Higher is Faster: Pitch Register and Tempo Preferences

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While determining an appropriate tempo is crucial to music performers, composers and listeners, few empirical studies have investigated the musical factors affecting tempo choices. In two experiments we examined how aspects of musical pitch affect tempo choice, by asking participants (musically trained and untrained) to adjust the tempi of melodic sequences varying in pitch register and pitch direction, as well as sequences typically associated with specific registers in common period music. In Experiment 1, faster tempi were assigned to higher registers. Specific melodic direction (rise vs. fall) did not affect tempo preferences; nevertheless, pitch change in both directions elicited faster tempi than a repeating, unchanging pitch. The effect of register on tempo preference was stronger for participants with music training, and also (unexpectedly) for female participants. In Experiment 2, melodic figures typically related to lower and higher parts in common-period music were associated with slower and faster tempi, respectively. Results support a "holistic" notion of musical tempo, viewing the choice of proper tempo as determined by interactions among diverse musical dimensions, including aspects of pitch structure, rather than by rhythmic considerations alone. The experimental design presented here can be further applied to explore the effects of other musical parameters on tempo preferences.

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Determining a Preferred, "Proper" tempo for a piece of music is crucial to performers, composers, and listeners alike. For performing musicians, defining the tempo of a piece is a critical interpretive act (particularly in music preceding the invention of Meltzel’s metronome in the early 19th century, where exact tempo is not specified by the composer), affecting not only the piece’s general character but important aspects of performance detail such as expressive timing and melodic ornamentation (Desain & Honing, 1994; Honing, 2006). Treatises and textbooks concerning music performance thus dedicate detailed discussions to the issue of determining the "right" tempo in a performed piece (e.g., Jordan & O’Regan, 2008). Tempo choice is also central for composers and listeners. Contemporary composers often meticulously suggest precise tempi and tempo changes for each segment in a composition. In Eliot Carter’s music, for instance, tempo “modulations,” precisely marked in the score, serve central structural functions (Bernard, 1995), and in recent “New Complexity” music, minor agogic fluctuations are embedded into the notation by the use of complex rhythmic ratios (e.g., Clarke, Cook, Harrison, & Thomas, 2005; Ferneyhough, 1995). Tempo choice also seems important in listeners’ aesthetic evaluation of music. Though no empirical study investigating the relationship of tempo choice and listeners’ evaluation of music performance is known to us, criticisms of inappropriate tempo choice abound in concert reviews and among concert-goers.

Musicians and music scholars have suggested that “correct” tempo is subtly associated with a variety of musical dimensions. Thus, Epstein (1995, p. 99) states that, “Tempo is a consequence of the sum of all factors within a piece – the overall sense of a work’s themes, rhythms, articulations, “breathing,” motion, harmonic progressions, tonal movement, contrapuntal activity . . . Tempo . . . is a reduction of this complex Gestalt into the element of speed per se, a speed that allows the overall, integrated bundle of musical elements to flow with a rightful sense.”

How do musical dimensions affect tempo preferences? While some aspects associated with tempo perception have been investigated empirically, the factors affecting tempo preferences, their vital role in music notwithstanding, have been all but neglected. As discussed below (pp. 7-9), preferences (e.g., a hypothetical tendency to choose faster tempo for higher-pitched melodies) cannot simply be deduced from perceptual biases (e.g., a tendency to perceive higher-pitched melodies as faster; Boltz, 2011). Moreover, even for tempo perception, studies have largely concentrated on temporal variables...
such as event density (Madison & Paulin, 2010), temporal predictability (McCauley & Kidd, 1998), and expressive timing (Honing, 2006). Less attention has been given to possible effects of dimensions such as pitch, intensity, and timbre on the perception of tempo. The present study examines some of the musical factors that may affect listeners’ preferences of musical tempo, focusing on “non-temporal” dimensions, particularly melodic features such as pitch register, pitch direction, and pitch intervals.

**TEMPO AND PITCH REGISTER**

A central concern of this study is the relationship of preferred tempo and pitch register. Specifically, we examine whether a higher pitch register is associated with preferences for faster tempo. Western music and its theory exemplify this tempo-register correlation in different ways. Thus, lower voices in Western music commonly move at slower rates, and idiomatic writing for higher pitched instruments tends to be faster than that for lower-pitched instruments (Broze & Huron, 2013). Correspondingly, a relationship of tempo (or rhythmic pace) and register has been observed and speculated upon by music theorists since the 16th century. Prominent 16th century theorists, including Giuseppe Zarlino, Girolamo Mei and Vincenzo Galilei, have addressed this relationship (Galilei, 1581/2003, pp. 200-203; Palisca, 2006, pp. 188-189; Zarlino, 1558/1983, p. 178). Zarlino’s cross-dimensional ideas are based upon the traditional four elements, and are closely tied to Plato’s ideas of art as a mimetic form of real life. Mei, and following him Galilei — both associated with the Florentine Camerata — base their theory on oration, rhetoric, and affect. Notably, while providing very different theoretical frameworks, all three theorists agreed on the positive correlation between higher pitch and faster tempo or pace. In the 20th century, composers such as Henry Cowell (1930/1996) and Karlheinz Stockhausen (1959) relied on modern acoustics in proposing a conceptual (though not necessarily perceptual) analogy between pitch and tempo. They observed that beats and pitches both arise from periodic vibrations, the one giving way to the other at around 20-25 Hz. Thus, in a sense, faster tempo is higher pitch (see Russo & Jones, 2007, for a relevant perceptual study, manipulating pulse rate to span the continuum from beat to pitch).

In line with the above observations, a number of auditory perception studies, some using musical stimuli, suggest that pitch register indeed affects tempo perception, such that higher pitch is associated with faster tempo. In two experiments concerning speech perception, vocal frequency and intensity were found to have influenced the perception of speech rate (both separately and jointly), which was perceived as faster as frequency and intensity rose (Feldstein & Bond, 1981). A corresponding relationship was also found in an experiment using a Stroop-like paradigm (Walker & Smith, 1984), in which the words “fast” and “slow” (among others) accompanied by high or low pitch (5,500 and 50 Hz) were presented to participants, who were then asked to respond rapidly to the words. Results revealed Stroop interference, as it took longer for participants to identify the word “slow” when it was accompanied by a high pitch sound than when it was accompanied by a low pitch sound; similarly, the word “fast” was identified faster when accompanied by a high pitch sound. A comparable association of high pitch register with the verbal designation “fast” was found in rating tasks involving actual music (segments from Beethoven’s piano sonata Op. 111 and Bach’s Goldberg Variations) in higher and lower pitch registers (Adler & Eitan, 2012; Eitan & Timmers, 2010). Similarly, Collier and Hubbard (2004) observed an interaction between pitch register and tempo, such that accelerations were perceived as faster in higher pitch registers, and decelerations were perceived as slower in lower registers. Finally, in a recent study participants judged high-pitch melodies as faster than lower comparison melodies (Boltz, 2011).

Correspondingly to the association between higher pitch and faster tempo, ascending melodies were associated with faster or increasing tempi. Boltz (2011, Experiment 2) found that ascending melodies are judged as faster than descending ones. Eitan and Granot (2006), in a music-induced imagery task, found a similar association between pitch rise and visuospatial acceleration (also see Eitan & Tubul, 2010, for a replication involving children). Notably, their studies demonstrated directional asymmetry: though pitch rise is strongly associated with acceleration, pitch fall is not associated with deceleration. The association of speed and pitch, they suggest, may be grounded in environmental experience: larger objects, which generate lower frequency sounds, are also associated with slower motion. A similar directional asymmetry has also been found by Matthews (2013). Using segmented short intervals as stimuli in a duration judgment task, Matthews found that the interaction between the interval’s inner divisions and its estimated overall duration is more pronounced for ascending pitch sequences than descending ones.

