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Does Higher Music Tend to Move Faster? Evidence For A Pitch-Speed Relationship.

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ABSTRACT

We tested whether higher-pitched music is associated with faster melodic speeds in Western music. Three empirical studies produced results consistent with the hypothesized pitch-speed relationship. This pitch-speed correspondence was evident when analyzing musical parts and instruments, but not when considering isolated notes. We sketch five possible origins for the observed effect: acoustic, kinematic, music theoretical, sensory/perceptual, and psychological.

Study 1 tested the idea that high-pitched notes will tend to be faster than low-pitched notes, regardless of musical part or instrument. Using an electronic database of 174 scores of Western music, we calculated correlations between pitch height and note duration. Results were mixed, and dependent on genre. Study 2 tested whether higher-pitched musical parts tend to be faster than lower-pitched ones. Using an independent sample of 238 Western scores, we tallied the number of pitched events per musical part to index melodic speed. Statistically significant effects were observed in every subsample studied when considering the music part-by-part. Study 3 directly measured melodic speed in notes per second using 192 live recordings of solo instrumental performances. A strong correlation ($r = 0.754$, $p < .001$) between observed median melodic speed and instrumental midrange.

I. INTRODUCTION

Zohar Eitan recently observed that lower voices in Western music appear to move more slowly than higher voices. Listeners might have certain expectations concerning just how fast music of a certain pitch range ought to go. On one hand, such expectations might be the direct result of crossmodal perceptual interactions. For example, recent work by Collier & Hubbard (2001) suggests that percepts of musical speed are importantly influenced by pitch height, with higher-pitched tone sequences being perceived as having faster speeds. On the other hand, the intuition that faster musical speeds are associated with higher pitch might accurately reflect the compositions and performances which constitute one's musical environment.

In order to investigate the latter possibility, we conducted both score-based and recording-based analyses to empirically quantify pitch-speed relationships in Western music. Generally speaking, we suspected that music of high pitch would tend to be faster than music of low pitch.

Here, we employ three complementary methods, each of which testing different predictions of the pitch-speed hypothesis. Study 1 tests the idea that high-pitched notes will tend to be faster (i.e., shorter) than low-pitched notes, regardless of musical part or instrument. To this end, we determined the notated pitch height and duration of notes in a sample of Western music, and calculated correlations to characterize each sample. Study 2 is inspired by the fact that music tends to be organized into individual 'parts' or 'voices.' If higher musical parts tend to be faster than lower musical parts, then one would expect higher musical parts to contain more notes. Using an independent sample of musical scores, we tallied pitched events per musical part as an index of that part's musical activity. The note counts of the musical parts were then compared based on their relative position in the musical texture. In Study 3 we investigate whether music written specifically for high-pitched instruments tends to be performed faster than music written for low-pitched instruments. In contrast to the score-based studies, this test for the effect of instrument employs recorded performances. Musical speed was calculated in notes per second, and correlations measured with respect to each instrument's tessitura.

To anticipate our results, we find empirical evidence consistent with a pitch-speed relationship in which higher music is indeed faster. Furthermore, it seems that this relationship becomes most evident when the experimental method preserves the notion of musical 'line.'

II. STUDY 1: NOTEWISE RELATIONSHIP BETWEEN PITCH HEIGHT AND DURATION

If there is a relationship between pitch height and musical speed, then one might predict that high-pitched notes would tend to exhibit shorter durations than low-pitched notes, regardless of instrument or musical part. In order to test this hypothesis, we queried six existing databases of notated Western art music, representing contrasting styles and periods. Specifically, our convenience sample included 34 assorted motets by English composers Leonel Power (c1370-1445), John Dunstable (c1390-1453), and Thomas Morley (1557-1602), 21 movements from the Brandenburg concertos by Johann Sebastian Bach (1685-1750), 24 movements from orchestral symphonies by Franz Joseph Haydn (1732-1809), 27 movements from the nine symphonies by Ludwig van Beethoven (1770-1827), 23 piano preludes by Frédéric Chopin (1810-1849), and 45 piano rags by Scott Joplin (1867-1917). Although these works span nearly six hundred years of musical history, they were not chosen to be representative of Western music as a whole; therefore we will analyze each corpus individually.

