Does Tuning Influence Aesthetic Judgments of Music? Investigating the Generalizability of Absolute Intonation Ability

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Abstract

Listening to music is an enjoyable activity for most individuals, yet the musical factors that relate to aesthetic experiences are not completely understood. In the present paper, we investigate whether the absolute tuning of music implicitly influences listener evaluations of music, as well as whether listeners can explicitly categorize musical sounds as “in tune” versus “out of tune” based on conventional tuning standards. In Experiment 1, participants rated unfamiliar musical excerpts, which were either tuned conventionally or unconventionally, in terms of liking, interest, and unusualness. In Experiment 2, participants were asked to explicitly judge whether several types of musical sounds (isolated notes, chords, scales, and short excerpts) were “in tune” or “out of tune.” The results suggest that the absolute tuning of music has no influence on listener evaluations of music (Experiment 1), and these null results are likely caused, in part, by an inability for listeners to explicitly differentiate in-tune from out-of-tune musical excerpts (Experiment 2). Interestingly, listeners in Experiment 2 showed robust above-chance performance in classifying musical sounds as “in tune” versus “out of tune” when the to-be-judged sounds did not contain relative pitch changes (i.e., isolated notes and chords), replicating prior work on absolute intonation for simple sounds. Taken together, the results suggest that most listeners possess some form of absolute intonation, but this ability has limited generalizability to more ecologically valid musical contexts and does not appear to influence aesthetic judgments of music.

Keywords: *Auditory Perception, Aesthetics, Music Cognition, Tuning, Absolute Pitch, Relative Pitch, Implicit Memory*

Does Tuning Influence Aesthetic Judgments of Music? Investigating the Generalizability of Absolute Intonation Ability

Most individuals find listening to music to be a pleasurable experience, despite the fact that music provides no obvious biological advantages (Mas-Herrero et al., 2014). The ability of music to both represent and evoke emotions in listeners has been discussed for millennia; for example, Plato and Aristotle both discussed how music could regulate emotion and was an integral part of perfecting human nature (Schoen-Nazzaro, 1978). More recent neuroscientific approaches have found that music-induced pleasure is associated with neural signatures that overlap with both primary (e.g., food, sex) and secondary (e.g., money) rewards (Blood et al., 1999; Blood & Zatorre, 2001; Montag et al., 2011), highlighting the importance of music as a pleasure-inducing signal.

How is music able to generate pleasurable, aesthetic reactions in listeners? Although this question at first glance might appear to be ill-formed, as musical preferences might be too variable and idiosyncratic to be characterized more broadly, there have been several complementary contributions to the understanding more general aesthetic reactions to music. Rentfrow et al. (2011) discuss a five-factor MUSIC model (Mellow, Urban, Sophistication, Intensity, and Campestral) that is theoretically dissociable from musical genre and can explain individual preferences to music. Other approaches to answering this question have focused on more general features of music, such as predictability and uncertainty (Gold et al., 2019) and perceptions of musical consonance (Bowling & Purves, 2015; McDermott et al., 2010). The focus on more general musical features in eliciting aesthetic responses from listeners is particularly compelling, as it suggests that there are some basic auditory features that may contribute to musical pleasure responses regardless of individual differences in musical taste.

In the present paper, we investigate whether musical tuning may serve as an additional feature that influences the aesthetic evaluation of music. Musical tuning has already been shown to influence listener evaluations of music; however, this prior work has focused on relative (rather than absolute) tuning. For example, regardless of formal musical training, listeners appear to be adept at identifying mistuned (“sour”) notes in melodic sequences that are sung (e.g., Larrouy-Maestri, 2018; Larrouy-Maestri et al., 2013, 2019) as well as played on an instrument (e.g., Hutchins et al., 2012; Lynch et al., 1990; Lynch & Eilers, 1992). Listeners are able to detect mistuned notes in otherwise well-tuned melodies presumably because they have developed rich implicit representations of the typical relative pitch changes in musical sequences (cf. Tillmann & Bigand, 2000). However, the role of *absolute* tuning (e.g., tuning the

1 “A” above “middle C” to 440 Hz versus another standard) in listener perceptions and evaluations
2 of music remains unexplored.

3 Perhaps the most significant reason why the relationship between absolute tuning and
4 listener evaluations of music has remained unexplored is because music is thought to be
5 processed *relatively* by the vast majority of listeners (e.g., Miyazaki, 1995; Plantinga & Trainor,
6 2005; Saffran et al., 2005). As such, the *absolute* tuning of music should be largely
7 inconsequential, as long as the relative relations among notes are preserved and as long as the
8 individual does not possess absolute pitch (AP; e.g., see Takeuchi & Hulse, 1993). Interestingly,
9 although individuals with AP can make consistent judgments about whether musical sounds are
10 “in tune” or “out of tune” based on an absolute standard (Levitin & Rogers, 2005), these
11 individuals also show some flexibility in adapting to new tuning standards, at least when relative
12 pitch relationships are preserved (Hedger et al., 2013; Van Hedger et al., 2018), highlighting the
13 importance of relative pitch processing more generally in music perception.

14 Yet, despite these reasons to expect that absolute tuning does not influence music
15 perception, there is intentional variability in absolute tuning standards across different musical
16 contexts, suggesting that tuning is thought to influence listener experiences of music. Although
17 the majority of modern Western music recordings adheres to the tuning standards established
18 by the International Standards Organization, in which the “A” above “middle C” (i.e., A⁴) is tuned
19 to 440 Hz (hereafter referred to as A440 tuning), this value is arbitrary and there are several
20 examples of music that deviates from this standard. Historical music (e.g., Baroque pieces)
21 often adopt more period-appropriate tuning standards, such as A415 tuning, which is an entire
22 semitone (100 cents) lower than A440 and can thus pose initial challenges for listeners with AP
23 (Lebeau et al., 2020). Additionally, several modern symphonic orchestras tune to different
24 standards for ostensibly aesthetic reasons (e.g., to achieve a more “brilliant” timbre; see
25 Farnsworth, 1968). Some notable examples of this higher, sharpened tuning within the past
26 several decades include the New York Philharmonic (A442 / +8 cents higher than A440), the
27 Berlin Philharmonic (A448 / +31 cents higher than A440), and the Moscow Symphony Orchestra
28 (A450 / + 39 cents higher than A440) (Abdella, 1989).