Recently, Lake, LaBar, and Meck (2014) have found that an increase in a stimulus’ flanker tone’s pitch level resulted in an underestimation of the duration of a following silent interval. They proposed that different
pitch levels attract differing levels of attention, and consequently influence latencies of the onset and offset of timing mechanisms.

**TEMPO AND OTHER MELODIC FEATURES**

During the nineties, Boltz and associates conducted a systematic investigation of the effects of melodic features on tempo and duration estimations (Boltz, 1991, 1993, 1995, 1998; Boltz & Schmuckler 1994). These experiments showed that melodies are judged to unfold more slowly when they comprise more changes in pitch direction and larger pitch intervals. In addition, the judged duration of a sequence may be over or underestimated depending on whether the melody is manipulated to direct attention to lower or higher order patterns. Musical sequences that were filled with regularly timed information and that ended predictably were judged most accurately. Furthermore, when a melody’s structure was obscured by prolonging tones to conflict with phrase boundaries, time estimates were less accurate and more variable, and durations were consistently overestimated. Ammirante and associates (Ammirante & Thompson, 2010; Ammirante, Thompson, & Russo, 2011) used a continuation-tapping paradigm to investigate whether melodic features associated with tempo perception also affect action. In line with Boltz’s perceptual findings, they found that tapping rate decelerates following a decrease in melodic distance, and accelerates following increase in melodic distance. Tapping rates also decelerated following contour changes, and accelerated when melodic direction was preserved. Ammirante and his associates interpreted results as reflecting perception-motion coupling, such that changes in tapping pace reflect analogous situations in bodily motion (e.g., change of motion direction necessitates slowing down).

**PERCEPTION VS. PREFERENCE**

While the studies surveyed above examine perceptual correspondences between tempo and melodic features, here we examine how melodic features affect tempo preferences, asking participants to determine the subjectively appropriate tempi for stimuli varying in features such as pitch register and pitch direction.

Obviously, human preferences are strongly linked with perceptual constraints and biases. For instance, preference for “prototypical” or symmetrical shapes has been explained in terms of facilitation of perceptual processing (Winkielman, Halberstadt, Fazendeiro, & Catty, 2006). However, preferences cannot be directly and unequivocally inferred from corresponding findings regarding perception. A wealth of studies in domains as diverse as language processing (utilizing word priming paradigms; Huber, Shiffrin, Lyle, & Ruys, 2001) decision-making (e.g., Tversky & Kahneman, 1981), or body self-image (Farrell, Lee, & Shafrazi, 2005; Mohr et al., 2010) indicate that preferences interact with perceptual, cognitive, and emotional factors in complex and not easily predictable ways. Preferences may correlate with perceptual biases positively (as, e.g., in preferences for symmetrical shapes) or negatively (e.g., overestimation of bodily size is associated with preference for thin body shape; Fallon & Rozin, 1985; Mohr et al., 2010). Even given the same stimuli and experimental design, task modifications may completely reverse preferences. For instance, passive vs. active processing of visual (orthographic and semantic) primes engender contrasting preferential tendencies in target stimuli (Huber et al., 2001). Nevertheless, perception and preference are often blurred in the music perception literature. Kopiez (2004), for instance, notes that results from a discrimination task using the same head-turn paradigm were interpreted in one case only in perceptual terms (Lynch, Eilers, Oller, & Urbano, 1990) and in another in preferential terms (Schellenberg & Trehub, 1996).

With regard to the present topic, one should not automatically infer from a perceptual correspondence of tempo and a melodic feature (e.g., melodies higher in pitch are perceived as faster, Boltz, 2011) that listeners would necessarily prefer comparable associations (i.e., choose faster tempi as more appropriate for higher-pitched melodies). Rather, contrasting hypotheses may be raised concerning such relationships. On the one hand, one may predict that tempo preferences would correspond with the perceptual bias (i.e., participants would indeed prefer faster tempi for higher-pitched melodies), since both are generated by exposure effects; that is, the correlation of higher pitch and faster tempo (or higher event density) in music and in other domains of auditory experience (Broeze & Huron, 2013) may generate both perceptual correspondences of tempo and pitch height and aesthetic preferences for a higher-faster coupling.

On the other hand, one may predict that tempo preferences would negatively correlate with perceptual biases (i.e., participants would prefer slower tempi for higher-pitched melodies). This may be the case if participants select perceptually equivalent tempi for higher- and lower-pitched melodies, compensating for the perceptual bias. Since a higher-pitched melody would be perceived as faster than an equivalent lower-pitched melody, participants may choose a slower objective tempo for the former, thus producing equivalent
subjective tempi (comparably to psychophysical matching tasks, e.g., Stevens, 1975).

The Present Study: General Design and Hypotheses.

As our survey indicates, perceived musical tempo is associated with pitch register, as well as other melodic features, such as pitch contour and pitch intervals. However, no study so far has directly examined how melodic variables, pitch register in particular, affect listeners’ and performers’ tempo preferences. Given the importance of “proper” tempo choice for musicians and listeners, a systematic investigation of the way melodic features affect the sense of tempo appropriateness for music is called for.

This study begins such an investigation, presenting two experiments in which participants adjusted the tempo of short melodic stimuli to a subjectively appropriate tempo. Note that rather than passively rating tempo appropriateness, participants actively adjusted stimuli’s tempi, repeatedly examining the results, until a subjectively satisfactory tempo was attained. Both experiments examined the effect of pitch register on preferred tempo, hypothesizing (in line with previous music theory and empirical research) that higher pitch register would be associated with faster preferred tempo.

In addition to pitch register, Experiment 1 examined the effect of pitch direction (up, down, or level) on tempo preferences. Some recent research (Boltz, 2011) suggests an association between pitch direction and tempo perception, such that rising contours sound faster than falling contours. Friberg (1991) has suggested a generative rule for music performance in which the duration of a tone should be shortened if preceding tone is lower and following tone is higher. Other studies, however, are equivocal (Ammirante et al., 2011; Eitan & Granot, 2006). The effect of pitch direction on tempo preference, and its interaction with pitch register, are thus in need of empirical investigation.

In Experiment 2 we examined (in addition to pitch register) the effect of prototypic melodic patterns on listeners’ tempo preferences, hypothesizing that melodic patterns commonly associated in Western music with higher-pitched instruments or upper melodic parts would suggest faster preferred tempi.

Both experiments use a factorial design. In Experiment 1, combining two distinct pitch registers (octaves 1-2 vs. octaves 6-7), three pitch directions (ascending, descending, and level), and three initial tempi resulted in 18 unique stimuli presented to participants. In Experiment 2, the 18 stimuli combined the two registers, three initial tempi, and three melodic patterns (two prototypic patterns, associated with low and high melodic parts, and a control, consisting of repeated equidurational tones). This design enables us to examine systematically possible interactions among the musical variables. For instance, we may thus examine whether pitch register influences the effect of pitch direction (up vs. down) on tempo preferences (see Granot & Eitan, 2011, for a comparable interaction concerning perceived musical tension).

We also examined the effect of music training on tempo preferences. We assume that musicians are more likely than nonmusicians to be exposed to music in more active ways, such as music performance. Such active exposure to music is more inherently multimodal than passive listening, and may afford the development of higher sensitivity to correlating parameters. Music training may also contribute to a more nuanced conceptualization of music (manifest, for instance, in critical listening), which may also enhance sensitivity to musical detail. We hypothesized accordingly that participants with music training would exhibit stronger preferences for faster tempi in higher pitch ranges, and for slower tempi in lower ranges. We also hypothesized (Experiment 2) that participants with music training would be more sensitive to the registral associations of prototypic melodic patterns.

