PITCH CHANGE, SONIFICATION, AND MUSICAL EXPERTISE: WHICH WAY IS UP?

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ABSTRACT

Frequency change is one of the most widely used acoustic dimensions in auditory display, and pitch perception is among the most widely researched topics in audition. Nonetheless, there is little research on the appropriate mapping and scaling of information to acoustic frequency in sonification. Here, we show that musical training is a contributing factor to the mapping, scaling, and conceptual relationships that exist between the information to be sonified and its acoustic representation. In Experiment 1, three groups of listeners that varied in musical expertise moved a slider to indicate the amount of pitch change that they heard in ten non-standard musical intervals. Listeners with more musical training showed greater slider movement in response to pitch change than musical novices, but not in response to brightness in a visual control condition. Novices also made significantly more errors in identifying the direction of pitch change for intervals that were well above discrimination thresholds. Experiment 2 showed that the errors by novices were due primarily to conceptual errors in labeling 'rising' and 'falling' pitch with a small but significant number of perceptual discrimination errors. The results suggest that musical training is an important factor in the mapping, scaling, and conceptual relationships used in sonification.

1. INTRODUCTION

In many auditory displays, changes in frequency are used to represent changes in the value or state of a variable of interest. Frequency change is used in a wide variety of applications including the sonification of blood oxygen levels [1], geological and geophysical data in gas and oil explorations [2], graphical information from bivariate scatterplots [3], elementary mathematics instruction [4], historical weather patterns [5], and even internet traffic and performance [6, 7].

Although our knowledge of how the auditory system processes pitch is far from complete, many of the mechanisms by which acoustic frequency is transduced, perceived, and represented cognitively have been well described and explained. Auditory researchers have studied pitch perception for hundreds of years and this effort has produced literally thousands of studies (for excellent reviews see [8-14]).

Yet, despite the ubiquitous use of frequency change in auditory display, and the wealth of knowledge and data relevant to the perception of pitch, there is very little empirical work that addresses the appropriate mapping of frequency change to changes in the variables that are to be sonified. Some recent work has examined the relationships between the conceptual aspects of the variables and the perceptual characteristics of the acoustic signal, as well as the scaling factors that would best represent changes in variables with changes in sound [15, 16]. Specifically, this recent work has addressed important questions regarding whether an increase in an acoustic dimension (e.g., rising frequency) should represent an increase or a decrease in a variable dimension, and what magnitude of acoustic change is appropriate to accurately represent a given magnitude of change in the variable.

In the present work, we show that a contributing factor to the efficacy of the relationship between variable change and sound is the musical training and expertise of the listener. Experienced musicians and musical novices hear the world differently. Skilled musicians interpret musical sounds within a framework of prior knowledge and expertise. This framework has been called a musical schema and reflects perceptual similarity relationships between harmonic tones [14, 17-20]. Differences between musicians and non-musicians have been show in many areas including tuning, categorization, memory, selective attention, and neurophysiological structure and function [21-32].

In Experiment 1, we instructed three groups of listeners with three different levels of musical training to move a slider to indicate the amount of pitch change that occurred in a signal. We found that those listeners with more musical experience moved the slider farther in response to changes in frequency. However, in a visual control condition where the listeners were asked to move the same slider in response to the brightness of a disk, there were no differences between the groups. Moreover, 24% of the responses from the group of musical novices were in error regarding the *direction* of pitch change. That is, many times musical novices labeled rising frequency as falling, despite the fact that the smallest frequency interval presented was greater than two semitones (over thirty times greater than the threshold for frequency discrimination). In Experiment 2, we examined further the relationship between musical expertise and accuracy in labeling the direction of changes in pitch.

