The Mind of the Listener: Acoustics, Perception, and the Musical Experience

Do longer gestures make longer notes?

By Michael Schutz

Is music a purely acoustic phenomenon? Although the melody to "Yankee Doodle Dandy" would be easy to identify when centered on A-440, it would become unrecognizable if transposed six octaves higher, as it would be undetectable by the human ear. While scientists could analyze this acoustic information and recognize it contains the exact melodic contour of "Yankee Doodle Dandy," few would classify this inaudible sound as "music."

Although acoustics play an important role, in the final analysis it is not sound but the *way that sound is perceived* that defines the musical experience. This article will demonstrate that sound becomes music only within the mind of the listener, an insight that is as much practical as philosophical in that it resolves longstanding disagreement over the role of gestures in controlling note duration.

DOES GESTURE LENGTH MATTER?

There has been great debate among percussionists as to whether it is possible to create long and short notes on the marimba. Well-trained, well-respected musicians routinely disagree on what initially appears to be a simple question: Does the length of the physical gesture (e.g., the up-down motion used to strike a note) have any effect on its duration? Longtime New York Philharmonic percussionist Elden "Buster" Bailey observed that, "[When] sharp wrist motions are used the only possible results can be sounds of a staccato nature… [When] smoother, relaxed wrist motions are used, the player will then be able to feel and project a smoother, more legato-like style" (1963). Others, such as Leigh Howard Stevens, are adamant that gesture length in and of itself is irrelevant, arguing it has "no more to do with [the] duration of bar ring than the sound of a car crashing is dependent on how long a road trip was taken before the accident." (2004)[1]

Both views initially appear quite reasonable; much as a longer swing of the bat generally sends the ball farther, it is plausible that longer gestures produce longer notes. On the other hand, holding constant a myriad of variables (such as the angle of attack, tension on the mallet, placement of mallet on the bar, mallet speed at impact, etc.), if energy is transferred from mallet to bar according to the equation: energy = 1/2 mass x $velocity^2$, differences in gesture length are irrelevant in that the velocity and mass of the mallet (and attached limb) fully dictate the physics of the impact. This view is supported by evidence suggesting that differences in gesture do not reliably produce differences in acoustic duration (Saoud, 2003). The following research stems from my interest in understanding the role of physical gesture length, which differs from previous work by distinguishing between its effect on sound (e.g., acoustic information) and the way that sound is *perceived*.

In everyday use, the term "perception" often carries a connotation of being incorrect or wrong (e.g., "although flying is perceived as dangerous, it is actually statistically safer than travel by car"). However, within the realm of scientific psychological research, the term has a different, specific meaning. In such contexts, "perception" refers to our internal experience of the external world. For example, in Figure 1a we perceive an upward pointing white triangle despite the fact that the figure consists only of three "Pac-man" images and three pairs of lines forming 60-degree angles. (This triangle disappears in Figure 1b when some of the items are rotated.) Our internal experience (a.k.a. perception) is constructed through a combination of external input (e.g., the ink on the page) and hard-wired, preconscious mechanisms for interpreting this input. It is in this sense—our internal experience of the physical world—that the term "perception" will be used throughout this article.

The first section of this article describes an experiment examining the effectiveness of gestures used to control note duration, demonstrating that while they fail to alter *acoustic* note length, they succeed in altering our *perception* of note length. Given this disconnect, the second section discusses the nature of the perceptual system, examining the relationship between energy in the physical world (acoustics) and the

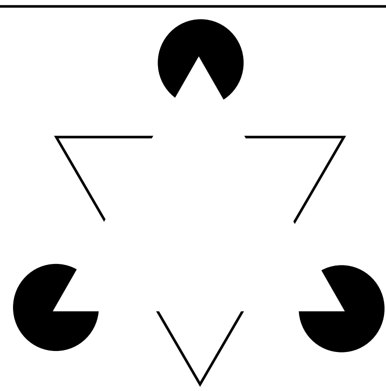


Figure 1a. Kaniza Triangle
Humans perceive an upward pointing white triangle even though it is not printed on the page