To sum up, we suggest the following hypotheses:

1. **Melodic Register Cross-Dimensionality Hypothesis**: Higher pitch registers would be associated with faster preferred tempi, as compared to lower registers (Experiments 1 & 2).

2. **Pitch Direction Cross-Dimensionality Hypothesis**: Ascending pitch contours would be associated with faster preferred tempi, as compared to level and descending contours (Experiment 1).

3. **Repertory Association Hypothesis**: Prototypical upperline patterns would be associated with slower preferred tempi, compared to both prototypical bass-line patterns and control (Experiment 2).

4. **Training Enhancement Effect Hypothesis**: The above effects will be stronger for participants with music training.

5. **Initial Tempo Anchoring Bias Hypothesis**: The faster the initial tempo of the stimulus is, the faster the final choices of preferred tempo would be.

A SHORT DESCRIPTION OF TASK AND PROCEDURES FOR BOTH EXPERIMENTS

Three pitch patterns (consisting of a “control” stimulus and two contrasting experimental stimuli) were
presented to participants in random order, each pattern in two different pitch registers (high, low) and three different tempi (slow, moderate, fast). Participants’ task was to choose their tempo of preference for each stimulus. The experiments were conducted on two PC stations, using customized software. The stimuli’s tempo could be changed by a mouse-controlled slider on screen, as well as played back by pushing a “Playback” button. The participants indicated their final tempo choice by pushing a “Final” button. The task was self-paced, with unlimited time or number of trials per stimulus.

Experiment 1

METHOD

Participants. Sixty-seven Tel Aviv University students and staff, aged 18–58 (mean age = 26.3 years; SD = 7.4), 37 males and 30 females, took part in the experiment. Thirty-five participants (musicians) had at least seven years of music training or playing an instrument (M = 14.86, SD = 6.6, range = 7–46); 27 out of the 35 musicians were pursuing an academic degree in music at the time of the experiment. The remaining 33 nonmusicians had little or no music training. (M = 0.83, SD = 1.67, range = 0–6); 24 of the nonmusicians had not received any music training or played an instrument (for Sex X Musical Training crosstabulation, see Table 1). All participants reported normal hearing. Participants were paid 20 NIS (about $5) for their participation.

Musical Stimuli. We used eighteen stimuli (see Figure 1), consisting of all combinations (3 x 3 x 2) of three short monophonic (unaccompanied) pitch patterns, each set in one of three initial tempi and in one of two pitch registers.

Initial tempi. To address possible anchor biases caused by the tempo in which the stimulus is first presented to participants, each stimulus was presented in three different initial tempi: slow (60 BPM), moderate (90 BPM), and fast (135 BPM). The moderate value of 90 BPM is within the range of the maximal pulse salience (Parncutt, 1994). The tempo values represent gradual incremental steps of 50%. Thus, the moderate tempo is a 50% increase from the slow tempo, and the fast tempo is a 50% increase from the moderate tempo. Note that all the chosen initial tempi are common in Western art music, and could be roughly referred to as Largo, Andante, and Allegro.

Pitch registers. The pitch registers for the stimuli were chosen to be distinctly high and low, yet within the range of the piano and orchestral instruments. The low register was set as A, to D, - within the range of double basses, tubas, contrabasses, and importantly - the piano, whose midi sound was used in the experiment. Meanwhile, the high register was set as A, to D, (C, = middle C), within the instrumental range of instruments such as flute (both regular and piccolo), violin, and piano.

Pitch contours. All pitch contour patterns were seven equidurational notes long. Contour patterns differed in terms of pitch direction (ascending, descending, and level). The control melody in this experiment was a repeating tone (A, in the low register, and A, in the high register). The contours under the experimental condition comprised of ascending and descending chromatic scales. Chromatic scales were chosen since they suggest no subgroupings or hierarchical representations, and thus minimize the interference of implied musical meter or tonal hierarchy. The pitch range for each of the scales was identical: In the low register, the ascending scale started at A, and ended at D, while the descending scale started at D, and ended at A,. In the high register, the ascending scale started at A, and ended at D, while the descending scale started at D, and ended at A,.

All stimuli were created with a general MIDI grand piano sound; with uniform articulation (80% of the IOI - what may be referred to as détaché in musical terms); and with equal intensity.

The duration of the stimuli ranged from slightly more than 3 s for the fastest initial tempo (135 BPM) to 7 seconds for the slowest initial tempo (60 BPM).

Task and Procedure. Stimuli were generated and responses recorded by a PC-running customized software (programmed in VB), installed on two stations (a standard PC, and an Averatec AV3225HS laptop, both with operating system Windows XP), and delivered over a set of noise attenuating headphones (Clark 10S-DC) in a quiet room.

Since perceived loudness is influenced by pitch register and varies widely among individuals (Fletcher & Munson, 1933; International Organization for Standardization, 2003), the experiment’s software recalibrated the loudness levels individually for each participant in each register, so that the registers were perceived as equally loud (see Appendix B for more details).

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<th>TABLE 1. Experiment 1: Sex x Music Training Crosstabulation</th>
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Participants were instructed to adjust the tempo of each item to the most appropriate and natural tempo according to their individual taste. The visual interface for all stimuli was identical, and consisted of a mouse-controlled button on a horizontal slider, as well as a “Playback” and a “Final” button. In order to avoid visual biases, the slider was designed so that the button’s starting position was always at the middle, regardless of the stimulus’s initial tempo value. The opposite ends of the slider were verbally anchored as “slow” and “fast.” The scale was built to conform to Weber’s law of perception, with linear steps on the screen resulting in logarithmic changes of tempo in the playback, and with a single step’s change corresponding to 2% of the current tempo value, which was chosen to be smaller than the commonly found Tempo-JND thresholds (e.g., Friberg & Sundberg, 1995). The upper and lower tempo bounds were kept constant through the use of dummy sections in both ends of the scale. Being relatively small, the dummy sections were not reported as noticeable by participants in a pilot run as well as during the experiment itself (for more information on the slider, see Appendix A). The participants controlled the stimulus’s tempo by moving the slider’s button to either side, and could listen to their choices by pressing the “Playback” button. The experiment was self-paced, limited neither in time nor in the number of iterations. Upon reaching a tempo of preference, participants were required to

FIGURE 1. The melodic patterns in Experiment 1.
press the “Final” button. They were consequently given the option to comment on their choice before moving on to the next stimulus. A white-noise masking of 2 s was presented between consecutive stimuli. Although sessions were not limited in duration, they seldom lasted more than 15 min.

Each session consisted of 18 experimental trials, each involving one of the 18 different stimuli in the factorial matrix. Participants could adjust the tempo of each stimulus (and rehear the stimulus in the adjusted tempo) an unlimited number of times. The average duration of each trial was 22 s, while the average stimuli duration was 4.5 s. Hence, we estimate that each stimulus was altered and reheard 3-4 times on average (allowing time for both tempo adjustment and auditory feedback). The overall presentation total is therefore around 60 min (18 * 3.5 = 63).

The stimuli were semi-randomized individually under several constraints. In order to account for learning effects, the first-presented stimulus was counterbalanced so each of the eighteen items was presented an equal number of times at the start of the sequence. Furthermore, to minimize carry-over effects, special attention was given to the avoidance of clusters of consecutive stimuli that share two out of three of the within-subject independent variables (see Appendix C for more details on the randomization method).

**Results and Discussion**

This experiment has a 2 x 2 x 3 x 3 mixed design, with Music Training as a between-participants variable, and three within-participants variables: initial tempo, pitch register, and contour (pitch direction). Initial tempo had three levels (slow, moderate, and fast); pitch register had two levels (low and high); and contour had three categories (control, ascending, and descending).