For a given work, the pitch height of each note was characterized according to its distance in semitones from middle C (C4) and its notated duration (measured in quarter durations). For example, a half note G4 would be coded as having the pitch +7 and duration 2.0. To determine whether longer notes tended to be lower, we quantified the relationship between note length and pitch height using Pearson's coefficient of correlation (r). Given pitch and duration measurements for several notes, a positive (+) correlation would indicate that long durations are associated with higher pitches. By contrast, the hypothesized pitch-speed relationship predicts that long durations (i.e., slower music) would be associated with lower pitches. Therefore, negative (-) correlations would be consistent with the experimental hypothesis. Correlations were calculated independently for each work.

Table 1 and Figure 1 summarize the measured correlations for all six musical subsamples. For each genre, the number of works exhibiting positive and negative correlations between pitch height and duration is tabulated. Average correlations are also reported, in order to provide a rough indication of the strength of the association; negative correlations indicate presence of the predicted effect. As can be seen, the motets, Bach concertos, Chopin preludes, and Joplin rags all skew in the predicted direction, with the rags exhibiting the strongest effect. However, the Haydn and Beethoven symphonies appear to show the opposite effect.

If no relationship exists between pitch height and notated duration, one would expect the number of positive correlations and the number of negative correlations within a corpus to be roughly equal. Accordingly, two-sided binomial sign tests for statistical significance were performed on the correlations for each corpus, and p-values were computed. In order to control for multiple tests, we applied the Bonferroni correction, treating p-values below $\alpha = .05/6 = .008$ as statistically significant. By this criterion, we can conclude that English motets ($p < .0001$) and Joplin rags ($p < .0001$) are more likely than chance to have their longer notes in the lower register and higher notes in the upper register, consistent with our hypothesis. However, the results for the Bach concertos, Haydn symphonies, and Chopin preludes are inconclusive, and the Beethoven symphonies surprisingly exhibited a statistically significant effect in the opposite direction ($p = .006$).

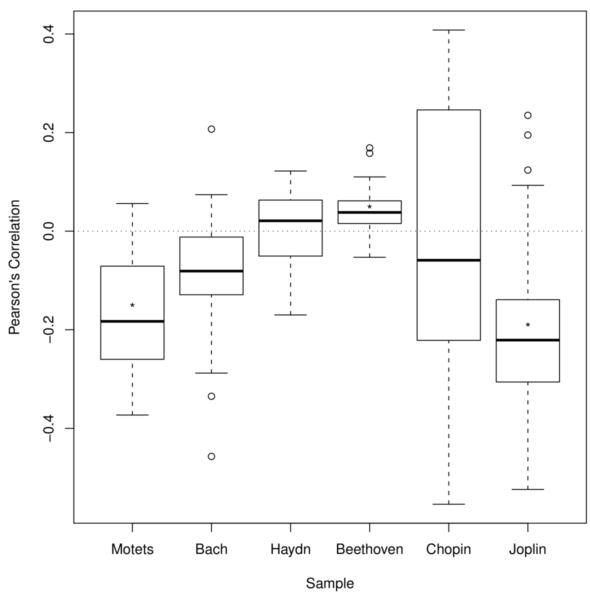

Figure 1. Correlations between Pitch Height and Note Duration for sampled works . Boxed regions correspond to the 25th through 75th percentiles for each corpus, and the dark bars represent the median correlations per sample. Outliers are plotted as points if they fall outside 3/2 the interquartile range. Whiskers represent maximum and minimum nonoutlying values, and are not confidence intervals. Composer names refer only to the sample studied and should not be taken to represent the whole of their oeuvre. Starred (*) samples exhibit statistical significance in binomial sign tests (Bonferroni-adjusted α = .008). the strength of the association; negative correlations indicate presence of the predicted effect. As can be seen, the motets, Bach concertos, Chopin preludes, and Joplin rags all skew in the predicted direction, with the rags exhibiting the strongest effect. However, the Haydn and Beethoven symphonies appear to show the opposite effect.

Table 1. Sample Correlations between Pitch Height and Note Duration. Counts of positive and negative correlations between pitch height and note duration, calculated for individual pieces. The leftmost column identifies the mean correlation across all works in a given corpus as a summary measure. The middle two columns show the number of positive and negative correlations observed. The rightmost column reports two-tailed p-values computed for each corpus based on a binomial sign test. Starred (*) *p*-values indicate statistical significance (adjusted α = .008). If higher notes tend to be faster (i.e., shorter), one would expect that more negative correlations than positive correlations should be observed. Note that the Beethoven and Haydn symphonies are skewed contrary to the hypothesis, and that the effect for Beethoven symphonies reaches statistical significance.

