Music Education Research
Vol. 9, No. 1, March 2007, pp. 129–143

Choice and effects of instrument sound in aural training

Christian Sebastian Loh*
Collaboratory for Interactive Learning Research (CILR), Southern Illinois University Carbondale, USA

A musical note produced through the vibration of a single string is psychoacoustically simpler/purer than that produced via multiple-strings vibration. Does the psychoacoustics of instrument sound have any effect on learning outcomes in music instruction? This study investigated the effect of two psychoacoustically distinct instrument sounds on pitch discrimination achievement of college music students. Repeated-measures analysis revealed a significant difference between achievement scores of students by instrument sounds, which indicated that psychoacoustic complexity of instrument sound could affect learning outcome in music instruction.

Introduction

The requirement to pass a music aptitude test for admission into college music programs means that many first-year (freshmen) college music students would have had some prior musical training, and be able to sing or play musical instrument(s). Nevertheless, college music instructors often find that these music students fall short of acceptable aural discrimination skills. Hence, for many college music programs, one of the first learning tasks for freshmen is 'learning to hear' (Kraft, 1967). Aural training is necessary because higher-level music classes often require them to have a firm foundation in basic listening skills. College music students who possess better listening skills tend to do better in class and are therefore more likely to succeed as musicians (Worthington & Szabo, 1995). Similarly, successful musicians are often able to identify intervals readily and accurately (Killam *et al.*, 1975; Burns & Ward, 1982).

The ability to discriminate musical pitches is a first step in understanding the building blocks of music. Thus, pitch discrimination has become the first prescribed learning task in aural training for freshmen music students in many college music programs. Before the advent of computer technology, music instructors had to give students individual training in aural skills, and, because acoustic piano is used by most music program as the classroom 'instructional tool,' the aural training is

*Collaboratory for Interactive Learning Research (CILR), Curriculum & Instruction—Mail code 4610, Southern Illinois University Carbondale, Carbondale, IL 62901, USA. Email: csloh@siu.edu

ISSN 1461-3808 (print)/ISSN 1469-9893 (online)/07/010129-15

DOI: 10.1080/14613800601127619

frequently conducted using the piano. This practice is questionable because, on the one hand, it might lead to piano majors performing better than other instrumentalists due to their greater familiarity with the timbre; and on the other hand, as most musicians do not work exclusively with their principle instrument, over-specialization on a single instrument sound might be limited in its usefulness.

The advent of computer and Musical Instrument Digital Interface (MIDI) technology brought about many positive changes in aural training. The benefits are not only for music instructors, who have several excellent aural-training computer programs (such as Auralia, GUIDO, and Musica Practica) to choose from; but also for the music students, who can make use of these programs for individualized, 'self-guided,' anytime- anywhere training at their convenience. A computer aural training program also allows music students to pick from a large range of MIDI instrument sounds for a potentially 'more rounded' aural training, instead of being limited to only the acoustic piano sound.

However, despite many years of music technology advances, there is very little supporting evidence for the advantage of using single versus multiple instrument sound for aural training. There appeared to be a gap in the research literature in this aspect. This research report is therefore a first attempt to clarify the relationship between choice and effect of instrument sound used in aural training.

Computer and web-based music instruction

In the USA, computer-based music instruction (CBMI) for aural training was first introduced in the mid-1970s as the 'Graded Units for Interactive Dictation Operations' (or GUIDO). The computer program took several years and development cycles to progress from a mainframe-based 'programmed instruction' to computer-based training software used in the recognition of musical intervals, melodies, chords harmonies and rhythms for college music students (Hofstetter, 1975, 1978, 1985; Peters & Beiley, 1995). Positive reports on the early use of CBMI for aural skills development eventually led to its formalized incorporation into the US college music theory curriculum in later years (Eddins, 1981; Davis, 2001). Today, CBMI for ear training is regarded not only as a feasible substitute for classroom music instruction (Kuhn & Allvin, 1967; Deihl, 1971; Killam *et al*., 1975; Wittlich, 1987), but also a reasonable and effective 'tutor' (Taylor, 1980) capable of assisting students' learning (Kemmis *et al*., 1997).

The advent of the Internet in the last decade has brought about many changes in education, most notably Web-based means of instruction or online learning (El-Tigi & Branch, 1997; Khan, 1997; Starr, 1997; Berge, 2000). Because students could be motivated by educational Websites (Arnone & Small, 1999; Loh & Williams, 2002), it is appropriate that music instructors should harness the technology for Web-based music instruction (WBMI). In comparison with other subject areas, there was a noticeable gap in the literature on the use and effects of WBMI, particularly at the college level (Coffman, 2000). Music instructors have lamented the lack of WBMI, while others have gone so far as to unplug the network cable from computers to prevent students from 'wasting time' surfing the Internet (Spangler, 1999). Although some techno-savvy music educators (e.g. Estrella, 1999, 2001; Kothman, 2000) have begun developing WBMI for college use, thus far the development efforts have been sporadic suggesting that more development is needed.