To test our main hypotheses, we ran a mixed 2 x 2 x 3 x 3 ANOVA. Since the design was balanced, where sphericity is violated we report Greenhouse-Geisser corrected df.

The results show significant main effects in the predicted directions for pitch register \(F(1, 64) = 25.52, MSE = 12861, p < .001, \eta^2_p = .29\) and initial tempo \(F(2, 128) = 48.02, MSE = 6013, p < .001, \eta^2_p = .43\) as well as a highly significant main effect of contour, \(F(2, 109) = 12.25, MSE = 19455, p < .001, \eta^2_p = .16\). There was no main effect of music training.

High register yielded faster tempo preferences (\(M = 189, SE = 8.63\)) than low register (\(M = 156, SE = 7.12\)), corroborating our pitch register cross-dimensionality hypothesis. In line with our initial tempo anchoring bias hypothesis, the tempo main effect demonstrated a strong bias, with fast initial tempo (135 BPM) leading to faster preferred tempo rates (\(M = 199, SE = 8.65\)) than the moderate (90 BPM) and slow (60 BPM) initial tempi (\(M = 174, SE = 7.98\) and \(M = 145, SE = 6.87\), respectively). Lastly, the main effect for contour showed that faster tempo rates were chosen for the chromatic ascending scale (\(M = 188, SE = 8.51\)) and descending scale (\(M = 183, SE = 9.47\)), compared to the repeating tone control (\(M = 146, SE = 8.8\)). Follow-up t-tests (Bonferroni .05/3 = .0167) revealed that participants’ tempo preferences for both ascending and descending scales were significantly different than the control, \(t(66) \geq 3.49, p \leq .001\). In contrast, the difference between the ascending scale and the descending scale, though in the predicted direction (ascent faster than descent) was nonsignificant, \(t(66) = .60, p > .05\). This stands in contrast with our pitch direction cross-dimensionality hypothesis, according to which faster preferred tempi would be chosen for the ascending scale, compared to level and descending contours. Results suggest that although the contour’s directionality in itself is an important contributor to participants’ choice of preferred tempo rates, the specific direction (up or down) matters less than directed movement itself.

There was one significant interaction, register by music training, \(F(1, 64) = 8.77, MSE = 12861, p = .004, \eta^2_p = .12\), revealed in Figure 2. Follow-up t-tests (Bonferroni .05/2 = .025) revealed that register significantly affected the tempo choices of musicians, who preferred faster tempi for the high register than for the low register (\(M = 197, SE = 11.83\) vs. \(M = 144, SE = 9.76\), respectively; \(t(34) = 5.46, p < .001\). Although nonmusicians also preferred faster tempi for the high register (\(M = 181, SE = 12.57\)) than for the low register (\(M = 167, SE = 10.37\)), the effect was not significant, \(t(31) = 1.69, p = .10\). There were no other significant interactions. As is evident by this interaction, musicians’ preferences in this experiment are more strongly influenced by register, compared to those of nonmusicians. This is generally in line with our training enhancement hypothesis.

Although we did not have a hypothesis regarding gender, a scan of the raw data seemed to reflect sex differences in response to register. To examine this observation, we analyzed the data using a 2 (register) x 2 (sex) mixed ANOVA. Beside the expected main effect of register, similar to that found in the main analysis, \(F(1, 65) = 29.05, MSE = 1482, p < .001, \eta^2_p = .31\).
the results indeed show a significant sex by register interaction, \( F(1, 65) = 5.17, \text{MSE} = 1482, p = .03, \eta^2_p = .07 \), shown in Figure 3. Follow-up \( t \)-tests showed that tempo preferences for both subgroups were affected by register, preferring faster tempi for the higher register (men: \( M = 183, SE = 11.44 \) for high register, vs. \( M = 162, SE = 9.52 \) for low register; \( t(36) = 2.38, p = .02 \); women: \( M = 197, SE = 12.71 \) vs. \( M = 146, SE = 10.58 \); \( t(29) = 5.02, p < .001 \). To analyze the results further, we computed a difference score between the high and low register. A follow-up \( t \)-test revealed that, for women, register effect was significantly larger, with a mean difference score of 51.25 (\( SE = 10.21 \)), compared to only 20.84 (\( SE = 8.75 \)) for men, \( t(65) = 2.27, p = .03 \). While this finding should be taken cautiously, it is nevertheless intriguing and calls for further investigation. Importantly, since this was not an integral part of our design, the groups were not balanced for gender: the majority of the men were musically trained (22 from 37), while the majority of the women were not (17 from 30). However, note that this interaction cannot be attributed to residual effects of training: were that the case, the effect would have been reversed. Thus, had the gender/musicianship variables been counterbalanced, a larger - rather than smaller - gender effect would have been expected. We discuss this result further in the General Discussion.

Experiment 1’s results demonstrate strong effects of pitch register and directionality on participants’ tempo preferences. However, due to the controlled and simplified nature of the stimuli, one may question whether similar pitch effects would occur when more music-like stimuli are put into use, a pertinent question when the ecological validity of the results is concerned. In particular, it may be interesting to examine the effect of register when musical stimuli suggest a particular register and tempo, which can either match or differ from the one suggested by their actual register. We therefore decided to run a second experiment. The stimuli in this experiment consisted of two experimental conditions that may be described as simple prototypical melodies, each commonly associated in Western music with a specific register and tempo: a bass-line pattern and a double neighbor pattern. These were presented alongside the same repeating tone control used in Experiment 1. We hypothesized that the prototypical double neighbor pattern, which commonly appears in medium-to-high musical registers, would be associated with faster preferred tempi, compared to both the prototypical bass-line pattern and the control (repertory association hypothesis). We also expected to replicate the main effects of register and initial tempo that were observed in Experiment 1. In addition, we hypothesized that music training would enhance participants’ sensitivity to the association between the “prototypical” melodic stimuli and the registers and tempi they imply.

**Experiment 2**

**METHOD**

**Participants.** Sixty-five participants, who had also participated in Experiment 1, aged 18-58 (mean age = 26...
year; SD = 7.05), 36 males and 29 females, took part in Experiment 2; 35 were musicians, and 30 were nonmusicians (for Sex X Musical Training crosstabulation, see Table 2). Two participants who failed to answer more than half of the questions were omitted from the statistical analysis. All the participants were paid 20 NIS (about $5) for their participation.

Musical Stimuli. As in Experiment 1, we used 18 different stimuli, presenting all combinations (3 x 2 x 3 factorial design) of three initial tempi, two pitch registers, and three melodic patterns. Initial tempi and pitch registers replicated those in Experiment 1. The melodic patterns consisted of a repeating tone (A1 in the low register, and A6 in the high register) — a control stimulus identical to that used in Experiment 1 — and two prototypical melodies, each commonly associated in Western music with a different register and tempo (see Table 3 and Figure 4). Pattern 2a is a typical bass progression (here, in A major), usually associated with low register and slow pace: A1 E2 F#2 C#2 D2 E2 A1 in the low register, and A6 E7 F#7 C#7 D7 E7 A6 in the high register. Pattern 2b is a double-neighbor melodic pattern (here, around A), commonly associated with middle or high registers and a faster pace: A1 B1 A1 G#1 A1 B1 A1 in the low register, and A6 B6 A6 G#6 A6 B6 A6 in the high register. In terms of contour, both patterns contain three changes in melodic direction: In the bass progression these changes occur on the third, fourth, and sixth notes, while in the double-neighbor pattern they occur on the second, fourth, and sixth notes. Note that as opposed to the psychophysical nature of Experiment 1’s contours, the stimuli in this experiment are more easily described as musical patterns. Nevertheless, the difference between the melodies in Experiment 2 could also be defined in terms of their mean melodic interval, with the bass progression advancing mostly in leaps and reaching a mean melodic interval of four semitones, and the double-neighbor pattern moving entirely in stepwise motion, resulting in a lower mean interval of 1.66 semitones.