29 This tendency to tune to increasingly higher frequencies reflects a general trend of *pitch*
30 *inflation* over the last couple of centuries (Lawson & Stowell, 1999); however, it is unclear
31 whether most listeners would be able to appreciate these differences in absolute tuning.
32 Although prior research has demonstrated that listeners might have a preference for sharper
33 tuning in orchestral recordings (Geringer, 1976), the participants in this study were all musicians

1 and some reported possessing AP. Additionally, the tuning of the recordings in this study was
2 manipulated via audiotape, meaning pitch changes also resulted in changes to playback speed
3 (tempo). Thus, it is unclear whether listeners – regardless of formal musical training or
4 possession of AP – would demonstrate tuning-related musical preferences when factors such
5 as tempo are held constant.

6 It is reasonable to predict that musically untrained listeners might not be sensitive to
7 changes in absolute tuning. This is because relative pitches can be maintained regardless of the
8 tuning standard (e.g., a perfect fifth is 700 cents regardless of the absolute frequencies of the
9 notes). However, more recent work has suggested that an *implicit or latent* memory for absolute
10 pitch is a widespread ability regardless of formal musical training. Research in this area has
11 consistently demonstrated that most listeners, regardless of musical training, have an implicit
12 understanding of the musical key of well-known music recordings (e.g., Frieler et al., 2013;
13 Jakubowski & Müllensiefen, 2013; Levitin, 1994; Schellenberg & Trehub, 2003; Van Hedger et
14 al., 2017). These results are thought to be driven by familiarity with specific recordings;
15 however, more recent research has demonstrated that implicit absolute pitch memory can
16 generalize beyond specific familiar recordings. For example, Ben Haim et al. (2014) found that
17 isolated notes were more liked if they came from relatively uncommon pitch classes (e.g., G#)
18 compared to common pitch classes (e.g., C). Additionally, using a classic probe-tone paradigm
19 (see Krumhansl, 1990), Eitan et al. (2017) found that absolute pitch implicitly influenced
20 listeners' judgments of tonal fit and tension. These results, taken together, suggest that
21 listeners' memories for absolute pitch are better than previously assumed and reflect more
22 generalized knowledge about how frequently particular notes and musical keys are
23 encountered.

24 Perhaps most relevant to the present paper, *implicit* absolute pitch memory has recently
25 been discussed in the context of absolute tuning as well. Van Hedger et al. (2017) found that
26 most listeners, regardless of formal musical training, were able to differentiate “in tune” (A440)
27 from “out of tune” (A453 / +50 cents higher than A440) musical notes, although performance
28 was only modestly above chance and did not generalize to nonmusical timbres. This prior
29 research framed the categorization task as differentiating “good” (in-tune) and “bad” (out-of-
30 tune) notes, which suggests that listeners may have different affective judgments for isolated
31 notes based on tuning, but this prior work only tested single, isolated notes. As such, it is
32 unclear how these reported findings would extend to richer samples of music (e.g., excerpts
33 from actual pieces of music), which have more ecological validity.

The present experiments were therefore designed to assess how nonstandard tuning might influence listener perceptions and evaluations of music in more ecologically valid contexts. In Experiment 1, participants rated both standard (A440) and nonstandard (A453) musical excerpts in terms of how much they liked the excerpt, how interesting they found the excerpt, and how unusual they found the excerpt. Tuning was not mentioned to participants to assess whether any influences in aesthetic evaluations would be implicit. In Experiment 2, participants provided explicit intonation judgments (i.e., whether a sound was “in tune” or “out of tune”) across several types of musical stimuli differing in complexity and ecological validity (isolated notes, chords, scales, and excerpts from musical compositions).

Grounding our hypothesis in the prior literature on implicit absolute pitch (e.g., Ben-Haim et al., 2014; Van Hedger et al., 2017), we predicted that listeners in Experiment 1 would differentially rate musical excerpts based on tuning. Given the prior reports that less-frequently-encountered notes might be more liked (Ben-Haim et al., 2014), we specifically hypothesized that listeners would like the nonstandard excerpts more, as well as find the nonstandard excerpts to be more interesting and unusual. In Experiment 2, we predicted that listeners would be above chance in differentiating in-tune from out-of-tune musical sounds, conceptually replicating prior work (Van Hedger et al., 2017). However, given the prevalence of relative pitch cues for more ecologically valid musical stimuli (e.g., excerpts from compositions), we additionally hypothesized that intonation judgments for these richer stimuli might be attenuated relative to simpler stimuli such as isolated notes. Overall, these experiments were designed to test whether listeners demonstrated any evidence of tuning-based influences to aesthetic and perceptual evaluations of music using more complex, ecologically valid musical sounds.

Experiment 1

Method

Participants

A total of 100 participants were recruited from Amazon Mechanical Turk and 92 were retained for the final analyses ($M_{\text{AGE}} = 41.87$ years, $SD_{\text{AGE}} = 12.26$ years, range of 20 to 71 years old). The *Data Exclusion* section provides details on participant exclusion. We used Cloud Research (Litman et al., 2017) to recruit a subset of participants from the larger Mechanical Turk participant pool. Participants were required to have at least a 90% approval rating from a minimum of 50 prior Mechanical Turk assignments, and had to have passed internal attention checks administered by Cloud Research. All participants received monetary compensation upon

completion of the experiment. The protocol was approved by the Research Ethics Board of Huron University College.