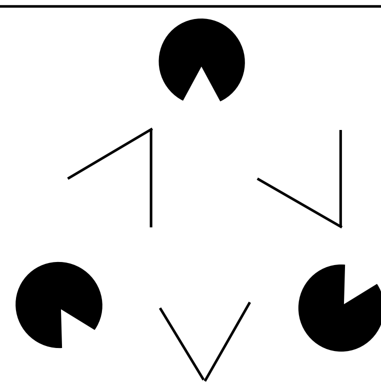


Figure 1b. No perceived triangle
When some of the elements are rotated 90 degrees, the perceptual experience of the white triangle vanishes

way we experience that energy (perception). The third illustrates it is the latter that defines the musical experience, and therefore by altering our perception of note-length gestures ultimately can be used to control the duration of musical notes.

Through this research I have come to realize that understanding the perceptual system is an important part of understanding music itself, an insight relevant to performers, educators, and audiences alike. While this study focuses on gestures used by marimbists, the conclusions drawn from this research are applicable to performances on other percussion instruments as well.

1. EXPERIMENT

Perceptual psychologists often conduct research by isolating specific components of an event and constructing experiments to test each individually. Accordingly, the following experiment was designed to independently analyze the acoustic and perceptual consequences of gestures used by percussionists. To ensure relevance to a wide audience of educators and performers, it was based upon the recordings of marimbist Michael Burritt using an instrument, technique, mallets, gestures, and a recording environment[2] similar to those used in actual performances. The first section of this article contains a summary of the experimental design, methodology, and analysis before concluding with a discussion of its implications with respect to the role of gesture in music.

1.1 Design

Videos. Michael Burritt was video recorded performing single notes on a variety of pitch levels: E1 (lowest E on a 5-octave marimba, sounding at ~82 Hz), D4 (~587 Hz), and G5 (highest G on a 5-octave marimba, sounding at ~1568 Hz) using both long and short gestures (six recordings total). In order to isolate the individual contributions of gestures and the acoustic information resulting from these gestures, the videos were split into auditory [*long-audio*, *short-audio*] and visual [*long-gesture*, *short-gesture*] components. Note: the terms *long-audio* and *short-audio* refer to the auditory components of notes produced with long and short gestures, regardless of their actual acoustic length.

These components were then mixed and matched such that in addition to the "natural" pairings of *long-gesture* with *long-audio* and *short-gesture* with *short-audio*, participants saw two hybrid combinations: *long-gesture* with *short-audio* and *short-gesture* with *long-audio*. A screenshot taken from one of the videos is shown in Figure 2 (sample videos can be seen online at www.michaelschutz.net/thelistener.html).

Participants. Fifty-nine Northwestern University undergraduate music majors participated in return for extra credit in their music theory or aural skills classes. While participants were all trained musicians, none considered percussion their primary instrument[3].

Procedure. The purpose of this study was not to examine whether gestures *look* different, but rather whether they cause notes to *sound* different. Therefore, participants were informed that some auditory and visual components had been mismatched (e.g., *long-gesture* with *short-audio*), and asked to rate note duration in each video *based on the sound alone*. This design allows us to understand the effect of visual information on auditory perception by examining how the perceived duration of each sound differs depending upon the gesture with which it is paired.

The experiment took place in a computer lab at the Northwestern University Library. The videos were presented in blocks organized into two conditions: (i) audio-visual, combining the visual gesture and auditory note, and (ii) audio-alone. After each stimulus, participants were asked to make a duration rating using a slider with endpoints labeled "Short" and "Long." For purposes of the statistical analysis the position of this slider was translated into a numeric value ranging from 0 (short) to 100 (long).

1.2 Results

The difference of opinion over the effect of gesture stems in part from overlooking the distinction between physical energy (sound) and the way that energy is perceived. Resolution, therefore, requires examining the question from both the acoustic and perceptual perspectives. Results are summarized below; for full details see the technical version of this paper published in the scientific journal *Perception* (cited in the references).