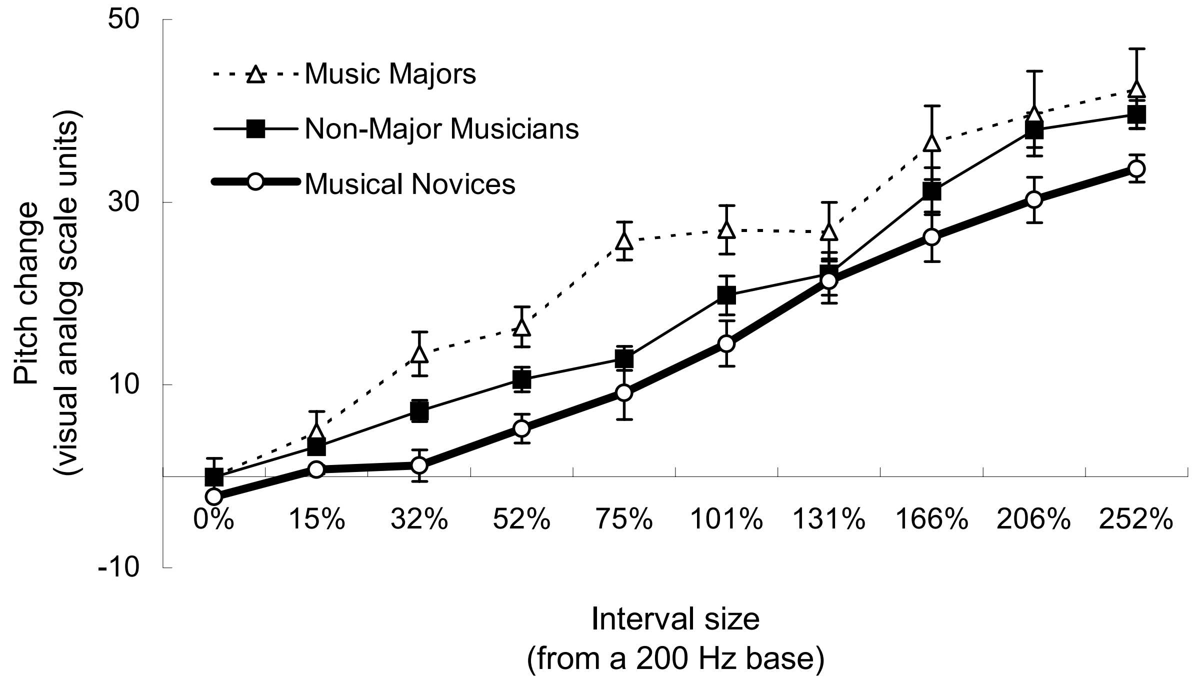

Figure 1. Mean pitch change ratings as a function of interval size and musical expertise in Experiment 1. Error bars represent ± 1 S.E.

2. EXPERIMENT 1

2.1. Method

2.1.1. Participants

All participants were college students between the ages of 18 and 22 years of age. Eleven (5 males, 6 females) were music majors with at least nine years of formal music training; 13 (5 males, 8 females) were non-music majors with at least seven years of music training or experience; and 16 (7 males, 9 females) were non-music majors with no significant musical training or experience. All listeners reported normal hearing and received class credit for participation.

2.1.2. Apparatus and Stimuli

Stimuli were presented in a sound attenuated booth via Sony MDR-v600 headphones. Stimulus tones were generated by a 16 bit sound card in a Pentium PC computer. Listener responses were collected by the same computer. Listeners heard ten unfamiliar melodic musical intervals composed of sine-wave tones at 75dBa that had a base of frequency of 200 Hz and one of ten frequencies above 200 Hz that increased successively by in frequency by 15% (230 Hz, 265 Hz, 304 Hz, etc.), thus creating ten intervals that did not correspond to any standard musical scale. Each tone had duration of 1 s with 50 ms of silence between each tone in the interval. We used sine-wave tones and a novel musical scale in order to minimize any potential advantage that musicians might have because of extensive experience with a particular scale or timbre.

2.1.3. Design and Procedure

The task was to indicate the perceptual magnitude of the interval created by the successive presentation of the 200 Hz base and the tone that followed. Responses were made on an unmarked visual analogue scale and recorded by computer. The intervals were presented in random order, and each interval was played a total of

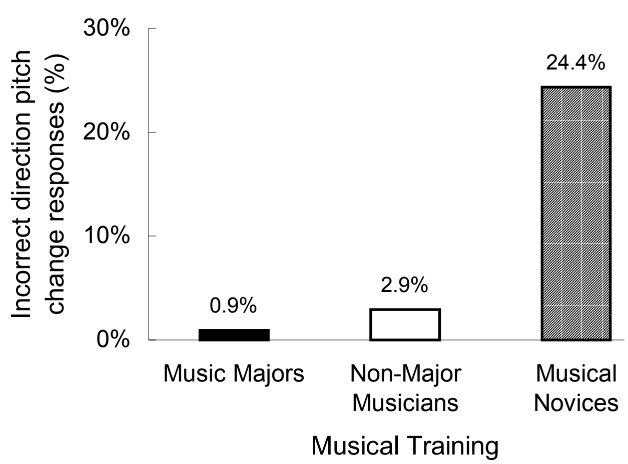

Figure 2. Overall error rates in judgments of frequency change direction in Experiment 1.