Materials

All materials associated with the experiment are provided on Open Science Framework. The experiment was programmed in jsPsych 6 (de Leeuw, 2015). The 30 musical excerpts were selected from four multi-movement piano compositions. Nine excerpts were selected from *Opus 109* (18 Etudes) by Friedrich Burgmüller (1858), seven excerpts were selected from *Petite Suite* by Alexander Borodin (1885), six excerpts were selected from *Opus 165* (España) by Isaac Albéniz (1890), and eight excerpts were selected from *Suite Española* by Isaac Albéniz (1886). These particular pieces were selected because each contained several short piano movements and were hypothesized to be generally unfamiliar to participants. The excerpts were imported into Reason 4 (Propellerhead: Stockholm) as MIDI files and exported using a grand piano timbre. In-tune excerpts were exported as audio files with Reason's master tuning of Reason set at +0 cents (i.e., A440 tuning), whereas out-of-tune excerpts were exported as audio files with the master tuning set at +50 cents (i.e., adhering to ~A453 Hz tuning). All musical excerpts had a 44.1 kHz sampling rate and 16-bit depth. Excerpts were then trimmed to 15 seconds in duration with a 1000ms linear fade out and then root-mean-square normalized to -20 dB Full Spectrum in Matlab (MathWorks: Natick, MA).

The auditory calibration stimuli consisted of a 30-second brown noise, generated in Adobe Audition (Adobe: San Jose, CA), as well as sine tones meant to assess whether participants were wearing headphones (see Woods et al., 2017). All sine tones were presented in stereo. The "standard" sine tones in phase across stereo channels, whereas the "quiet" sine tone was 180 degrees out-of-phase across the stereo channels. Differentiating the standard and quiet sine tones is easy when the right and left channels are clearly separated (e.g., when wearing headphones) due to phase cancellation but virtually impossible when listening over standard computer speakers.

Procedure

After reading the letter of information and providing informed consent by clicking on a checkbox on the computer, participants completed the auditory calibration. Participants first heard a calibration noise and were instructed to adjust their computer's volume such that the noise was being presented at a comfortable volume. Following the volume adjustment, participants completed the headphone assessment (Woods et al., 2017). The headphone

assessment consisted of six trials. On each trial, participants heard three sine tones and had to judge which tone was quietest. The task was designed to be easy if participants were wearing headphones but difficult if participants were listening over computer speakers.

Next, participants completed the main intonation judgment task. Participants were instructed that they would hear 30 15-second excerpts of piano music and would be asked to rate each excerpt on a few terms. The tuning of the excerpts was not explicitly mentioned to participants. For each participant, half of the 30 excerpts were randomly assigned to be in tune and the other half were selected to be out of tune. The excerpts were presented in a randomized order. Following each excerpt, participants were asked to rate, on a 100-point slider scale, (1) how much they liked the music, (2) how interesting they found the music, and (3) how unusual they found the music. After each excerpt, participants were asked whether they recognized the piece of music and, if so, to provide as many details as they could about the piece title and composer. Two auditory attention checks were added at the end of the intonation judgment task, in which a recording prompted participants to click a specific button on the computer.

Following the main intonation judgment task, participants completed a short questionnaire. The questionnaire assessed participants' age, gender, level of education, primary language, hearing aid use, self-reported musical skill, self-reported intonation perception, self-reported absolute pitch ability, and formal musical training. Following the questionnaire, participants were given a unique completion code, which they entered into Mechanical Turk to receive compensation for participating.

Data Exclusion

Of the 100 recruited participants, one participant's data was not successfully transferred to our server. Of the remaining 99 participants, we adopted three exclusion criteria: (1) failing at least one of the two auditory attention checks, (2) reporting the use of a hearing aid or otherwise indicating that they had a health concern that might affect the results of the study, or (3) self-identifying as an absolute pitch possessor. Five participants were excluded due to failing at least one auditory attention check, no participants were excluded due to the reported use of a hearing aid or disclosing a health-related concern, and two participants were excluded for self-identifying as absolute pitch possessors. Thus, 92 participants were included in the main analyses.

Data Analysis

To assess whether the tuning of the musical excerpts influenced participants' ratings, we constructed linear mixed-effect models using the "lme4" package in R (Bates et al., 2020). We generated three models – one using the *liking* rating as the dependent variable, one using the *interesting* rating as the dependent variable, and one using the *unusual* rating as the dependent variable. Each model contained random intercepts for both participant and musical excerpt. Each model also contained a dummy term for intonation (standard vs. nonstandard tuning). To assess the importance of the intonation term in the model, we used both a null hypothesis significance testing (NHST) and a Bayesian approach. For the NHST approach, we calculated *p*-values associated with the intonation terms using package "lmerTest" in R (Kuznetsova et al., 2020). For the Bayesian approach, we compared each model containing the intonation term to a null (intercept-only) model and calculated Bayes Factors. The reported Bayes Factors (BF_{10}) represent how likely the intonation model is, relative to the null model, given the data. For example, a BF_{10} of 5 would mean that the model containing the intonation term is five times likelier than the null, intercept-only model given the data, whereas a BF_{10} of 0.20 would mean that the model containing the intonation term is one-fifth as likely as the null, intercept-only model given the data.