Task and Procedure. Upon finishing Experiment 1, the participants filled out a short questionnaire for approximately 5 min, after which they proceeded immediately to Experiment 2 (the experiments were presented in fixed order to avoid carryover from the more complex melodies in Experiment 2). Task and procedure were identical to those in Experiment 1, with the following changes, concerning the order of the stimuli. For each pattern, the prototypical stimulus was defined as the melodic pattern in its common register and tempo values (i.e., the bass progression in a low register and slow initial tempo, and the double-neighbor pattern in a high register and fast initial tempo). The order of the stimuli in Experiment 2 was semi-randomized individually under the same constraints used in Experiment 1. However, in order to account for the possible effect of the prototypical stimuli, these two stimuli occurred only at the beginning or end of the stimuli sequence. Thus the following six situations were counterbalanced:

Both prototypical stimuli appear in the beginning: the bass progression (4a) as the first stimulus, and the double neighbor pattern (4b) as the second stimulus.
Both prototypical stimuli appear in the beginning: the bass progression (4a) as the second stimulus, and the double neighbor pattern (4b) as the first stimulus.
The bass progression (4a) as the first stimulus, and the double neighbor pattern (4b) as the last stimulus.
The bass progression (4a) as the last stimulus, and the double neighbor pattern (4b) as the first stimulus.
Both prototypical stimuli appear in the end: the bass progression (4a) as the penultimate stimulus, and the double neighbor pattern (4b) as the second stimulus.

### Table 2. Experiment 2: Sex x Music Training Crosstabulation

<table>
<thead>
<tr>
<th>Sex</th>
<th>Music training</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>M</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>F</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

### Table 3. Experiment 1 and 2: Mean Pitch Values by Melodic Pattern

<table>
<thead>
<tr>
<th>Melody</th>
<th>Register</th>
<th>Pitch range</th>
<th>Mean pitch</th>
<th>Mean pitch (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>High</td>
<td>A6</td>
<td>A6</td>
<td>1760.00</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>A1</td>
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<td>55.00</td>
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<tr>
<td>Ascending/Descending Chromatic Scales</td>
<td>High</td>
<td>A6-D#7</td>
<td>C7</td>
<td>2093.00</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>A1-D#2</td>
<td>C2</td>
<td>65.41</td>
</tr>
<tr>
<td>Bass Progression</td>
<td>High</td>
<td>A6-F#7</td>
<td>D7</td>
<td>2349.32</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>A1-F#2</td>
<td>D2</td>
<td>73.42</td>
</tr>
<tr>
<td>Neighboring tones melody</td>
<td>High</td>
<td>G#6-B6</td>
<td>A#6</td>
<td>1864.66</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>G#1-B1</td>
<td>A#1</td>
<td>58.27</td>
</tr>
</tbody>
</table>
Both prototypical stimuli appear in the end: the bass progression (4a) as the last stimulus, and the double neighbor pattern (4b) as the penultimate stimulus.

RESULTS AND DISCUSSION
We used a 2 x 2 x 3 x 3 mixed design. Variables were identical to those in Experiment 1, except for the melodic patterns, which were changed to a control of a repeating tone, a typical bass progression, and a double neighbor pattern. Trials were counterbalanced as described in the Method section.

Repeated measures 2 x 2 x 3 x 3 ANOVA, with preferred tempo as the dependent variable, was used to analyze the data. Where sphericity was violated, we report Greenhouse-Geisser corrected df.

Significant main effects in the direction predicted by our hypotheses were found for register \( F(1, 63) = 40.18, MSE = 7471, p < .001, \eta^2_p = .39 \), initial tempo \( F(2, 126) = 51.78, MSE = 3758, p < .001, \eta^2_p = .45 \), and melodic pattern \( F(2, 126) = 21.03, MSE = 16744, p < .001, \eta^2_p = .25 \). There was no main effect of music training. We replicated our register effect from Experiment 1: High register yielded faster tempo preferences \( (M = 168, SE = 8.28) \) than low register \( (M = 136, SE = 6.45) \), again corroborating our melodic register cross-dimensionality hypothesis. Similarly, the main effect of tempo from Experiment 1 was replicated, demonstrating a strong anchoring bias, with fast initial tempo (135 BPM) leading to faster preferred tempo rates \( (M = 174, SE = 7.73) \) than the moderate (90 BPM) and slow (60 BPM) initial tempi \( (M = 153, SE = 7.82; and M = 130, SE = 6.66, respectively) \). Lastly, the main effect for melody concurred with our repertory association hypothesis, as faster tempo rates were chosen for the double neighbor pattern \( (M = 187, SE = 10.46) \), associated with upper voices and faster tempi in musical repertoires, compared to the typical bass progression \( (M = 138, SE = 6.95) \) and the control, a repeating tone \( (M = 132, SE = 6.48) \).
Follow-up $t$-tests (Bonferroni $0.05/3 = 0.0167$) revealed that preferred tempo rates for the double neighbor pattern were significantly different from those chosen for the typical bass progression and for the control, $t(64) \geq 5.86$, $p < .001$. No significant difference was found between the control and the bass progression, $t(64) = .35$, $p > .05$.

Interestingly, a closer look at the music training subgroups showed that the apparent lack of difference between the bass progression and the control was mediated by contrasting tempo preferences in each group. As can be seen in Figure 5, we found a significant melodic pattern and music training interaction, $F(2, 126) = 6.56$, $MSE = 1674.4$, $p = .002$, $\eta^2_p = .09$. Follow-up $t$-tests (Bonferroni $0.05/2 = 0.025$) confirmed that musicians preferred slower tempi for the bass progression ($M = 123$, $SE = 9.44$), than for the control melody ($M = 151$, $SE = 11.74$; $t(34) = 2.37$, $p = .02$). In contrast, for nonmusicians the preference was reversed, with faster tempi preferred for the bass progression ($M = 153$, $SE = 10.12$) as compared to the control ($M = 113$, $SE = 12.69$; $t(29) = 2.39$, $p = .02$). The fact that musicians associated the bass-related pattern with the slowest tempi is in line with our hypothesis that training would enhance sensitivity to melodic patterns associated with specific registers. This higher sensitivity may have been particularly strong for bass patterns due to the frequent training of classical musicians in bass harmonization, using comparable patterns as input.

We found an unpredicted significant third-order interaction of initial tempo, register, and music training, $F(2, 126) = 5.74$, $MSE = 3616$, $p = .004$, $\eta^2_p = .08$. The effect consisted of attenuation of melodic register effects for nonmusicians when the initial tempo was fast. Follow-up $t$-tests (Bonferroni $0.05/2 = 0.025$) showed that, given fast initial tempo (135 BPM), musicians preferred faster tempi for the higher register, $t(34) \geq 3.51$, $p \leq .001$, while for nonmusicians there was no significant difference between registers in this respect, $t(29) = .46$, $p > .05$. The interaction suggests a stronger association of the upper register with faster tempi for musicians, perhaps based on their experience (as performers and listeners) with rapid figurations common in this register. We also found a significant but weak four-way interaction between melody, initial tempo, register, and music training [$F(4, 218) = 2.96$, $MSE = 4076$, $p = .05$, $\eta^2_p = .04$], with enhanced interaction of melody and initial tempo for nonmusicians, and reduced influence of register for nonmusicians. The effect size was small and we believe this to be a marginal effect explained by the three-way interaction between initial tempo, register, and music training.

No other significant interactions were found. Interestingly, while Experiment 2 revealed an interaction between music training and melodic patterns, it failed to replicate the significant interaction between music training and register found in Experiment 1. We further discuss the training-related effects from both experiments in the general discussion.