Sample (n)	Correlations			Binomial
	Mean	(+)	(-)	*p*-value
English Motets (34)	-0.170	2	32	*p* < .0001 **
Bach Concertos (21)	-0.089	5	16	*p* = .03
Haydn Symph (24)	0.003	14	10	*p* = .54
Beethoven Symph (27)	0.089	21	6	*p* = .006 *
Chopin Preludes (23)	-0.024	8	15	*p* = .21
Joplin Rags (45)	-0.204	4	41	*p* < .0001 **

Based on these results, it appears that any pitch-speed relationship depends on the particular composer and style of the music analyzed. Across all six samples, we find that the combined number of correlations shows only a slight tendency toward negative values. Broadly speaking, results of this study are not consistent with the hypothesized pitch-speed relationship; at best, the results are equivocal.

It is possible that the purported pitch-speed relationship has been obscured by one or more uncontrolled confounds. As noted above, notated tempo changes and expressive markings are not addressed by the notewise index of musical speed. One could notice that the two genres with statistically significant results, the motets and rags, are both unlikely to have changes in tempo or significant expressive modification by performers. By contrast, symphonies and concerti tend to be longer pieces more likely to include tempo changes, and the works of Chopin in particular are commonly associated with the use of tempo rubato.

Other possible methodological shortcomings could be identified. First, one may question whether note duration is an adequate operationalization of the concept of melodic speed; a combination of duration and intervallic span might be more appropriate. Second, Pearson's r is intended to measure the degree of linear relationship between two variables. It is possible that a simple linear relationship is not the most appropriate way to understand pitch height's interaction with note duration.

III. STUDY 2: PARTWISE DISTRIBUTION OF MUSICAL ACTIVITY

In Western music, it is common to organize music according to musical 'parts' or 'voices.' These are typically distinguished by the person, instrument, or group of instruments performing the part. For example, a choral work might have four separate musical parts—soprano, alto, tenor, and bass—and each would be performed by a different group of musicians. Musical parts can also be understood in a more general sense as being distinct musical melodies occupying a certain pitch range or tessitura. In this way, music written for a single polyphonic instrument such as the organ might also be organized into parts, despite there being only a single performer.

While Study 1 measured individual notes and ignored the partitioning of music into parts, this second study addresses the hypothesized pitch-speed association by examining whether lower musical parts are comparatively slower than higher musical parts. The musical activity in a given musical part might be recorded by simply counting the number of notes present in a section of music. Voices with faster musical speeds would be expected to contain more notes than voices with slower speeds. If the pitch-speed hypothesis were true, then lower parts would tend to contain fewer notes than higher parts.

Measurements of the effect of musical part per se might be easily confounded by instrumental effects. In a given ensemble, it is common for particular instruments to carry certain musical parts. It is therefore possible that any observed differences in speed across parts might actually arise from properties of an instrument rather than of the musical part's position in the texture. In order to minimize the potential confounding effect of instrument, we made an effort to sample works whose parts or voices share similar instrumentation. Moreover, we aimed to assemble a sample of music whose musical lines are clearly divided into parts.

Specifically, the sample included 37 four-part keyboard fugues by Johann Sebastian Bach, 100 six-part mass movements by Giovanni Palestrina (c1525-1594), and 100 string quartet movements primarily by Mozart and Beethoven with additional quartets by Schubert, Mendelssohn, and Brahms. In the case of the Bach fugues, additional voices occasionally enter the texture toward the end of the piece; in this case, this material was omitted from the analysis.

For each piece, the tessitura of each musical part was computed by averaging the pitch heights of every note, measured in semitones from middle C (C4). Average tessiture are reported in Table 2.

In each of the three samples, we measured musical activity by counting the notes in each musical part across all works in the sample. In order to facilitate interpretation, these note totals are also expressed as normalized proportions: For each part, the number of pitched events was divided by of the total number of events in all parts, and subsequently multiplied by the number of parts in the sample. Using this scheme, the expected ratio of note counts for each part would be 1.00 in the absence of any pitch-speed effects. Values greater than 1.00 indicate parts that are especially busy relative to the other parts. Conversely, values below 1.00 indicate parts that are relatively sparse in their activity.