Results

The Influence of Intonation on Excerpt Ratings

Intonation was not a significant predictor of how much participants reported liking an excerpt, $B = -0.94$, $SE = 0.74$, $p = .204$. On average, participants' mean *liking* rating was 58.19 ($SD: 12.12$) for in-tune excerpts and 57.42 ($SD: 12.58$) for out-of-tune excerpts. The BF_{10} in comparing the intonation model to the intercept-only model was 0.095, meaning the *null* model was 10.53 times more likely than the intonation model given the data. Intonation was also not a significant predictor of how interesting participants perceived the excerpts, $B = -0.89$, $SE = 0.77$, $p = .248$. On average, participants' mean *interesting* rating was 57.73 ($SD: 12.07$) for in-tune excerpts and 57.14 ($SD: 12.24$) for out-of-tune excerpts. The BF_{10} in comparing the intonation model to the intercept-only model was 0.081, meaning the *null* model was 12.35 times more likely than the intonation model given the data. Finally, intonation was not a significant predictor of how unusual participants perceived the excerpts, $B = -0.85$, $SE = 0.75$, $p = .257$. On average, participants' mean *unusual* rating was 39.67 ($SD: 15.95$) for in-tune excerpts and 39.11 ($SD: 15.04$) for out-of-tune excerpts. The BF_{10} in comparing the intonation model to the intercept-only

model was 0.080, meaning the *null* model was 12.50 times more likely than the intonation model given the data. Mean rating are plotted in Figure 1.

[[Figure 1 about here]]

Correlating Ratings with Questionnaire Measures

We examined how our questionnaire measures correlated with the mean *liking*, *interesting*, and *unusual* ratings (i.e., regardless of intonation), as well as with intonation difference scores for each rating. For example, the intonation difference score for *liking* ratings was calculated by subtracting the in-tune liking rating from the out-of-tune liking rating for each participant.

Correlation results are reported in Table 1. Overall, we found several intercorrelations among participant ratings and difference scores, suggesting that all three ratings had considerable overlapping variance and that the ratings, as a whole, can be taken to reflect a more general aesthetic evaluation of the pieces. Mean liking ratings were positively correlated with mean interesting ratings, and mean interesting ratings were positively correlated with mean unusual ratings. Moreover, all three intonation difference scores were positively intercorrelated. However, importantly there were no individual difference measures collected in the questionnaire that related to the intonation difference scores. All musical measures (musical training, self-reported pitch ability, self-reported musical skill) were strongly intercorrelated, but no musical measure related to excerpt ratings in any way.

Excerpt Familiarity

Participants reported essentially no prior familiarity with the musical excerpts. Out of the 30 total excerpts, the mean percentage that participants reported to recognize was just 1.23% (i.e., just 0.37 excerpts per participant). The modal number of recognized pieces across participants was 0, and the maximum number of recognized pieces was 5. Even when an excerpt was reported to be familiar, no participant was able to provide additional details related to the composer or the name of the piece.

[[Table 1 about here]]

Discussion

Experiment 1 was designed to assess whether intonation (i.e., tuning a piece of music to be conventionally “in tune” or “out of tune”) would influence listeners’ aesthetic evaluations of unfamiliar musical excerpts. Although a significant proportion of Western music tunes the A

above middle C to 440 Hz (A440 tuning), as established by the American Standards Association and the International Organization of Standardization, several music ensembles tune to different standards, for reasons ranging from historical accuracy (e.g., Baroque tuning standards) to artistic decisions related to perceived changes in sound quality. Given the increased understanding of implicit memory for absolute pitch in the general population (e.g., Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003; Terhardt & Seewann, 1983), including an implicit understanding of whether musical notes are tuned according to A440 standards (Van Hedger et al., 2017), it was hypothesized that the nonstandard tuning might influence listeners' ratings of novel musical excerpts. This is ostensibly because unconventionally tuned music is encountered less frequently in the environment and therefore might be more liked compared to conventionally tuned music (cf. Ben-Haim et al., 2014).

Overall, the results of Experiment 1 do not support the hypothesis that intonation influences listener evaluations of musical excerpts. Participants were asked to rate each excerpt of music in terms of how much they *liked* the music, how *interesting* they found the music, and how *unusual* they found the music. Notably, the tuning of the musical excerpts did not influence these ratings, with the null model (i.e., that did not include the intonation term) being 10.53 to 12.50 times more likely than the intonation model given the data. Musical self-report measures also did not relate to intonation differences in ratings. Finally, perhaps most strikingly, the three ratings were all within a *single point* of each other for in-tune and out-of-tune excerpts on a 100-point scale.

These findings, taken together, suggest that intonation had no measurable influence on listener evaluations of musical excerpts in the present experiment. Although null results cannot conclude that intonation has no effect on aesthetic ratings in all circumstances, it is worth discussing why null results were observed in the present experiment, particularly given prior reports of implicit absolute intonation ability (Van Hedger et al., 2017). First, the null results might have been driven by the implicit nature of the task. Although the ratings themselves were explicit, tuning was never mentioned to participants at any point during the task. As such, participants might have relied on other musical features that were more obvious (e.g., tempo, pitch range, tonality) in making their ratings. Thus, it is possible that alerting participants to the fact that some of the musical pieces would have nonstandard tuning might have changed how participants attended to the excerpts and thus could have influenced ratings based on the intonation of the musical excerpt.

Second, it is possible that intonation might only influence aesthetic ratings of *familiar* musical pieces that have been consistently heard with a specific tuning. Intonation was hypothesized to influence ratings in the present experiment because unconventionally tuned music is less commonly encountered in one's listening environment, but it is unclear whether this experience-based explanation would necessarily generalize to all music or would only be observed for previously heard music. It is possible that using highly familiar musical recordings, similar to other investigations of implicit absolute pitch memory (e.g., Jakubowski & Müllensiefen, 2013; Schellenberg & Trehub, 2003; Van Hedger et al., 2017), would have afforded participants the ability to judge the music based on how the current intonation adheres to (or deviates from) their prior experiences with that recording. Such an explanation would suggest that intonation might only influence aesthetic ratings in more limited circumstances and might not reflect a generalized ability.