Figure 2. Michael Burritt performed individual notes using either long and short gestures. Full stroke preparation and release were visible in each video. Reproduced from Schutz & Lipscomb (2007), with permission from Pion Limited, London.

Acoustical Analysis

As shown in Figure 3, the acoustic profiles of notes produced with long and short gestures were indistinguishable. Therefore, gesture length had no effect[4] on acoustic duration. These results are consistent with previous work suggesting it is not possible to produce reliable acoustic differences in duration through the manipulation of gesture length alone (Saoud, 2003).

Perceptual Analysis

As shown in Figure 4, which averages across ratings for all three pitch levels, there was no difference[5] in perceived duration (y-axis) based on the auditory component of the videos in either the audio alone (left) or audio-visual (right) conditions. However, large differences were observed when the same audio examples were paired with long (dark red) and short (light blue) gestures in the audio-visual condition. That the gestures influenced ratings so strongly despite instructions to ignore visual information suggests integration is obligatory; it is no more possible to ignore the gesture than to read the letters D-O-G without understanding they refer to the four-legged animal commonly known as "man's best friend."

1.3 Discussion: Who was right?

In the end, the naysayers were vindicated; long and short gestures produced notes with acoustically indistinguishable profiles. Consequently, there was no perceptual difference when presented as audio alone, validating Stevens' assertion that gestures do not alter note length. That much is straightforward. The twist comes in reconciling this finding with results supporting the opposite opinion—that long and short gestures do change note length when participants were watching as well as listening. Such results corroborate Bailey's assertion that changes in gesture *do* play a role in musical performances. Coming to terms with these differences requires recognizing that the conflict stems not from the answers, but rather the question (or more specifically, the way in which it was asked).

While seemingly simple, the question "does gesture length matter?" is really two questions rolled into one—questions requiring different approaches, which in turn yield different answers. As shown by the results, those who dismiss the role of gesture are clearly correct within the realm of acoustics (Figure 3), whereas those who acknowledge the role of gestures are correct within the realm of perception (Figure 4b), at least as long as audiences are watching as well as listening.

Ultimately, resolution comes not from the results of the experiment itself but rather in their interpretation: Which domain (acoustical vs. perceptual) is most representative of the musical experience? Before making such a determination, it is useful to clarify the relationship between energy in the physical world (e.g., acoustic information) and the way that energy is perceived within the mind of the listener.

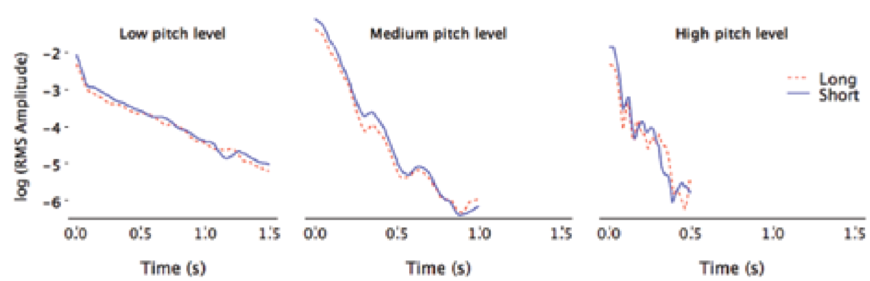


Figure 3. Acoustic Profiles as depicted by the RMS (root-mean-square) of energy (y-axis) over time (x-axis) show no meaningful differences between notes produced with long (solid blue) and short (dashed red) gestures.