three times yielding a total of 30 trials per listener. A visual control condition was employed to rule out the possibility that any differences between the groups could be contributed to their motor skills (use of the mouse to move the cursor) rather than some difference in auditory processing. The control condition consisted of a series of circles of varying brightness presented by the computer. Participants judged the brightness of each circle using the same visual-analogue scale employed in the auditory task.

2.2. Results and Discussion

An analysis of variance (ANOVA) showed a significant difference in perceived pitch change as a function of musical training, $F(2,41) = 6.05$, $p < .01$ (see Figure 1). The highly trained music majors rated intervals as significantly larger than the musical novices did. The mean for the musically experienced non-majors fell between the majors and the novices. There were no significant differences among the groups in the control task of rating visual brightness. This suggests that the differences in performance found between musicians and non-musicians in the auditory task were perceptual in nature and not simply due to differences in motor responses required for moving the slider.

We also analyzed the percentage of errors that occurred in each in each group (see Figure 2.). Because all of the changes in frequency were increases, an error was defined as any response that indicated falling pitch. A significantly larger number of errors occurred in the non-musician group compared to the two groups of musicians $\chi^2_{(2)} = 58.1$, $p < .001$.

3. EXPERIMENT 2

In Experiment 2, we had three primary goals. First, we wanted to examine more closely the relationship between musical expertise and accuracy in detecting the direction of pitch change. Because listeners in Experiment 1 were presented with only rising frequency intervals, we also wanted to present both rising and falling changes in frequency. Finally, we wanted to examine whether the errors in pitch change made by musical novices were the result of perceptual discrimination difficulties or simply due to a lack of appropriate learned labels for 'rising' and 'falling' frequency.

3.1. Method

3.1.1. Participants

All 211 participants were college students between the ages of 17 and 48 years of age (75 males, 136 females). Participants were divided into two groups (musicians and non-musicians) based on a yes/no answer to the question *"Do you play a musical instrument?"* All listeners reported normal hearing and received class credit for participation.

3.1.2. Apparatus and Stimuli

Listeners heard ten melodic intervals composed of triangle-wave tones. The first tone in the interval had a base of frequency of 800 Hz and and the second had one of five frequencies above 800 Hz or one of five frequencies below 800 Hz. Each melodic interval increased or decreased in successive steps of 5%, thus creating ten intervals that did not correspond to any standard musical scale. An additional tone pair was composed of two successive 800 Hz tones for a total of 11 stimulus pairs. Each tone had duration of 1 s with 50 ms of silence between each tone in the interval. Stimulus pairs were generated by a laptop computer and fed into a TOA M-900MK2 mixer powered by a 200 watt QSC CX204V 4 channel amplifier. The amplifier drove an array of twelve 6" Bose speakers mounted on the ceiling of an auditorium. Listeners marked their responses to stimuli on an answer sheet that was marked with the response options "UP", "DOWN", and "SAME".