Third, and perhaps most fundamentally, it is possible that participants simply cannot determine whether musical excerpts are conventionally "in tune" versus "out of tune," even when explicitly prompted. This possibility initially seems at odds with Van Hedger et al. (2017); however, it is important to note that the authors of this prior work only tested single, isolated musical notes. Given the importance of relative pitch processing in music (e.g., Miyazaki et al., 2018) and the discussion of how relative and absolute pitch processing might interfere with one another (Miyazaki, 1993; Miyazaki, 1995), it is reasonable to predict that isolated musical notes might provide a different pattern of results than rich, polyphonic musical compositions that contain salient relative pitch cues. Thus, the primary goal of Experiment 2 is to explore this third possibility.

Specifically, Experiment 2 aims to replicate and extend the phenomenon of implicit absolute intonation reported by Van Hedger et al. (2017), with a particular emphasis on whether implicit absolute intonation is observed when relative pitch information is present. If participants can reliably differentiate "in tune" from "out of tune," even when the to-be-judged stimuli contain relative pitch cues (e.g., when judging the same excerpts from Experiment 1), this suggests that participants in Experiment 1 could, in principle, use tuning information to influence their ratings. In contrast, if participants show no reliable differentiation of "in tune" from "out of tune," this provides a more straightforward interpretation of the null results in Experiment 1.

Experiment 2

Method

Participants

A total of 200 participants were recruited from Amazon Mechanical Turk and 193 were retained for the final analyses ($M_{\text{AGE}} = 40.43$, $SD_{\text{AGE}} = 12.03$, range of 21 to 70 years). The *Data Exclusion* section provides details on participant exclusion. Similar to Experiment 1, we used Cloud Research (Litman et al., 2017) to recruit a subset of participants from the larger Mechanical Turk participant pool. Participants were required to have at least a 90% approval rating from a minimum of 50 prior Mechanical Turk assignments, could not have participated in Experiment 1, and had to have passed internal attention checks administered by Cloud Research. All participants received monetary compensation upon completion of the experiment. The protocol was approved by the Research Ethics Board of the University of Western Ontario.

Materials

The experiment was programmed in jsPsych 6 (de Leeuw, 2015). The to-be-judged musical sounds were all created in Reason 4 (Propellerhead: Stockholm) and used a piano timbre. Given that the musical sounds were initially generated in MIDI format, the tuning of each sound was altered prior to exporting each as an audio file. Specifically, the in-tune sounds were exported by setting the master tuning option to the default (+0 cents; A440 tuning), whereas the out-of-tune sounds were exported by setting the master tuning option to +50 cents (~A453 tuning). All sounds had a sampling rate of 44.1 kHz and 16-bit depth.

The isolated musical notes were similar to those reported by Van Hedger et al. (2017). We tested 12 notes, ranging from C4 to B4. Each of the 12 notes in this range had two versions – an in-tune version (e.g., C4) and an out-of-tune version (e.g., C4 +50 cents), resulting in 24 total stimuli. The isolated musical chords consisted of 12 major triads in root position, with the root note ranging from C4 to B4. Similar to the isolated notes, each of the 12 major chords in this range had two versions – an in-tune version (e.g., C4 major) and an out-of-tune version (e.g., C4 major +50 cents), resulting in 24 total stimuli. The musical scales consisted of the first five notes of 12 major scales, with the initial note of each scale ranging from C4 to B4. Similar to the isolated notes and chords, each of the 12 major scales in this range had two versions – an in-tune version (e.g., C4 major scale) and an out-of-tune version (e.g., C4 major scale +50 cents), resulting in 24 total stimuli. The musical notes, chords, and scales were all 1000ms in duration. The musical excerpts were taken from Experiment 1. Given that 30 total musical

excerpts were used in Experiment 1, 24 excerpts were randomly selected for each participant. Half of the randomly selected excerpts were in tune and half were out of tune. Each excerpt was trimmed to 5000ms, with a 500ms linear fade in and fade out. All musical stimuli were root-mean-square normalized to -20 dB Full Spectrum.

The inter-trial “scramble” sounds were designed to disrupt echoic and short-term memory of the preceding musical stimulus (cf. Nees, 2016). Each inter-trial scramble sound consisted of $1/f$ pink noise, which was mixed with *tone clouds*. The tone clouds contained 50 sine tones per second – in other words, a new tone onset occurred every 20ms. Each sine tone was 75 ms in duration, and the tones were randomly generated within a range of 147 to 1320 Hz. The scramble sounds were 5000ms in duration, with the tone clouds spanning over the first 4500ms of the sound (i.e., 225 tones). The tone clouds and pink noise were created with a custom script in Matlab (MathWorks: Natick, MA). The auditory calibration materials were identical to those described in Experiment 1.

Procedure

After reading a letter of information outlining the details of the study and providing informed consent, participants completed the same auditory calibration as reported in Experiment 1. Following the auditory calibration, participants were randomly assigned to one of four conditions: (1) notes, (2) chords, (3) scales, or (4) excerpts. Regardless of condition, participants were instructed that they would be making judgments about the tuning of piano sounds. Specifically, participants were told that some of the sounds would be *in tune* and some would be *out of tune*. In case participants had little or no musical training, *in tune* was also defined as sounding *familiar* or *good*, whereas *out of tune* was also defined as sounding *unfamiliar* or *bad*. Participants were additionally instructed to base their decisions on their initial, “gut” feeling.

Participants then completed the main task, in which they judged 24 musical sounds (12 in tune, 12 out of tune) in a randomized order. Each trial consisted of (1) the sound presentation, (2) a forced-choice judgment of whether the sound was *in tune* or *out of tune*, and (3) a 5000ms inter-trial “scramble” sound. The scramble sound, which consisted of pink noise imposed on a random “tone cloud” of sine tones, was meant to prevent relative pitch information of prior trials influencing subsequent trials. Participants repeated this procedure until all 24 musical sounds had been rated. At the end of the main task, participants were presented with

two auditory attention checks, in which they were instructed to click on a specifically marked button on the computer via spoken instructions.