Table 2 reports tessiture, note tallies, ratios of note distribution, and statistical results for the Bach fugues, Palestrina mass movements, and string quartet movements. For all three samples, the distribution of notes is skewed toward the higher voices. This pattern is consistent with the hypothesis that higher voices move more quickly than do lower voices.

A simple inferential test of the experimental hypothesis would examine whether the number of notes in a given part differs significantly from the number of notes in the parts immediately adjacent. Accordingly, we performed chi-squared tests for significance between each adjacent pair of voices. With eleven comparisons, we took marginal tests to be statistically significant when their p-values were below .05/11 = .004. All pairwise comparisons exhibited statistical significance, except for the Soprano/Alto pairing in the Bach Fugues, and the Cantus 1 / Cantus 2 and Cantus 2 / Altus pairings in the Palestrina Masses. Based on these results, it would seem that higher musical parts do indeed show more note activity.

Table 2. Note Distributions Between Musical Parts . Tessituras were calculated for each piece; reported values represent the mean across all pieces in the corpus with each piece weighted equally. Note counts are summed across all pieces in the corresponding corpus; a normalized ratio of note counts is supplied to facilitate comparison. If notes were evenly distributed across parts, a ratio of 1.00 would be expected. Chi-squared tests for statistical significance are shown for each adjacent pair of voices. A starred (*) *p*-value indicates a statistically significant difference in note density compared with the musical voice immediately below. With the expection of the uppermost parts in the Palestrina masses and Bach fugues, all other neighboring pairs of voices display activity differences consistent with the experimental hypothesis.

Bach Fugues (4 parts, 37 fugues)				
Part	**Tessitura**	**Notes**	**Ratio**	**χ2 (*p*)**
Soprano	12.91	14850	1.08	2.55 (p = .11)
Alto	6.40	14576	1.06	9.63 ($p < .002$) *
Tenor	-1.70	14051	1.02	206 ($p < .001$) *
Bass	-9.65	11745	0.85	
Palestrina Masses (6 parts, 101 movements)				
Part	**Tessitura**	**Notes**	**Ratio**	**χ2 (*p*)**
Cantus I	11.64	16440	1.08	.004 (p = .95)
Cantus II	7.21	16429	1.08	3.79 (p = .05)
Altus	4.32	16784	1.10	29.8 ($p < .001$) *
Tenor	0.53	15799	1.04	168 ($p < .001$) *
Baritone	-1.40	13578	0.89	81.6 ($p < .001$) *
Bassus	-7.20	12130	0.79	
String Quartets (4 parts, 100 quartets)				
Part	**Tessitura**	**Notes**	**Ratio**	**χ2 (*p*)**
Violin 1	14.80	60989	1.232	955 ($p < .001$) *
Violin 2	7.61	50661	1.023	197 ($p < .001$) *
Viola	1.38	46296	0.935	441 ($p < .001$) *
Cello	-8.65	40124	0.810	

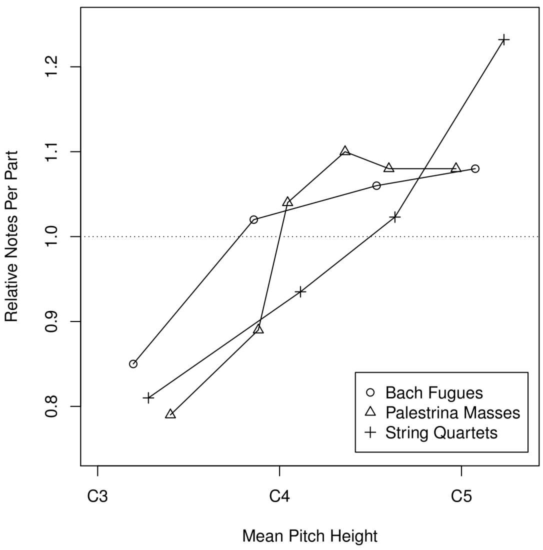

Figure 2. Relative Note Distributions by Average Part Tessitura. Relationship between the relative number of notes in a part compared with the part's average tessitura. Tessitura was indexed by mean pitch height within a part, with each musical work per corpus weighted equally. Relative notes per part was calculated by tallying the notes found in each musical part across all pieces in the sample. Counts were then divided the total number of notes in a sample, and multiplied by the number of parts. Using this normalization scheme, values of 1.00 would be produced by an equal distribution of notes across parts. While the string quartets show a gradual increase in note frequency from lowest to highest part, the Palestrina masses and Bach fugues show more even distributions among the top voices.