Lastly, we ran a $2 \times 2$ mixed ANOVA to see if the sex by register interaction from Experiment 1 was replicated. There was no replication of the interaction effect, $F(1, 63) = .31$, $MSE = 869$, $p = .58$. The interaction in Experiment 1 should therefore be considered tentative, and requires scrutinizing investigation. However, it makes sense that if sex differences indeed exist, they would be more apparent given the simple "psychophysical" stimuli of Experiment 1, compared to the musically specific stimuli of Experiment 2. We discuss this finding briefly in the following general discussion.

Comparing experiments. Since participants took part in both experiments, we conducted a repeated-measures ANOVA of the data across experiments. Independent variables included Register, Initial Tempo, and Experiment (within participants) as well as Music Training (between participants).

Results reveal significant main effects in the expected directions for Register [$F(1, 62) = 43.49$, $MSE = 4713$, $p < .001$, $\eta^2_p = .41$] and Initial Tempo [$F(2, 113) = 89.38$, $MSE = 2001$, $p < .001$, $\eta^2_p = .59$], as well as a main effect for Experiment, $F(1, 62) = 13.26$, $MSE = 4503$, $p = .001$, $\eta^2_p = .18$. High register yielded, in accord with our
melodic register cross-dimensionality hypothesis, faster tempo preferences \((M = 178.30, SE = 8.02)\) than low register \((M = 145.10, SE = 6.35)\). Faster initial tempi yielded faster preferred tempi \((M = 187.06, SE = 7.74)\), as compared to moderate \((M = 161.73, SE = 7.38)\) and slow \((M = 136.34, SE = 6.20)\) initial tempi. The main effect of Experiment stemmed from overall faster tempi in Experiment 1 \((M = 170.57, SE = 7.36)\), as compared to Experiment 2 \((M = 152.85, SE = 7.08)\). This effect may be related to the more complex melodic stimuli used in Experiment 2 (see General Discussion).

There was no main effect of music training \((F < 1)\), suggesting that training did not affect preferred tempi generally. However, a significant interaction of Music Training x Register was found, \(F(1, 62) = 8.18, MSE = 4713, p = .006, \eta^2_p = .12\). In line with our training enhancement effect hypothesis, this interaction stems from a stronger effect of register on musicians’ preferred tempi: musicians’ preferred tempo for higher registers was faster \((M = 185.74, SE = 10.80)\) than that of nonmusicians \((M = 170.50, SE = 11.86)\), while their preferred tempo for lower register \((M = 138.39, SE = 8.55)\) was slower than nonmusicians’ \((M = 151.91, SE = 9.39)\).

In addition, two three-way interactions proved significant: Tempo x Register x Music Training \([F(2, 124) = 3.64, MSE = 1168, p = .03, \eta^2_p = .06]\), an interaction similar to that reported for Experiment 2 alone, with an enhanced effect of register on musicians (see above), and Music Training x Tempo x Experiment, \(F(2, 120) = 3.22, MSE = 1491, p = .05, \eta^2_p = .05\).

**General Discussion**

Taken together, the results of Experiments 1 and 2 support a “holistic” approach to musical tempo, suggesting that tempo choice in music is affected by interactions of diverse musical dimensions (e.g., Epstein, 1995). Specifically, this study suggests that aspects of musical pitch, including melodic register, contour, and (possibly) interval size, as well as the connotations of conventional melodic patterns, partake in determining the choice of a subjectively appropriate tempo. Notably, these cross-dimensional effects may be discerned even when simple auditory stimuli are used, as in Experiment 1.

While previous research (Boltz, 1998, 2011) has focused on the effect of different musical dimensions on tempo perception, this study deals for the first time with subjective tempo propriety — a crucial aspect of musical activities, hardly explored empirically. Our methods required active adjustment of tempo by participants, thus enabling a much finer resolution of listeners’ tempo preferences, compared to tasks involving verbal or numerical ratings of tempo appropriateness. Furthermore, although the stimuli were quite controlled and did not involve complex recorded music, the task simulates the active trial-and-error tempo selection involved in music activities, thus presenting a simple, embryonic model of the holistic act of tempo selection. Results, then, may shed some light upon aspects of crucial performance and listening decisions that were not within the scope of previous research paradigms. The novel experimental paradigm presented in this research can be extended to test other music performance preferences (e.g., loudness, articulation), thus paving the way for further research in this important yet underexplored area.

In what follows we reassess our hypotheses in view of the study’s main findings, discuss possible interpretations of these results, and conclude by pointing out some directions for further research of the myriad ways musical dimensions may shape tempo preferences.

**REGISTER**

As hypothesized, a highly significant main effect of pitch register on tempo preferences was found in both experiments, suggesting that listeners prefer faster tempo rates for higher register melodies. While a strong anchoring bias was found in both experiments, as expected (the faster the initial tempo of a stimulus — the faster its preferred tempo), the effect of register on tempo preference was maintained across initial tempi, and there was no interaction between initial tempo and register in either experiment.

The tendency to prefer faster tempi for higher registers is consistent with findings concerning tempo perception (e.g., Boltz, 2011), and with the intuitions of Western music theorists and composers since the 16th century (see Introduction). It is also consistent with the correlations between durational density (average interonset interval) and pitch height found in diverse Western musical repertories (Broze & Huron, 2013). Statistical learning of such correlations may account in part for the strong associations of register and preferred tempo in Experiment 2, where musical patterns typically associated with different registers were used. While the source of such pitch height/duration correlations is yet to be determined, several factors seem to suggest themselves. First, pitch and tempo may also correlate in our daily extramusical experience: higher-pitched sounds are associated with smaller, lightweight objects, and those — with faster motion (Eitan & Timmers, 2010). More abstractedly, both higher pitch and faster tempo are associated with greater arousal and intensity, particularly in music (Eitan, 2007; Eitan & Granot, 2007); Consequently,
the association of faster tempo with higher pitch may be related to their mutual association with higher intensity, a primary expressive factor (Osgood, Suci, & Tannenbaum, 1957). Lastly, the pitch-tempo association is also consistent with psychoacoustic constraints on pitch perception. The duration threshold for pitch perception is shorter for higher pitch, since a minimum number of cycles is required for a perception of pitch (e.g., 8-10 for sine tones between 100 and 900 Hz; Patterson, Peters, & Milroy, 1983). Though pitch perception thresholds are considerably shorter than most durations used in music (and in the present experiment), the substantial difference between threshold durations for pitch perception in high and low registers may be one source of the preference for slower tempi in the lower pitch range.

**INITIAL TEMPO**
In line with our Hypothesis No. 5 (initial tempo anchoring bias hypothesis), an anchoring bias has been found in both experiments: faster initial tempi resulted in faster tempo preferences. Yet, one may question whether this is indeed an auditory anchoring effect, or rather a visual one — an artifact of the experimental procedure. Since same visual points represented faster tempo values for the faster conditions, an apparent anchoring effect could also have been produced if participants tended to gravitate toward a specific visual point on the screen, regardless of initial tempo. However, if this were the case, the ratios between mean preferred tempi and initial tempi would be roughly constant, since the scale on screen was actually built with percent increments (see Appendix A for further details). As Table 4 indicates, these ratios actually vary considerably. Therefore, it seems likely that an auditory anchoring effect is indeed involved.

**PITCH DIRECTION**
In addition to pitch register, Experiment 1 focused on melodic direction, comparing an ascending pitch stimulus, a descending one, and a “control” stimulus — a repeating tone. While the effect of melodic direction proved significant, melodic ascent and descent did not elicit significantly different tempi. Rather, both directions, while similar to each other, were associated with preferred tempi faster than those of the repeated tone control. Thus, it seems that melodic directionality itself is a contributing factor to tempo preferences, rather than the specific direction (ascent or descent).