Following the main rating task, participants completed a short questionnaire. The questionnaire assessed age, gender, highest level of education, hearing aid use, primary and secondary languages, self-reported musical ability, self-reported pitch perception, formal musical training, childhood musical appreciation, and childhood musical encouragement. Participants were also given a free response option to disclose any information they thought might influence their results. Participants were then provided a unique completion code and compensated.

Data Exclusion

There were three primary reasons why participants were excluded from analysis. The first was providing an incorrect answer for the auditory attention checks administered in the experiment. Given that these attention checks occurred without prior warning, failing to provide a correct answer was taken to indicate that a participant had not consistently listened to the musical stimuli. The second reason was if participants reported the use of a hearing aid or otherwise indicated that they had a health concern that might affect the results of the study. The third was if participants self-reported possessing absolute pitch, which was a response option on the self-reported pitch perception question. Of the 200 recruited participants, one failed to correctly answer both auditory attention assessments, one participant reported the use of a hearing aid, one participant disclosed that their perception of pitch had significantly deteriorated with age, and four participants reported possessing absolute pitch. This left 193 participants in the primary analysis (Note Condition: $n = 45$, Chord Condition: $n = 51$, Scale Condition: $n = 52$, Excerpt Condition: $n = 45$).

Data Analysis

To assess whether participants in each condition were above chance in determining the intonation of the musical sounds, we used one-sample t-tests, with mean accuracy being tested against the chance estimate of 50%. To assess whether mean accuracy differed across conditions, we used a one-way ANOVA with Condition (notes, chords, scales, excerpts) as a between-participant factor. Reported post-hoc tests used Bonferroni-Holm corrections. Correlations between questionnaire measures and performance were assessed via uncorrected Pearson Product-Moment Correlations. Finally, similar to Experiment 1, for each analysis we report both p -values and Bayes Factors – calculated via Bayesian equivalents of the reported

tests in JASP (Marsman & Wagenmakers, 2017) – to facilitate the understanding of the relative evidence for or against our hypothesis. The reported Bayes Factors (BF_{10}) represent how likely the alternative hypothesis is, relative to the null hypothesis, given the data.

Results

Mean Performance Tested against Chance

Overall, we found clear evidence for above-chance performance when the to-be-judged musical sounds did not contain temporally unfolding relative pitch cues (Figure 2). Mean performance in the isolated note condition was 57.4% (SD : 11.0%), which was significantly above chance, $t(44) = 4.51$, $p < .001$, $d = 0.67$; $BF_{10} = 463.2$. Mean performance in the isolated chord condition was 57.8% (SD : 11.1%), which was also significantly above chance, $t(50) = 5.17$, $p < .001$, $d = 0.73$; $BF_{10} = 4405$.

In contrast, the musical scales and musical excerpts – which both contained relative pitch changes that unfolded over time – did not show clear above-chance performance. Mean performance in the musical scale condition was 52.1% (SD : 9.5%), which did not statistically differ from the chance estimate, $t(51) = 1.58$, $p = .120$, $d = 0.22$, $BF_{10} = 0.484$. Mean performance in the musical excerpt condition was nominally lower, at 51.2% (SD : 9.9%), which did not statistically differ from chance, $t(44) = 0.82$, $p = .418$, $d = 0.12$, $BF_{10} = 0.221$. Notably, the Bayes Factor from the musical excerpt analysis suggests that the null hypothesis (i.e., at-chance performance) is approximately 4.5 times more likely than the alternative hypothesis given the data.

[[Figure 2 about here]]

Comparisons across Conditions

The one-way ANOVA found a significant main effect of condition, $F(3,189) = 5.56$, $p = .001$, $\eta^2_p = .081$, $BF_{10} = 22.56$, suggesting that at least one group significantly differed from one or more of the other groups. Post-hoc tests supported the hypothesis that the isolated notes and chords differed from the sounds containing relative pitch changes (scales and excerpts). Isolated musical notes were significantly higher than both scales, $t = 2.52$, $p = .038$; $BF_{10} = 3.67$, and excerpts, $t = 2.83$, $p = .025$; $BF_{10} = 6.58$. Isolated musical chords were significantly higher than both scales, $t = 2.90$, $p = .021$; $BF_{10} = 8.49$, and excerpts, $t = 3.21$, $p = .009$; $BF_{10} = 15.75$. Isolated notes and chords did not significantly differ from one another, $t = -0.28$, $p = 1$; $BF_{10} =$

0.22, nor did scales and excerpts significantly differ from one another, $t = 0.42$, $p = 1$; $BF_{10} = 0.23$.

Correlating Performance with Questionnaire Measures

The results of the exploratory correlation analyses are reported in Table 2. None of the measures collected in the questionnaire were associated with intonation performance accuracy. The only significant correlations we observed were between age and highest level of education, as well as strong intercorrelations among our music-related questionnaire measures (self-reported musical skill, self-reported pitch perception, the extent to which music listening was encouraged during childhood, the extent to which music listening was appreciated during childhood, and whether the participant reported formal musical training). The lack of an association between intonation performance accuracy and our collected measures was not driven by a particular condition – i.e., separately running the correlations for each condition yielded comparable (i.e., non-significant) results.

[[Table 2 about here]]

Discussion

Experiment 2 was meant to determine whether listeners could accurately judge the absolute tuning of different kinds of musical sounds. Although prior work has suggested that absolute memory for tuning is widespread (Van Hedger et al., 2017), this prior work only tested isolated musical notes, which have little ecological validity. Thus, in making claims that absolutely intonation perception might influence aspects of musical processing, it is important to determine under which circumstances listeners can make these judgments.