A visual representation of these data is given in Figure 2, where each corpus' distribution of notes across parts is plotted against each part's tessitura. All three genres of music display some form of the hypothesized pitch-speed effect. For the Bach fugues and Palestrina masses, the greatest differences in musical activity appear to involve the lowest voices. The string quartets, on the other hand, display a marked increase in activity between all musical parts—particularly between the first and second violin parts. The pattern of partwise pitch-speed association thus appears to differ qualitatively between the string quartets and the other two samples. In particular, the string quartets have significantly more musical activity in the top voice than any other, while the mass movements and fugues exhibit more parity between the top two voices.

One might interpret the outcome of this study as follows: The organization of music into parts does indeed appear to predict certain regularities in note distribution. In particular, a texture's lower parts seem to be considerably less active than a texture's higher parts, with the lowest part typically showing the least activity. This organizational pattern appears to be directly related to the ordinal position of the voices in a texture.

IV. STUDY 3: EFFECT OF INSTRUMENT

The results from our second study imply that musical parts tend to differ in musical activity based on their relative positions in a polyphonic texture. While this outcome is broadly consistent with the experimental pitch-speed hypothesis, we did not explicitly control for differences of instrumentation. Sometimes the observed speed differences occurred between parts which employ the same instrument (as in violin 1 versus violin 2 in the string quartets). In other cases, the differences were evident between parts played on different instruments (as in the viola and cello parts). It remains to be seen whether instrument alone has an effect on event density when "part" is controlled.

In Study 3, we focus specifically on the instrumentation issue, and attempt to answer the question: "Do lower-pitched instruments generally exhibit slower musical speeds, independent of what part they play in the music?" For this purpose, we chose to measure the speed at which various instruments tend to perform solo repertoire. In such music, a single featured instrument typically performs the primary melodic content of the piece, while other musicians provide supportive accompaniment. By considering solo literature for several different instruments, it would be possible to test for an effect of instrumental tessitura on pitch-speed relationships, while controlling for musical part.

Specifically, we identified 16 common monophonic orchestral instruments ranging from tuba to piccolo. These instruments are listed in Table 3, organized by traditional family classifications. For each instrument, the nominal highest and lowest sounding pitches are listed as reported in Samuel Adler's The Study of Orchestration, 3rd Edition (2002). The pitch located in the middle of this range was used to characterize the instrument's range. In the case of the string instruments (violin, viola, cello, double bass), this midrange pitch and the observed mean pitch heights from Study 2 have a correlation of r = .997, indicating that the calculated midrange provides a reasonable estimate of an instrument's practical tessitura.

As a complement to the first two score-based methodologies, the present study made use of recorded material from instrumental performances. In order to assemble a representative sample of typical solo literature, we used the Naxos Music Library's website for access to recordings (Naxos, 2011). Naxos is a major record label known for its extensive catalogue of recorded Western art music. At the time of this study, the catalogue was reported to contain 880,711 individual tracks. We assembled a sample of solo recordings for each target instrument by using the search string "[instrument name] recital." Conveniently, search results specifically identify "recital" performances, which are typically collections of works for solo instrument, usually with piano accompaniment, sometimes with guitar or harp, and occasionally with a larger instrumental ensemble.

We selected the first four albums returned by the search for each of the 16 target instruments. From each album, we randomly selected three tracks, subject to certain constraints. If any track appeared to have two or more soloists, or was a recording of a piece already sampled, it was excluded. For the euphonium and piccolo, four albums could not be identified, so the twelve tracks were drawn from just three unique albums. Similarly, the bass trombone proved to be an uncommon instrument in recital recordings; six tracks each were selected from the two available albums.