It would appear that the association of higher pitch with faster tempo, reported above, entails that ascending pitch would also be associated with faster tempi, and descending pitch – with slower tempi, and Boltz (2011) indeed reports such association in tempo perception. However, other studies suggest that the associations of pitch direction (ascent vs. descent) with tempo may differ from those of pitch level (high vs. low), and stem from different sources. Thus, in Eitan and Granot’s music-induced imagery experiment (2006), participants associated both rising and falling pitch patterns with accelerating motion. Ammirante et al. (2011), using a continuation-tapping paradigm, found that descending, rather than ascending contours were associated with accelerated tapping. These results may stem from the use of different, and sometime inconsistent, mapping strategies for different pitch directions. Listeners may map pitch fall onto spatial fall in a natural, gravitational field (Larson & VanHandel, 2005; Russo & Thompson, 2005), and hence associate it with accelerating motion. Yet, they may also associate pitch rise with increasing energy and intensity (Eitan & Granot, 2006, 2007), and that mapping may generate the association of rising pitch with a likewise increasing (accelerating) motion. It is thus possible that in the present study the faster overall tempi for the ascending and descending patterns, as compared to control stimuli, were due to two different mappings. Alternatively, these results may stem from mapping the “absolute magnitude” of pitch change, regardless of pitch direction, onto preferred tempo.

These interpretations notwithstanding, the differences found (here and elsewhere) between cross-domain mappings of static (melodic register) and dynamic (melodic direction) pitch properties may reflect a wide-ranging disparity between the processing of static and dynamic stimuli, which merits further investigation, particularly within musical contexts (see Eitan, 2013a, 2013b; Eitan, Schupak, Gotler, & Marks, 2013).

**TABLE 4. Experiment I: Mean Preferred Tempo Rates and Initial/Preferred Tempo Ratios**

<table>
<thead>
<tr>
<th>Initial tempo rates</th>
<th>Mean preferred tempo rates</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>136</td>
<td>2.266</td>
</tr>
<tr>
<td>90</td>
<td>162</td>
<td>1.8</td>
</tr>
<tr>
<td>135</td>
<td>187</td>
<td>1.38</td>
</tr>
</tbody>
</table>

**MUSIC-SPECIFIC PATTERNS**
Experiment 2 included two patterns modeled after figures associated in common-practice music with specific register and pace: a typical bass progression, associated with low register and slow pace, and a double neighbor pattern, commonly associated with middle or high registers and faster pace. As hypothesized, a highly
significant effect of melodic pattern was found: The preferred tempi for the double neighbor pattern were significantly faster than those for the prototypical bass progression. However, contrary to our hypothesis, the prototypical bass progression was not assigned tempi significantly slower than the control’s. As discussed below (“Music Training”), this apparent null effect actually stems from contrasting tendencies exhibited by musically trained and untrained participants.

Boltz (e.g., 1998) reports that two melodic features – the number of contour changes and the size of melodic intervals – are associated with perceived tempo, such that patterns containing more contour changes and larger intervals were perceived as slower. While the double neighbor and bass progression patterns consisted of an equal number of contour changes, the “bass” figure used larger melodic intervals (mean interval = 4 semitones, as compared to 1.66 semitones in the double neighbor pattern). Hence, two accounts for the effect of melodic pattern can be raised: one in terms of the musical context in which these patterns are commonly applied and learned, implicitly or explicitly (particularly by musicians); the other – in terms of the more general association of perceptual and motor representations of action, and specifically of interval magnitude and tempo, as Ammirante and colleagues suggest (2010, 2011).

Given these two alternative explanations, one may question whether results stem from top-down processing of conventional, “prototypical” patterns, as we hypothesized, or rather from processing simpler perceptual features, such as interval size and frequency of contour change. Moreover, for Western tonal music, the two explanations may be confounded, since conventional bass progressions often comprise successive leaps (e.g., 4ths and 5ths, or 4ths and 3rds) in changing directions, while upper-line figurations are mostly comprised of stepwise progressions.

However, these apparent confounds seem to cohere, in common-period Western music, to create the very prototypes we use in Experiment 2, where tempo and melodic features (such as interval size and contour) combine to suggest a typical register. Figure 6a-c, the introduction of Beethoven’s 15 Variations and Fugue, Op. 35 (also known as the “Eroica Variations,” as they serve as a basis for the 4th movement of Beethoven’s 3rd symphony, the Eroica), demonstrates in a compelling manner how a masterful composer may use the very expectations generated by such prototypes. Beethoven opens the piece (Figure 6a) with a typical bass pattern doubled in the “wrong” (upper) register and treated as a theme for the first three variations. The puzzling, humorous effect of this “wrong” use underscores the entire introduction, as exemplified by an excerpt from its second variation in figure 6b. The puzzle is resolved only following the third variation (Figure 6c), in which the prototypical bass pattern is finally treated “properly” — as the bass line for the “real” melodic theme (marked “Tema” by Beethoven, to avoid any confusion), featured in the upper register.

As this example suggests, although the two alternative explanations (interval/contour-based and prototypicality-based) are conceptually distinguishable from one
another, in practice they may coincide to a great extent. That is, in Western concert music, bass progressions may typically feature more frequent contour changes and larger intervallic leaps, compared to high-register melodies. However, the interaction of melodic pattern and music training, discussed below, suggests that recognition of prototypical patterns did affect tempo preferences in Experiment 2, at least for the participants with music training.

**MUSIC TRAINING**

While there was no main effect of music training in either experiment, two interactions involving this factor were discerned. In Experiment 1, a Register x Training interaction was found, such that a stronger (and statistically significant) effect of register on tempo choices was found for musicians, as compared to nonmusicians (whose tempo choices were not significantly associated with register). In Experiment 2, in contrast, tempo preferences of both musicians and nonmusicians show a significant effect of register, with no Register x Training interaction.

Given the significant interaction in Experiment 1, the absence of a Register and Training interaction in Experiment 2 is somewhat surprising, since it is Experiment 2 that employed music-specific patterns, and hence could be expected to generate even wider differences between participants with and without music training.

While no Register x Training interaction was observed in Experiment 2, another training-related effect emerged: a striking interaction between melodic pattern and music training, such that musicians chose slower tempi for the bass progression, compared to the repeating tone control, while nonmusicians’ tempo preferences were in the opposite order: slower tempi for the control. The fact that musicians associated the bass-related pattern with the slowest tempi is in line with our hypothesis that training would enhance sensitivity to melodic patterns associated with specific registers. This higher sensitivity might have been particularly strong for bass patterns due to the frequent training of classical musicians in bass harmonization, using comparable patterns as input. The association of the repeated-tone control stimuli with slower tempo by nonmusicians calls for a separate explanation. This association is particularly puzzling, given the fact that our “bass progression” pattern, beyond its specific association with bass lines in common-period music, also includes wider intervals (4 vs. 0 semitones) and more contour changes (3 vs. 0) than the control – two features that were, as noted above, shown to be associated with slower tempi for both perception (Boltz, 1998) and action (Ammirante et al., 2011). Together with the fact that substantial differences between musicians and nonmusicians are expected to arise when more complex musical considerations are put into use, we surmise that the contour and intervallic profile of the melodies are not sole contributors to the shaping of participants’ preferences, and that a broader and more “musical” perspective deriving from the stimuli’s prototypicality is involved in their shaping as well.

\[2\] A statistical analysis of relevant musical corpora that would establish this observation is called for.

\[3\] Since trained experimental subjects often exhibit lower variance in training-related tasks compared to untrained subjects, we had to make sure the statistical significance of the training effects in either experiment was not due to reduced variance in the musically-trained group. We ran a series of t-tests comparing musicians to nonmusicians, separately for high and low registers in Experiment 1, Experiment 2, and across the collated data of both experiments. In none of these tests was the Levene’s Test for Equality of Variances significant (F < 1, p > .05). We therefore conclude that there is no evidence that musicians’ responses show lower variability than nonmusician’s responses, and hence that training effects cannot be attributed to musicians’ reduced variance.
SEX DIFFERENCES

An intriguing finding of Experiment 1 was the sex by register interaction, in which the register effect was significantly larger for women, as compared to men (women chose faster tempi for the high register and slower tempi for the low register, compared to men). This result was not replicated in Experiment 2 and thus, particularly given the modest effect size, $\eta^2_p = .07$, should be considered tentative.