The results of Experiment 2 suggest that listeners can make accurate judgments of absolute intonation under limited circumstances. Specifically, listeners appear to be robustly above chance in determining whether “static” notes and chords, which do not contain relative pitch changes, are in tune versus out of tune. Strikingly, this ability is significantly attenuated (and does not significantly differ from chance) as soon as the to-be-judged sounds contain relative pitch changes. In this sense, the results from Experiment 2 provide a direct replication of Van Hedger et al. (2017) but also suggest that absolute intonation perception is only observed in highly artificial settings, in which the to-be-judged sounds do not contain relative pitch changes. Overall, then, the findings of Experiment 2 suggest that absolute intonation perception

1 is a replicable phenomenon but may not factor into situations in which relative pitch changes are
2 present (i.e., virtually all musical settings outside of an experimental context).

3 **General Discussion**

4 The present experiments were designed to assess how absolute tuning relates to the
5 evaluations of musical sounds. The deliberate adoption of different tuning standards (e.g., by
6 different music ensembles) is often justified aesthetically (e.g., creating a more brilliant sound;
7 Farnsworth, 1968), yet it was unclear whether tuning changes would influence evaluations of
8 musical sounds among everyday listeners, who were not specifically recruited for their musical
9 expertise. In Experiment 1, we assessed how tuning might influence aesthetic ratings of musical
10 excerpts. In Experiment 2, we focused on more explicit categorization judgments (i.e., whether a
11 sound was “in tune” or “out of tune”). The results suggest that absolute tuning might not
12 influence evaluations of musical excerpts (Experiment 1), possibly because listeners can only
13 differentiate “in tune” from “out of tune” sounds for simplistic musical stimuli that do not contain
14 relative pitch changes (Experiment 2). Measures of musical expertise did not correlate with
15 either finding.

16 The results of Experiment 1 contradicted our initial hypothesis that absolute tuning
17 would influence aesthetic evaluations of musical compositions. Participants' mean ratings for
18 how much they liked the music, how interesting they found the music, and how unusual they
19 found the music were all within a single point of one another for standard (A440) and
20 nonstandard (~A453) tuning, which is remarkable considering the responses were made on a
21 100-point scale. Additionally, the null models (i.e., that did not contain the intonation term in the
22 model) were over 10 times likelier than the models coding for intonation. Although the
23 interpretation of null findings must be made with caution, Experiment 2 provided an important
24 clarification of these null results by suggesting that listeners may not be able to perceive
25 absolute tuning differences with more complex musical stimuli (such as those used in
26 Experiment 1).

27 At first glance, the findings from the present experiments might appear to be
28 inconsistent, as they suggest that only *some* musical sounds are able to be differentiated based
29 on absolute tuning. However, the present findings are entirely consistent with both theoretical
30 and empirical discussions of absolute and relative pitch processing. Relative pitch (RP), which
31 can be defined as encoding the relational changes in musical notes rather than the specific
32 identities of each individual note, is considered the dominant mode of musical processing,

observable early on in development (e.g., Trehub & Hannon, 2006). Moreover, AP and RP processing are considered to be independent abilities, in that an individual's absolute pitch ability is not necessarily predictive of their relative pitch ability and vice versa (e.g., see Ziv & Radin, 2014). Despite their presumed independence, AP and RP are considered to be incompatible modes of musical processing (Miyazaki, 2004), meaning that these modes of processing might interfere with one another depending on the current listening context. In support of this idea, research has shown that musical tasks encouraging RP might interfere with AP (Hedger et al., 2013; Van Hedger et al., 2018) and tasks encouraging AP might interfere with RP (Miyazaki, 1993; Ziv & Radin, 2014). Thus, the present findings fit within this framework, as they suggest that musical stimuli containing RP cues encourage a relative mode of processing at the expense of absolute intonation processing.

The present findings additionally raise questions about intonation perception among AP possessors. The participants in both experiments self-identified as non-AP possessors (with AP identification serving as an exclusion criterion). The decision to limit analyses to non-AP possessors was made because AP possessors were hypothesized to engage in different strategies in making absolute intonation judgments. Specifically, by definition, AP possessors can explicitly identify musical notes by their note names (e.g., C), as well as make fine-grained "goodness-of-fit" judgments based on absolute tuning (see Levitin & Rogers, 2005). Thus, judgments of absolute tuning are more likely to be explicit among AP possessors (e.g., being able to explicitly report that a piece of music is +50 cents sharp), making it more likely that AP possessors would display tuning-related differences in aesthetic judgments (Experiment 1), as well as above-chance differentiation of in-tune and out-of-tune sounds even when relative pitch cues are present (Experiment 2). In fact, it is possible that AP possessors might show augmented effects for richer, more complex musical stimuli, as these contain more notes that can be independently judged as "in tune" or "out of tune." That being said, AP possessors can flexibly adapt their tuning standards when relative pitch cues are preserved (e.g., Hedger et al., 2013), raising the possibility that even AP possessors might show an attenuated ability to differentiate in-tune from out-of-tune sounds when the to-be-judged sounds contain salient RP cues. Thus, re-running this experiment using AP possessors as participants could provide insights into how absolute and relative pitch cues interact when absolute pitch information is able to be categorized explicitly.

