, & Gibbon, 1985; Penney et al., 2000). Additionally, we assessed if increasing the number of standard ISIs presented prior to the FI to be timed could reduce the magnitude of pitch-related distortion.

2.1. Method

2.1.1. Participants

Forty-six healthy adults participated in this experiment. One participant was removed from analyses due to fatigue and four participants were excluded for poor timing discrimination, such that logistic functions could not be properly fit to individual participant timing data, leading to a final sample size of 41 (20 males, 21 females; 18–40 years,