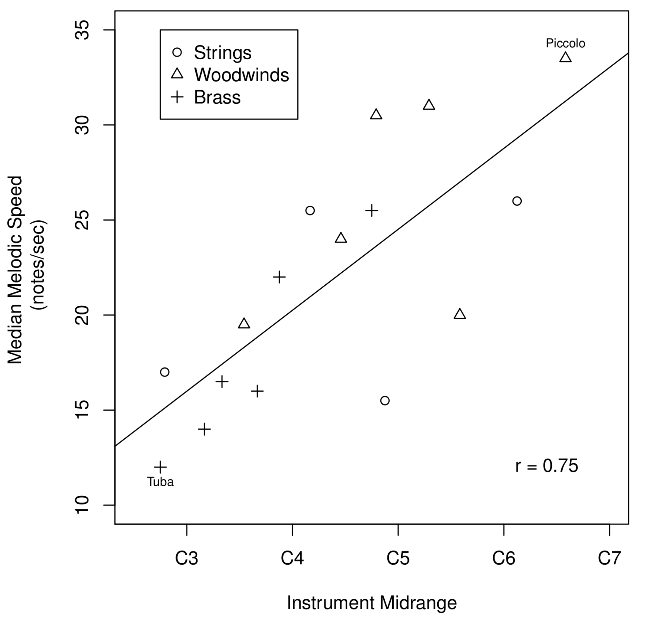

Figure 3: Instrumental Tessitura and Melodic Speed for 16 Solo Instruments . Tessitura is indexed by professional ranges adapted from Adler (2002, Appendix A). Median melodic speed was calculated from the first 10 seconds of twelve recorded performances per instrument (Naxos, 2011). The linear correlation between the two is r = .75, suggesting a strong relationship between instrumental tessitura and melodic speed.

Table 3. Instruments, Ranges, and Observed Speeds. Instruments and ranges adapted from Adler (2002, Appendix A). Range is as reported for professional-caliber orchestras. Midrange indicates the note whose pitch lies in the middle of the range, measured in semitones from middle C (C4). Speeds are measured in notes per second for the first 10 seconds of recital recordings.

Instrument	Range	Midrange	Median Speed (notes/sec)
Strings			
Violin	G4 – B7	25.5	2.60
Viola	C3 – A6	10.5	1.55
Cello	C2 – E6	2.0	2.55
Double Bass	C1 – G4	14.5	1.70
Woodwinds			
Piccolo	D5 – C8	31.0	3.35
Flute	C4 – D7	19.0	2.00
Oboe	B3 – A6	15.5	3.10
Clarinet (A)	C3 – F6	9.5	3.05
Alto Saxophone	D3 – B5	5.5	2.40
Bassoon	B1 – E5	-5.5	1.95
Brass			
Trumpet (C)	F3 – C6	9.0	2.55
Trombone	E2 – F5	-1.5	2.20
Horn	B1 – F5	-4.0	1.60
Bass Trombone	B1 – B4	-8.0	1.65
Euphonium	G1 – B4	-10.0	1.40
Tuba	B0 – G4	-15.0	1.20

For each track, we measured the initial speed of the soloist by counting the number of notes sounding in the first 10 seconds following the soloist's entry. Trills were counted as multiple notes. Dividing each note count by 10 seconds provided an estimate of melodic speed in notes per second. For each instrument, twelve speeds were calculated individually, and the median speed was chosen as the most representative measure of a given instrument's probable melodic speed.

We used Pearson's r to measure the linear relationship between median melodic speed and estimated tessitura. The correlation between instrumental midrange and median melodic speed was found to be quite high (r = .75 df = 14, $p <$ .001). This result is consistent with the hypothesis that high-range instruments tend to play faster than instruments with low range. The data are summarized in Figure 3, which plots the instrument midrange pitch in relation to the median melodic speed in notes per second. As can be seen, there is a clear positive association between instrumental tessitura and typical musical speed. For example, the piccolo exhibits both the highest midrange pitch and the fastest melodic speed, whereas the tuba exhibits the lowest midrange pitch and the slowest melodic speed.

Study 2's score-based results had already indicated that Western compositional practice sometimes specifies musical parts which systematically differ in their relative speeds by tessitura. The present instrumental study provides additional evidence consistent with the idea that high instruments tend to perform faster music than do lower instruments, in the absence of part effects. Our corpus studies necessarily neglect the contribution of performers in shaping musical speed. Because Study 3 utilized sound recordings instead of computerized scores, the observed pitch-speed relationship would presumably reflect some combination of compositional decisions and performance practices.