Additionally, given the discussion of AP as a more distributed ability (e.g., Bermudez & Zatorre, 2009; Van Hedger et al., 2020), it is possible that the best approach to take in future

investigations is to use performance-based assessments of AP and RP processing as an informative individual difference measure. Although we did not find any evidence that the administered musical measures were associated with individual differences in performance in the present experiments, these were all self-report measures and did not specifically probe relative and absolute pitch abilities. Given that AP and RP are theoretically independent (e.g., Ziv & Radin, 2014), researchers could calculate the relative strength of an individual's RP, normalized against their AP, to more directly assess whether these modes of processing influence absolute tuning perception. For example, a testable prediction that stems from this treatment of AP and RP processing is that an individual who has strong RP might be more likely to have disrupted absolute tuning judgments when RP cues are present (e.g., for scales and musical excerpts). Another testable and nonintuitive hypothesis is that "genuine AP possessors" might not actually have intact absolute tuning perception across all musical stimuli. More specifically, if an individual has strong AP but also strong RP, they might be more flexible and use RP processing in situations where this is salient (e.g., listening to musical scales or excerpts). Thus, these individuals who display strong AP and RP might show attenuated absolute tuning judgments depending on the context, despite possessing AP.

Finally, there are some limitations of the present experiments that could be addressed in future studies. As mentioned previously, the null effects found in Experiment 1 cannot determine conclusively that absolute tuning does not influence aesthetic judgments under all listening conditions. For example, the presumed "brilliance" of tuning to a sharper standard (Geringer, 1976) might be more salient for specific instruments. The piano was selected in the present experiments because prior research on absolute tuning has shown above-chance judgments using a piano timbre (Van Hedger et al., 2017), but it is possible that the use of a different instrument – with a more restricted pitch range – might be more successful in eliciting tuning-related differences in aesthetic judgments. If a brass instrument, such as a trumpet, were playing in the extreme high end of its register, then it is plausible that a sharpened tuning standard could influence aesthetic evaluations of the music, ostensibly because the trumpet would be heard playing frequencies that it cannot play when tuned to A440. Thus, future work should extend these findings to more instrumentally varied musical stimuli.

A second, related limitation is that the musical pieces were all relatively homogenous in terms of style. All of the musical excerpts were taken from piano compositions from the mid-to-late nineteenth-century, written by European composers. Thus, participants in the present experiments may have found these pieces too stylistically similar to one another, which could

1 have systematically compressed the aesthetic evaluations in Experiment 1. Assessing how
2 absolute tuning influences aesthetic evaluations across a wider range of musical compositions
3 (e.g., from classical compositions to contemporary pop) would provide a stronger sense of how
4 well the present results generalize to different listening contexts.

5 **Conclusion**

6 Most listeners find music to be aesthetically pleasing, however the specific features that
7 relate to aesthetic evaluations of music are not well understood. The present experiments
8 assessed whether absolute intonation (i.e., tuning) could influence perceptions of music among
9 everyday listeners, not specifically recruited for their musical expertise or absolute pitch ability.
10 In Experiment 1, we found no evidence that absolute tuning influenced listener evaluations of
11 unfamiliar music. In Experiment 2, we found that most listeners could reliably differentiate in-
12 tune from out-of-tune musical sounds, but only when they did not contain relative pitch changes.
13 Overall, then, these results suggest that absolute features of music related to tuning are
14 remembered by most listeners and can manifest in the form of explicit judgments, but these
15 memory representations are subject to interference by more salient relative pitch cues. Thus, it
16 is unlikely that absolute tuning influences aesthetic evaluations of music under ecologically valid
17 listening conditions, in which the music contains intact relative pitch cues.

18

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Tables and Figures

Table 1: Correlation Matrix from Experiment 1

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Liking Rating	-										
2. Interest. Rating	.545***	-									
3. Unusual Rating	.089	.218*	-								
4. Liking Diff.	.056	.628***	-.021	-							
5. Interest. Diff.	.064	.789***	.036	.812***	-						
6. Unusual Diff.	-.123	.257*	-.122	.234*	.446***	-					
7. Age	.129	.073	.209*	-.065	.018	.034	-				
8. Edu.	-.050	-.093	-.013	-.095	-.062	.008	.131	-			
9. Music Skill	.024	-.057	-.019	.004	-.094	.029	-.048	.066	-		
10. Music Training	-.016	-.068	.182	-.043	-.152	-.020	-.016	.010	.593***	-	
11. Pitch Perception	.126	.090	-.078	.158	.095	.109	.106	-.043	.503***	.369***	-

Note: Values represent Pearson correlation coefficients. Significant correlations are printed in bold. Interest. = Interesting; Diff. = Intonation Difference Score; Edu. = Education; * $p < .05$ ** $p < .01$ *** $p < .001$

1 Table 2: Correlation Matrix from Experiment 2

	1.	2.	3.	4.	5.	6.	7.	8.
1. Intonation Accuracy	-							
2. Age	.025	-						
3. Education	-.054	-.026	-					
4. Music Skill	.071	.193**	-.016	-				
5. Pitch Perception	.019	.134	.049	.393***	-			
6. Music Appreciated	-.064	.075	-.020	.445***	.263***	-		
7. Music Encouraged	-.017	.064	-.011	.334***	.241***	.737***	-	
8. Music Training (y/n)	.086	.100	-.081	.570***	.199**	.259***	.248***	-

2
3 *Note:* Values represent Pearson correlation coefficients. Significant values are bolded. ** $p < .01$
4 *** $p < .001$

5

1 **Figure 1:** Violin plots of aesthetic ratings split by musical excerpt tuning in Experiment 1

2
3 *Note: Lines connecting the in-tune and out-of-tune violin plots represent individual participant*
4 *data. Error bars represent plus or minus one standard error of the mean.*
5

1 **Figure 2:** Violin plots of intonation judgment accuracy across all conditions in Experiment 2

2

3 *Note: The dashed horizontal line represents chance performance. Error bars represent plus or*
4 *minus one standard error of the mean. Note and Chord Conditions were robustly above chance*
5 *(p s < .001), whereas the Scale and Excerpt Conditions did not significantly differ from the*
6 *chance estimate.*