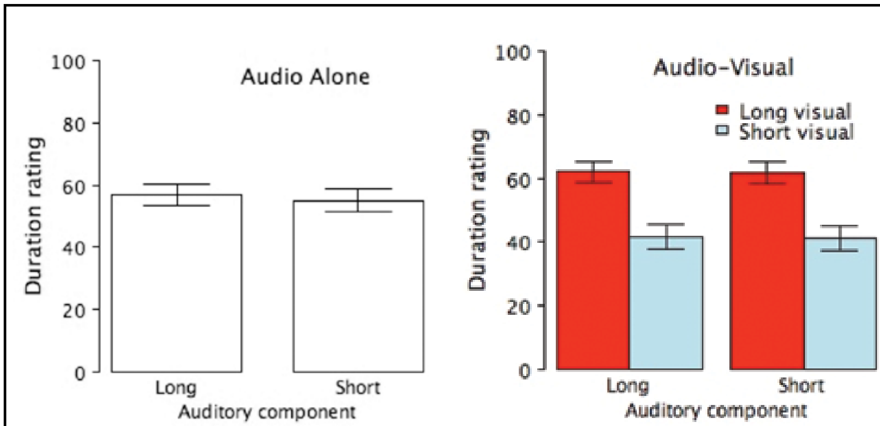


Figure 4a. Audio alone condition **Figure 4b.** Audio-visual condition

Ratings did not differ based on the auditory component of the videos (left panel), however they were strongly influenced by the visual component (right panel). The plot was generated by averaging ratings across all three pitch levels, with error bars representing a 95% confidence interval (margin of error) about the mean.

2. THE NATURE OF PERCEPTION

When an object such as a marimba bar is struck, energy from the mallet causes air molecules to vibrate, a phenomenon we call "sound." These air vibrations can be detected by a variety of sources including microphones, other musical instruments (e.g., the sympathetic vibration of a timpani head), and the human ear. This entire process can be described rather neatly through physics. However, understanding the way this sound is experienced inside the mind is more complex and beyond the reach of physics alone. Such a question falls under the domain of psychophysics: the study of the relationship between energy in the physical world and the way that energy is perceived and experienced. As a subfield within the study of perception, psychophysics offers a tool for understanding the relationship between acoustics (e.g., sound produced by musical instruments) and the way that acoustic information is perceived and experienced by listeners.

2.1 Perception and "Truth"

It is tempting to believe that we perceive the world "as it is," yet in reality our perception of the world reflects the design of our eyes, ears, and brains as well as the energy these organs are detecting. Consequently, perception is not necessarily in one-to-one correspondence with the physical world. For vision, this is illustrated clearly by the Müller-Lyer (Figure 5a) and Ebbinghaus (Figure 5b) illusions. These examples demonstrate that our *perception* of properties such as length (5a) and size (5b) is affected by factors other than the physical length/size of the object in question. These distortions are both powerful and obligatory; we know the lines and the circles within each illusion are identical, yet we cannot help but to see them as different.

While these visual illusions are purely unimodal, multi-modal illusions reflecting interactions between the auditory and visual systems demonstrate similar principles. One common example is the well-known "ventriloquist illusion" in which speech appears to emanate from the lips of a mute puppet. In addition to amusing audiences, it offers insight into another aspect of perception crucial to our understanding of music: the multi-modal nature of the perceptual system.

2.2 Sensory Integration

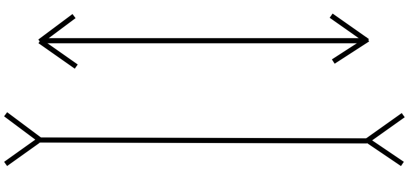
Cross-modal illusions in which information from one sensory modality influences perception of information in another are similarly fascinating and informative. One of the most compelling, known as the "McGurk effect," demonstrates that visual lip movements are capable of altering our perception of spoken syllables. In this illusion, watching a speaker's lips while listening to his speech results in a categorically different experience than when listening to the speech alone[6]. The explanation for this phenomenon is almost as fascinating as the illusion itself.

The McGurk effect works by exploiting the perceptual interpolation of conflicting auditory and visual information. On a continuum of speech syllables, the one consciously experienced falls between those presented through the visual (lip movements) and auditory (spoken) modalities—the event that could most plausibly have produced the discrepant sounds and images. It is important to remember that the perceptual system evolved in response to the natural world prior to the opportunity to experience such artificial pairings. Therefore, "averaging" conflicting sensory information is actually a robust way to make an educated guess as to the state of the world—a property of the mind that movie directors have been successfully exploiting for the better part of a century.