V. DISCUSSION

The motivation for these studies has been to test for the existence of a pitch-speed relationship in which faster musical speeds are associated with higher-pitched music. Three separate studies employed different operational definitions of 'musical speed.' The first study utilized a notewise approach, characterizing fast or slow notes individually based on their notated lengths. This methodology produced results that differed by genre, and no general relationship was evident. A second study used a partwise approach which attempted to measure the total activity in different notated musical voices. The results of this method were consistent with the pitch-speed hypothesis. Most—but not all—of the voice part pairs exhibited the association between higher pitch and faster speed in each corpus. Our third study, by contrast, directly measured speeds of instrumental performances in note onsets per second. These speeds were highly correlated with instrumental tessiture, as would be predicted by the pitch-speed hypothesis.

In this discussion we will interpret these findings as implicating musical 'line' as an important factor in the pitch-speed relationship, involving contributions both from musical part and from instrumental effects. We then offer several tentative explanatory accounts from different disciplinary perspectives.

A. Notewise versus Partwise Characterizations of Speed

First, we address the outcome disparity between the notewise approach and the partwise approach to characterizing melodic speed. Our first study failed to support a general association between pitch and note duration across the genres studied. There are at least two possible interpretations of this result. On the one hand, it might be that the notewise measurement provides an adequate index of musical speed, but the hypothesized pitch-speed association is simply absent in some of the sampled works. An alternative interpretation would posit that the hypothesized relationship does exist, but the notewise operationalization of musical speed is too crude to detect it. This interpretation is given credence by the fact that the partwise measurement in Study 2 produced results consistent with the hypothesis. This suggests we should examine in greater depth the two measurement strategies.

We interpret the results of the first two studies as indicating that any pitch-speed association probably depends more directly upon the activity of musical parts than upon isolated notes. In other words, the relationship becomes most obvious when the constituent tones are organized as a melodic 'line.' This is intuitively sensible from a perceptual point of view. Things which seem to have any speed at all must first somehow be perceived as being 'objects.' Through the process of auditory streaming, listeners are able to identify musical lines as independent auditory objects (Bregman, 1990). It might be the case that some types of musical speed percepts depend on the perceptual existence of musical lines, or melodies. In short, notes don't have speed, but lines do.

It is also worth noting that monophonic instruments are typically used to perform single melodic lines. Hence, the results of the third study on instrumental effects could be construed as broadly consistent with our conjecture that musical speed is line-dependent.

B. Five Theoretical Accounts

One could imagine several possible ways to explain the association between higher pitch and faster music. Here, we offer several preliminary accounts, roughly organized into five categories: acoustical, kinesiological, music theoretical, perceptual, and psychological. These accounts are by no means meant to be exhaustive, but only suggestive of possible lines of reasoning.

1) Acoustic. One could argue that the putative pitch-speed relationship originates in the physics of sound production. It is well known that tones produced on musical instruments include initial attack transients prior to the onset of steady-state pitched sound. If larger, lower-pitched instruments tend to require more time before the tone reaches full amplitude, this could potentially restrict a low-pitched instrument's ability to play music at rapid speeds.

The duration of instrumental attack transients is not insignificant. Pickering (1986) found that violins can take up to 300 ms or more before attaining a steady tone (cited in Fletcher & Rossing 1991). This duration corresponds to a common-time eighth note at 100bpm, which is perceptually salient in a musical context. If the durations of these transients is pitch-dependent, this could account for some or perhaps all of the observed relationship.

2) Kinesiologic. A pitch-speed relationship might arise from the kinetics of instrumental performance. Lower-pitched instruments tend to be larger and heavier, which could place increased demands on a performer's strength and agility. For instance, valves and fingerboards for large instruments tend to require more strength to operate than those of smaller instruments. It might be physically taxing to rapidly move slides or fingers the distances required in low pitch ranges. It is therefore possible that motor limitations are partially responsible for the putative pitch-speed relationship.

This conjecture could be thought of as a manifestation of Fitts's Law, a model of human motion (Fitts, 1954). According to Fitts's Law, muscular motion is subject to a tradeoff between simultaneous speed and accuracy. In particular, fast movements are unlikely to be very precise, and increasing precision tends to require slower movements. Huron (2001) reported an empirical study showing that melodic behavior is consistent with Fitts's Law, making a kinesiologic account particularly attractive.

3) Music Theoretic. A music scholar might point to the particular history of Western music's development as giving rise to the observed relationship. Two characteristic textures in Western music are polyphony and homophony; each texture offers its own reasons for exhibiting a pitch-speed association.