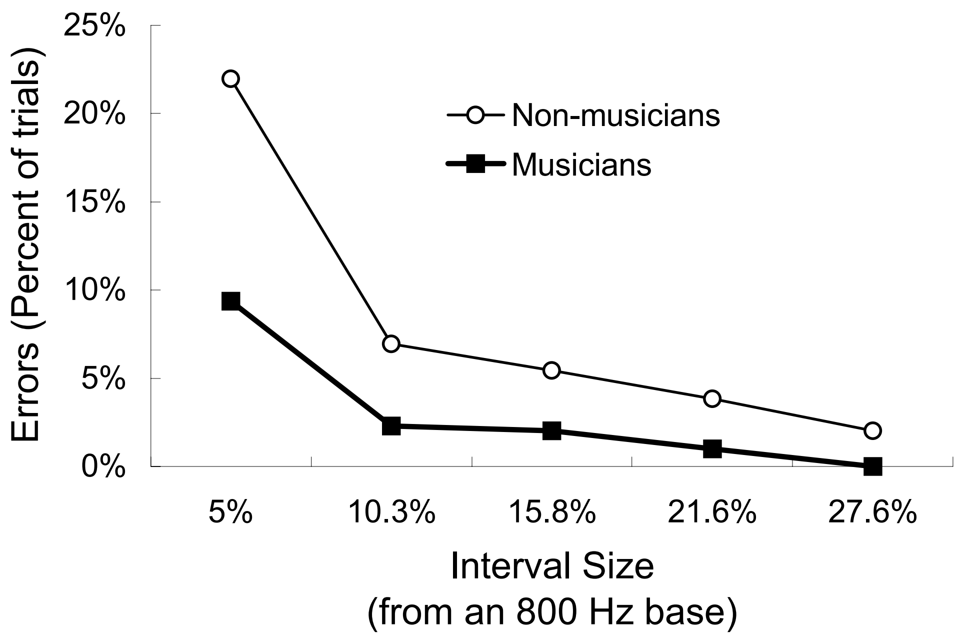

Figure 3. Mean error rates in judging direction of frequency change by condition in Experiment 2.

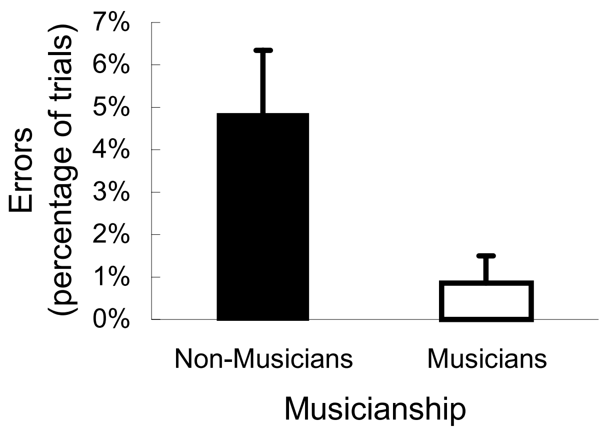

Figure 4. Mean error rates for judging the frequency change of two successive 800 Hz tones. The correct response was "SAME". Responses of "UP" or "DOWN" were counted as an incorrect response.

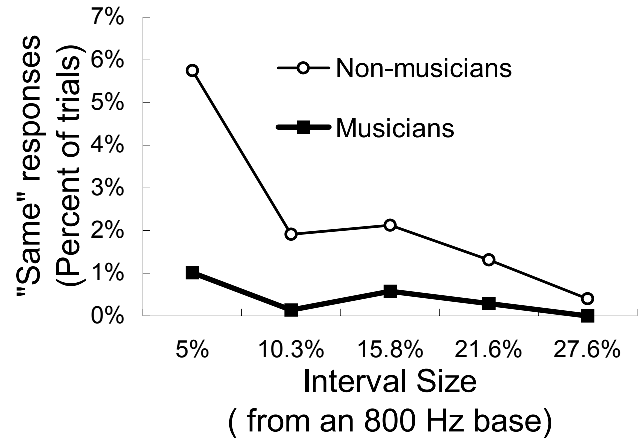

Figure 5. Mean number of "SAME" responses for changing frequency stimuli as a function of interval and musical experience. A "SAME" response to changing frequency tone pairs indicates perceptual errors.

3.1.3. Design and Procedure

Listeners entered the auditorium and filled out questionnaires about their musical experience. They then heard each of the 11 intervals 4 times each in a completely random order for a total of 44 trials. After each stimulus pair, listeners marked on their response sheet whether they heard the pitch change between the two tones go "UP", "DOWN", or stay the "SAME".

3.2. Results and Discussion

The mean percentage of errors in judging the direction of pitch change as a function of interval size and musical experience is shown in Figure 3. There was a significant effect for interval size indicating that listeners made significantly more errors at smaller intervals F (4, 836) = 81.36, $p < .001$. There was also a main effect for musical experience that indicated non-musicians made significantly more errors than musicians F (1,209) = 23.90, $p < .001$. In addition, there was a significant statistical interaction between interval size and musicianship that showed that as interval size got smaller (i.e. more difficult) the difference in error rates between musicians and non-musicians increased. Finally, there was a small, but statistically significant effect for the direction of pitch change that showed more errors for rising frequency intervals than for falling frequency intervals. F (1, 209) = 9.96, $p = .002$.