As unsuspecting moviegoers, we are generally unaware of the difference in the spatial location of an actor's face and voice. While facial images are free to move about onscreen, vocal sounds can originate only from immobile speakers in fixed positions. However, as the brain is wired to integrate related auditory and visual information (as in the McGurk effect), voices "sound" as if they are coming from the actor's lips. That we do not even notice the discrepancy is a testament to the efficiency of our perceptual system. It is so graceful and elegant that we are generally blissfully unaware of its role in everyday life, including the ways in which it shapes the musical experience. Yet similar principles of automatic audio-visual integration are precisely what allow skilled marimbists to control audience perception of note duration.

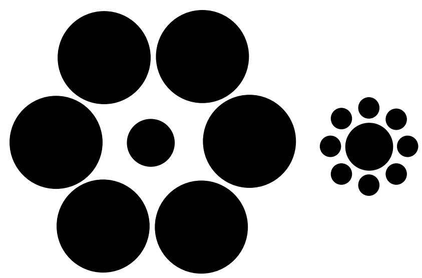
Figure 5. Visual Illusions demonstrate that our perception of objects is not always in agreement with the actual physical properties of those objects.

Müller-Lyer Illusion



5a. Despite their equal length, the horizontal line on the top *looks* shorter due to the orientation of the angled lines.

Ebbinghaus illusion



5b. The circle in the center on the left *appears* smaller than the one on the right even though they are identical.

3. CONCLUSIONS

Armed with a clear understanding of the distinction between events in the world and our perception of those events, we are now ready to tackle the philosophical question raised by the experiment: Where does music exist? In other words, given that gestures selectively affect our perception of a note rather than that note's acoustic properties, deciding whether the gesture "changes the music" requires determining which domain (acoustics or perception) defines the musical experience. Some purists may argue that music exists in the sound alone, reasoning that while gestures may alter perception, this is merely an interesting trick similar to the McGurk effect. However, as illustrated by the following example, the coloring of sound introduced by the perceptual system is actually a fundamental part of the musical experience itself.

3.1 The Mind of the Listener

Much as the Ebbinghaus illusion demonstrates that our perception of an object's size is not in one-to-one correspondence with its physical size, our perception of acoustic information is not a one-to-one reflection of that acoustic information in the physical world. All else being equal, a high-pitched tone will generally sound louder than a low-pitched tone when presented at equal decibel levels. This is because our hearing is not "flat" but favors high frequencies—those crucial for the processing of both speech and music. The consequences of these biases can be seen in the instrumentation of modern symphony orchestras, which employ about ten each of low-frequency instruments such as cello and bass, but rarely more than one piccolo.[7] This bias towards low-frequency instruments is a reflection of (and actually a requirement for) an audience in need of greater emphasis on low frequencies to produce the experience of a "balanced" performance.

A purely acoustic view of music ignoring the role of the perceptual system would erroneously conclude that the balance of music is always "wrong." However, as with the earlier example involving "Yankee Doodle Dandy," it is not the acoustic information but the way that information is perceived that defines the musical experience (Figure 6). Such transformations are entirely independent of listening environment and the presence/absence of visual information. Our greater sensitivity to high frequencies is identical for live vs. recorded music—with our eyes open vs. closed.

Accordingly, musical questions can never be resolved through an acoustic analysis alone, as sound becomes music only within the mind of the listener. In the Kaniza triangle we perceive an upward pointing white triangle even though it is not printed on the page. While philosophers can debate whether the perceived triangle is in principle "real," it is artistically real as it is "seen" within the mind of the viewer.

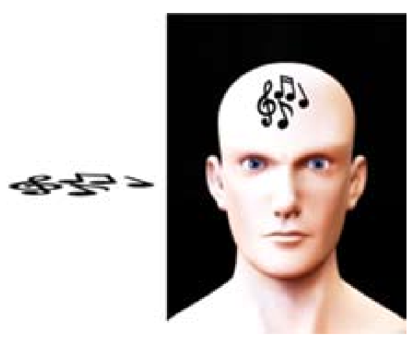


Figure 6. Musical "Balance" Music often contains significantly more energy at low (vs. high) frequencies. However, because we are more sensitive to high (vs. low) frequencies, the end result is one of a "balanced" performance.