If the Sex x Register interaction proves valid, it would be an intriguing finding, as it indicates that this fundamental population variable, overlooked in this context so far, may affect music performance and evaluation. Indeed, audiological research suggests that males and females have different hearing sensitivities (Corso, 1963), and process auditory stimuli differently (Kimura, 1985). Previous research has also demonstrated that other psycho-physiological attributes, such as age (McAuley, Jones, Holub, Johnston, & Miller, 2006) can affect preferred tempo rates in individuals. There are, however, very few studies on gender differences in tempo judgments in general, and preferences in particular. A notable recent exception is Rose, Müllensiefen, Stewart, and Lee’s (2012) study, in which certain anthropometric properties have been found significant in determining the preferred beat period only for male participants and not for females. Differences in tempo judgments were found in children as well, such that females gave higher evaluations to slow and moderate tempi (Montgomery, 1996). The present finding may serve as a basis for further research, specifically aimed at assessing the role of sex differences in tempo perception and preference.

FUTURE DIRECTIONS

This study enables for the first time a quantitative measurement of an important aspect of aesthetic preference in music, which has received little empirical examination: what is the proper tempo for a piece of music, tempo that is neither too fast nor too slow, but “just right.” Here, we have mainly examined the effect of the pitch dimension on perceived tempo propriety. However, our design may be adapted to measure the effect of other variables on tempo, including loudness, textural density, or timbre, as well as the effects of additional aspects of pitch, such as tonal structure, dissonance, or modality (major/minor).

Another expansion of the study is toward greater ecological validity, using less controlled albeit more complex musical stimuli. The present study aims for a tight control of manipulated variables, hence stimuli in both experiments are kept very simple. In particular, the current stimuli are devoid of any expressive timing fluctuations, whose effects are manifest in the perception of both musical structure (e.g., Friberg, 1991; Friberg, Bresin, & Sundberg, 2006) and musical emotions (e.g., Juslin & Timmers, 2010). The influence of expressive timing on tempo preferences seems like a natural extension of these findings. To further stress this point, it is worthwhile to mention that expressive timing itself behaves differently in various tempi, and is not relationally preserved under tempo transformations (e.g., Honing, 2007). Thus, in practice, these two parameters interact with each other in complex ways. The current stimuli’s mechanical expression could have contributed to participants’ ultimate tempo choices, which may have differed had more musically complex stimuli been involved. More generally, it would be worthwhile to investigate listeners’ tempo preferences using recorded performances of actual music, while utilizing a similar experimental paradigm.

Finally, our study suggests that different strategies may be used by listeners (even by the same listener in different circumstances) in their tempo judgments. A further investigation of how musical materials and task demands affect the strategies used in tempo judgments may shed more light on the ways experiential musical time unfolds, and in particular on the ways listeners and performers shape musical time in accordance with musical materials and contexts.

Author Note

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References


**Appendix A**

**THE SLIDER**

In the perception of tempo change, as in that of many other psychophysical parameters, the magnitude of a change in tempo is roughly perceived according to the ratio between the two compared tempi, and not according to their difference. Thus, a linear scale would have been perceived as deformed by the participants.

In order to solve this problem, a nonlinear, proportional scale was devised for the interface of this experiment. One notch on the onscreen slider was defined to be a change of 2% in the temporal speed (smaller than the threshold appearing in most tempo JND literature; see Friberg & Sundberg, 1995). The transformation from a position on the slider to a value in BPM is represented by the series:

\[ a_n = a_0(1.02)^n \]

where \( a_n \) is the \((n+1)\)-th element in the sequence, that is, the BPM value for the \((n+1)\)-th notch on the slider.

The slowest tempo available to the participants using the slider was set to \( a_0 = 30 \), and the fastest available tempo was set to \( a_{\text{max}} = 394 \).

Before the statistical analysis, the reversed formula was used in order to normalize the data:

\[ n = \frac{\ln(a_0) - \ln(a_n)}{\ln(1.02)}. \]

To avoid visual biases caused by a difference in the initial position of the button on the slider for stimuli with different initial tempi, the onscreen slider was built so that regardless of the initial tempo, the starting position of the button would always appear to be in the middle of the slider. To enable this, the slider contained small dummy sections at both ends. In these areas the button could be moved, but no consequent change in tempo occurred. The dummy sections enabled shifting the slider’s active part so that the middle point always represented the current initial tempo. Being relatively small, the dummy sections were not reported as noticeable by participants in a pilot run as well as during the experiment itself. Figure 3 (a to d) demonstrates the floating slider. Figure 3a presents a general view, while 3b, 3c and 3d present the slider for initial tempi 90, 60 and 135 respectively.

**Appendix B**

**LOUDNESS CALIBRATION**

Since pitch height has been known to affect loudness perception in a manner that varies widely among individuals (Fletcher & Munson, 1933, ISO, 2003), the software recalibrated loudness-levels to fit each participant in each register. For this end, prior to the experiment itself the participants were presented with a screen containing two sliders, each slider controlling the loudness level of a single tone in one of the experiment’s stimuli (General MIDI grand piano). The data were saved by the experiment’s software and used to individually generate each stimulus in the loudness level chosen by the participant for its register.

**Appendix C**

**THE ORDER OF THE STIMULI**

In order to account for learning effects, the stimuli were ordered so that the eighteen items were presented as the first heard stimulus for an equal number of times across participants. Furthermore, special attention was given to avoiding clusters of consecutive stimuli that share two or three of the within independent variables.

To this end five preprogrammed sequences were built. These sequences contained an ordered set of all 18 stimuli so that clusters of stimuli with high resemblance were avoided. Albeit ordered, the sequences contained no start and end points (conceptually, they were represented as rings), and could be read in both directions (clockwise or counterclockwise). As a consequence, each sequence represented 18 x 2 different orders of stimuli potentially presented to a participant, totaling at 18 x 2 x 5 = 180 possible orders for the whole pool.

Note also that as a side-effect of avoiding closely-related clusters of stimuli, the sequences were relatively equally distributed among the possible values of each independent variable throughout.

The actual order of stimuli presented to each participant was determined in two stages:

1. Before the first participant started the experiment, the software randomly chose one sequence from
the pool. This sequence determined the first stimulus of each participant.

2. For each participant, a sequence and direction were randomly chosen from the sequence pool. The starting point was determined by the location of the pre-assigned first stimulus within the sequence (Stage 1).

The randomization method in Experiment 2 was similar, except for the following additions:

1. Before the first participant started the experiment, the software randomly chose one sequence from the pool. This sequence, together with the counterbalance condition of the prototype stimuli (see Experiment 2, Method), determined the first stimulus for each participant, so that in Conditions 1-4 of the prototype stimuli the first stimulus was one of the two prototype stimuli, and in Conditions 5-6 it was determined by the chosen sequence.

2. After a sequence was chosen for a participant, the prototype stimuli were switched with the stimuli occupying their assigned places, to create a sequence that complies with the counterbalance conditions.

APPENDIX FIGURES A-D. Visual presentation of the presented scale with actual and dummy sections.