We also analyzed the percentage of errors for the two successive 800 Hz tones. In this case, because the frequency between the two tones remained constant, an error was defined as an indication that the pitch either increased or decreased. The mean error rates for musicians and non-musicians are shown in Figure 4. An independent samples t-test showed that non-musicians made significantly more errors than musicians, t (209) = 2.12. $p < .05$.

Finally, we analyzed the percentage of errors indicated by "SAME" responses for intervals that *changed* in frequency. A "SAME" response to an interval that changed in frequency is an error that suggests an inability to detect differences in pitch between the two successive tones. The mean "SAME" error rates for musicians and non-musicians at each frequency are shown in Figure 5. An ANOVA showed a main effect for interval size that indicated smaller intervals were significantly more likely to be labeled as the same pitch F (4, 836) = 9.78, $p < .001$. Non-musicians made significantly more "SAME" responses to changing frequency intervals than musicians F (1,209) = 12.57, $p < .001$. There was also a significant interaction between interval size and musicianship that indicated as interval size got smaller, the disparity in error rates between musicians and non-musicians increased F (4, 836) = 4.70, $p = .001$.

In Experiment 2, we analyzed the relationship between errors in judging the direction of pitch change, interval size, and musical expertise. The results were consistent with the findings of Experiment 1. We have differentiated between perceptual and conceptual errors in judging pitch change. Perceptual errors are errors of discrimination, where listeners fail to detect changes in frequency that are well above classic thresholds for frequency change. Conceptual errors occur when listeners detected a change in frequency but apply the wrong directional label to the change. We found evidence for both perceptual and conceptual errors in judging pitch change direction.

4. GENERAL DISCUSSION

The results of these two studies identify musical expertise as an important factor in the mapping, scaling, and conceptual relationships used in sonification. Listeners with more musical experience scaled frequency change to slider movement differently than non-musicians. These results suggest similar individual differences would occur in displays where frequency change is used to represent variable values. More importantly, on a large percentage of trials, musical novices made errors in judging the direction of pitch change. These results suggest that musical experience is predictive of not only the scaling of frequency change to a change in a variable, but also of the understanding or perception of the concept of rising and falling pitch. Previous work by Walker and colleagues [15, 16] has examined important questions regarding the conceptual relationships between variables and sound to determine whether increases or decreases in frequency are best mapped to increases or decreases in variable dimensions. However, the current work suggests that, for many musical novices, the accurate labeling of frequency increase or decreases must be *acquired* before such conceptual issues can even be addressed.

We also found a main effect for the effect of interval size on the number of errors committed. Despite the fact that all of the frequency change intervals were well above established thresholds for pitch change, error rates for both musicians and non-musicians were lower when interval size was larger. These findings suggest that if frequency change is to be used as a dimension to represent a variable in a display, then the changes in frequency employed should be sufficiently large in order to minimize errors in judging the direction of change. We found evidence that errors in judging the direction of change may be due to both lack of knowledge of the appropriate labels for rising and falling pitch, and to perceptual deficits such as “tune deafness”. Tune deafness is the inability to discriminate between pitches of different frequencies, and recent work has identified genetic components that contribute to the disorder [33-35]. Thus, while it may be possible through training for some listeners to learn the appropriate directional labels for changes in frequency that are above their thresholds for discrimination, it appears that such instruction would be of little value to the smaller portion of users who are tune deaf.

These findings also have important implications for the design of “immediately compelling and comprehensible” [36] auditory displays. One goal in the design of auditory displays is to develop techniques that allow users to readily and easily grasp the information represented in the display. Clearly, some of the musical novices in our study found nothing compelling or even comprehensible about directional frequency change. Thus, there may be other (perhaps more complex) auditory dimensions that are better candidates for such displays.

Finally, the difficulty encountered by our musical novices may in part explain relative differences in the comprehension of auditory and visual data representations. In addition to receiving extensive training in visual data representation, many observers appear to have a better grasp of ‘up’ and ‘down’ in the visual domain than they do in the pitch domain. When presented with changing frequency tone pairs, or frequency change of any kind, it appears that many musical novices struggle to answer the question “Which way is up?”

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