The same is true with music; while philosophers could debate which representation of sound (acoustic vs. perceptual) should be used in defining balance, as musicians we care not about the sound, but rather the way the sound *sounds*. Therefore, factors affecting our conscious experience of sound are as much a part of the music as the sound itself. Given that acoustic information becomes music only when perceived and gestures alter that perception, then by definition gestures shape musical reality by controlling what matters: the experience within the mind of listener.

Michael Burritt (the performer in the videos) was not coached on his gestures in any way; he was merely asked to perform his best "long" and "short" notes on the marimba. However, while the gestures were acoustically ineffective, they were (inadvertently) perceptually successful. In essence, while gestures cannot change the sound of the note, they can change *the way the note sounds*. That this is accomplished through sensory integration rather than acoustic manipulation is irrelevant to concert audiences who care only that a performance "sounds right." Furthermore, understanding this distinction is imperative for performers, as we are ultimately evaluated in part based on our ability to effectively communicate with our audiences.

3.2 Implications and Applications

It is possible (though not desirable) to perform a piece without analyzing its structural properties or exploring its historical significance. Yet most would agree that a basic understanding of music theory and history are essential components of being well-rounded musicians. Similarly, a basic understanding of the perceptual system is an equally important part of any musical education (Figure 7). While some may argue they have always "known" gestures to be important, it is doubtful that many truly understood the nature of their role. Furthermore, it is important to remember that others have argued against the role of gestures with equal fervor. Now, after distinguishing between their acoustic and perceptual effects (section 1) and recognizing it is the latter that defines the musical experience (section 3.1), we can conclude definitively that gestures *are* an effective technique for controlling musical note duration.

Figure 7. Practical Application Understanding the process of perception is an invaluable part of any musical education. Music relies on performer-audience communication, which inevitably requires dealing effectively with the perceptual system.

Fully comprehending the role of gesture requires a firm understanding its limits. Beautiful gestures cannot compensate for incorrect notes or a lack of phrasing. Likewise, they cannot counteract a lack of preparation or improper technique. Gestures are meaningless in and of themselves; music is an auditory phenomenon (though not a purely acoustic one) and gestures are useful only in that they affect what we hear. Consequently, not all gestures are created equal; those that do not change our perception of sound are not musically useful and could ultimately be distracting.

Understanding the perceptual consequences and applications of other potential gestures is a topic requiring future research, as is investigation into whether these principles apply to other percussion instruments. Because both the acoustic and perceptual analyses in this experiment were focused solely on note duration, these conclusions do not necessarily comment on the relationship between gestures and other sonic properties, such as the effect of gesture length on timpani tone quality (which would also make a fruitful topic for further research). However it is now clear that gestures can be used to overcome certain acoustic limitations of the marimba, making them a valuable technique for performing musicians to understand.

The conclusion that visual information plays a meaningful role in music perception is consistent with other studies demonstrating visual influences on ratings of musical expressiveness (Davidson, 1993), emotional intent (Dahl, 2007), performance quality (McClaren, 1988), and audience interest (Broughton & Stevens, 2009). Consequently, contexts that ignore visual information (e.g., radio broadcasts, CDs, blind auditions) are robbing both the performer and audience of a significant dimension of musical communication (see my 2008 review article "Seeing Music? What musicians need to know about vision" for a comprehensive overview of this topic).

Given the observed disconnect between sound and its perception, it is important to remember that virtuosos are masters at shaping the musical experience. Ultimately, this means sidestepping the acoustically impossible to control that which is musically desirable—the experience within the mind of the listener.