In twelfth century Aquitainian vocal polyphony, additional voices were composed atop extant—and generally slower-paced—chant melodies (Yudkin, 1989). An association between speed and pitch height would be a natural consequence of such compositional practices. In the case of homophonic music, chord roots are typically seen as being privileged, and so bass notes would tend to exhibit less embellishment than other voices. Such homophonic practices would similarly encourage a pitch-speed association.

In other words, a pitch-speed relationship might simply be an artifact of a given musical tradition. Such an explanatory account could be readily tested through comparative cross-cultural studies.

4) Sensory/Perceptual. The idiosyncratic design of the auditory system could also provide the inspiration for various sensory or perceptual accounts. In particular, pitch perception appears to be influenced by a tone's duration as well as its frequency (Houghty & Garner, 1947). Pollack (1968) asked musicians to match the pitch of short tone bursts to 1-second comparison tones. While perception of tonality above 1000 Hz seemed to require a constant length of about 8 msec., tones below 1000 Hz required a constant number of approximately 8 cycles. This indicates that as rapid tones become lower in frequency, perception of pitch becomes increasingly difficult. More recent work with complex instrumental tones has produced similar results (Robinson & Patterson, 1995).

Another account might begin by noting that uppermost voices in polyphonic textures tend to be the most perceptually salient (Huron, 1989). It would thus be sensible that melodies, which are often faster than accompaniment patterns, would be featured by placing them in the highest voice. However, certainly not all melodies move faster than accompaniments when measured in events per second. We might additionally note that this melody-driven account is not consistent with the results of our second study, where the largest inter-part differences were found to involve bass lines, rather than melody lines.

There might be additional perceptual factors linking pitch to size and speed judgments. Recent work suggests that auditory cues for size and speed might well be closely related, or even overlap in cross-modal interactions. For example, Houben et al. (2004) asked listeners to compare the sounds of two rolling balls, and identify which ball was rolling faster. Listeners frequently misidentified smaller balls (which make high-pitched sounds) as the faster ball when compared to larger (lower-pitched) balls. Similarly, Collier & Hubbard (2001) report that listeners judge both isochronous sine tones and musical scales as faster when they are at higher pitch levels. Together, these studies suggest that listeners associate higher pitched sounds with both smaller sizes and faster speeds.

One would predict based on this account that a melody played by a tuba would sound subjectively slower than the same melody played by a piccolo, even if the objective tempi were identical. Note however that this cannot explain why composers would choose to amplify the perceptual effect by writing music in which lower pitches move slower yet.

5) Psychological. A fifth category of accounts might be broadly deemed psychological in nature. It might be the case that learned associations play a role in the supposed pitch-speed association. If one's musical environment exhibits pitch-speed effects, one could plausibly come to expect such regularities in musical structure. These expectations might directly or indirectly influence perception, composition, and/or performance practice.

The pitch-speed relationship could also be the result of extramusical expectations generated by encounters with both physical objects and other living things. Through individual experience, it is easily learned that large objects tend to be more massive, and require more physical force to accelerate than small objects. At the same time, one could observe that elephants appear much less nimble than than do houseflies, and we associate high-pitched sounds with the insect and low-pitched noises with the pachyderm. It might be that listeners make similar associations for other low-pitched and high-pitched sounds. Indeed, listeners are able to detect musical instrument size based on sound alone (Dinther & Patterson, 2006), making it plausible that inferences of likely musical speed could be made on this basis.

If listeners do have implicit ideas of how fast certain instruments 'ought' to play, they might be expected to make speed judgments relative to these expectations. For example, a brisk melody performed on a tuba might be perceived as being noticeably fast, while the same melody played on a piccolo might not seem particularly fast at all. Note that this 'expectation calibration' argument makes a prediction directly opposite to the one based on perceptual speed cues.

C. Future Directions

One might suppose that a useful next step would be to flesh out each of these theories. Each account could be clarified to the point where it could be used to make testable predictions. Presuming that there are divergent predictions, one could then devise a critical experiment that would endeavor to resolve which of the theories is best. While this approach might successfully narrow the field of theoretical possibilities, there is reason to suppose that a complex network of interactions underlies the observed pitch-speed relationship. This causal interdependence might be obscured if hypotheses are tested independently. For example, small perceptual effects may favor certain musical practices, which are then amplified by cultural norms. Testing for a perceptual effect may therefore lead one to erroneously believe that the proximal cause is perceptual, when in fact the effect is primarily a consequence of cultural inertia. Future progress may depend on the development of causal models rather than testing single-cause conjectures.

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