I am grateful to Professor Michael Burritt for graciously volunteering to record the videos used in

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this experiment and for being an exceptional teacher and mentor. Additionally, Dr. Scott Lipscomb was instrumental to this project, serving as advisor for the Master of Music thesis on which this article is based. Finally, many thanks to Ted Rounds, Greg Beyer, Michael Overman, Brian McNulty, Kris Keeton, and the students of Longwood's 2007 "Science of Music" seminar for helpful comments on previous drafts of this article.

APPENDIX I: ADDITIONAL INFORMATION

McGurk effect

www.media.uio.no/personer/arntm/McGurk_english.html

Sample Videos from the Experiment

www.michaelschutz.net/thelistener.html

Further Reading on Music Cognition

This Is Your Brain On Music: Science of a Human Obsession. Dan Levitin

The Brain, Music, and Ecstasy: How Music Captures our Imagination. Robert Jourdain

Sweet Anticipation: Music and the Psychology of Expectation. David Huron

Musicophilia: Tales of Music and the Brain. Oliver Sacks

APPENDIX II: STATISTICAL ANALYSES

Acoustic analysis: Acoustic duration (Figure 3) was assessed by selecting "cutoff points" in the range of log (RMS) amplitude (–3, –5). A t-test examining the time at which each stroke type's acoustic profile first dropped below a given threshold found no statistically significant difference between notes produced with different gestures [t(122.18) =.0604, p=.952].

Audio alone: Duration ratings in the audio-alone condition were assessed with a 3 (pitch) x 2 (auditory stroke type) repeated-measures ANOVA (Analysis of Variance) with pitch and auditory stroke type as within-participants variables. While there was a main effect of auditory stroke type ($F_{1,58}$ =4.811, p = .032). As shown in Table 1, differences between stroke types were small in size (2 points), did not occur in the audio-visual condition, never replicated in subsequent experiments, and were similar in size to differences among stroke types intended to be identical (Saoud, 2003)[8]. Therefore, this difference is a reflection of natural variability in acoustic duration rather than a "true" difference produced intentionally by the performer (Figure 4a).

Audio visual: Duration ratings in the audio-visual condition were assessed with a 3 (pitch) x 2 (auditory stroke type) x 2 (visual stroke type) repeated-measure ANOVA with pitch, auditory stroke type, and visual stroke type as within-participants variables. The most important finding was a significant effect of visual stroke type ($F_{1,58}$ =148.424, p < .0001), indicating visual information affected duration ratings (Figure 4b). There was no main effect of auditory stroke type ($F_{1,58}$ =.218, p = .643), indicating no perceptual difference between the auditory information produced by long and short gestures (Figures 3a and 3b).

ENDNOTES

1. On the surface, the quotations address different issues in that the first discusses articulation (legato-staccato) and the second duration (long-short). However, they are useful in illustrating the general confusion regarding the role of gesture, and ultimately both share a common answer in that the gesture produces different perceptual and acoustic results.
2. The recital hall within Regenstein Hall, Northwestern University's primary venue for solo recitals.
3. As a later study replicated this experiment using participants without musical training, these results are not specific to musicians.
4. Details of statistical tests used for the acoustical analysis are summarized in Appendix 2.
5. Details of statistical tests used for the perceptual analysis are summarized in Appendix 2
6. This is best demonstrated by viewing the video online at the link listed in Appendix I.
7. A quick search of major American orchestras posting their complete instrumentation online indicates an average of 11 cello, 9 bass, and 1 piccolo positions.
8. After adjusting the acoustic note length data presented by Saoud (2003) to a scale equivalent to that used in this experiment, the standard deviation of note lengths intended to be identical was 1.93.

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Component		Condition: Audio visual Mean (95% CI)	Condition: Audio alone Mean (95% CI)
Auditory	Long	57 (+/- 2.8)	52 (+/- 2.7)
	Short	55(+/- 2.4)	52 (+/- 2.6)
Visual	Long		62 (+/- 2.8)
	Short		41 (+/- 3.3)

Table 1. Means and Confidence Intervals for key comparisons, showing average ratings as well as 95% confidence intervals for the auditory and visual components of the videos. Differences based on the auditory component were negligible compared to differences based on the visual.