This study represented a collaborative effort between a group of college music educators (who supplied the content) and an instructional technologist (who designed, developed, and evaluated the resulting application). Guitar and piano sounds were chosen to study how psychoacoustically simple or complex instrument sounds may affect music learning outcomes. The WBMI that was developed was field tested by practicing musicians, music professors, and teaching assistants at the department of Music, and pilot tested by college music and non-music students. This paper reports on the effects of two psychoacoustically different instrument sounds on pitch discrimination achievement of college music students using the WBMI developed.

Sound

Sound is produced through vibration. A vibrating object, such as a plucked string, causes the air particles around it to go through a series of compressions and decompressions. When this 'wave' of compressed and decompressed air particles reaches a person's ear, it is perceived and interpreted by the human brain as sound. It is also possible to electronically convert mathematic sine wave into sound or 'pure tone' using a tone generator. However, pure tones produced in this manner are physical anomalies because naturally occurring sounds exist only as 'complex tones.'

The mathematical reduction process known as *Fourier analysis* allows complex tones to be studied as a series of pure tone components. Theoretically, by reversing this process, one could re-synthesize a complex tone by using the correct combination of pure tones, a concept used by computer sound cards to recreate instrument sound using *Fourier synthesis* (Figure 1).

Unfortunately, the quality of the digitally synthesized sound is often limited by the processing power of the computer (sound) chip. It is therefore very difficult and expensive to recreate a highly complex sound (such as piano), and the result is often a

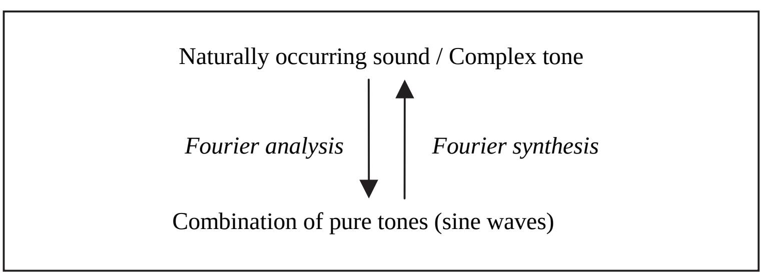

Figure 1. Conversion of complex tone to pure tones, and vice versa

tinny, low-fidelity instrument sound that sounds like a cheap replica of the original. In-depth discussions of the aural perception process may be found elsewhere (e.g. Deutsch, 1999; Thompson & Schellenberg, 2002). For this study, it is sufficient to note that an instrument sound produced using a single vibrating string (such as guitar) would be less complex than the piano sound that was produced through the vibration of several strings.

Pitch discrimination studies

Despite many extensive studies in human aural perception using pure tone as an artificial aural stimuli, pure tone was not 'compatible with the context in which the musical learning took place' (Sergeant, 1973, p. 15). Furthermore, because human ears were known to perceive pure tones quite differently from complex tones (Walker, 1990), it was generally difficult to directly apply the findings of pure tone studies into music education (Klonoski, 2000). The recommendation then, is to make use of naturally occurring sound, such as that produced by acoustic musical instruments, for musical learning.

Sampled instrument sound

Until a few years ago, music composers looking to add high-fidelity instrument sounds in CBMI would need either recordings of live performance, or sampled sound libraries (e.g. GigaStudio and the Vienna Symphonic Library). However, the need to preserve the fidelity of the sounds would result in massive file sizes that required CD-ROMs and DVDs for distribution, precluding the possibility for WBMI. Many producers of CBMI thus resorted to MIDI technology in order to circumvent the issue of file size by recreating or synthesizing instrument sounds using computer sound chips. However, because computer synthesized sounds were generally limited by the sound chip, this resulted in the use of low-fidelity instrument sounds in aural training.

The dependency of instrument sound quality on computer chips created yet another problem. Students who could afford professional-grade hardware (that uses expensive computer chips) would get higher-quality instrument sounds for music instruction, while those who could not must put up with low-grade sounds. The quality of ear training CBMI thus became dependent also upon the quality of sound used. While many college music labs were equipped with high-specification keyboards and professional sound cards, college students normally did not have such equipment at home. A performance gap was identified in the quality of sound between music instructions performed in school and at home. Unless there was some breakthrough in terms of sound file compression, it was virtually impossible to package high-fidelity sound effectively for WBMI delivery.

Quality of sound and WBMI

The maturation of transcoding technology, for example MP3 and OGG, finally made it possible for WMBI developers to greatly reduce the size of sound files (by approximately 10:1) for online music delivery. Table 1 shows the file sizes and download time of a CD recording that has been transform-coded into WAV, MP3, and OGG formats.

Once the problem of music file size was taken care of, WBMI using high-fidelity sounds (encoded in MP3 or OGG format) could now be conveniently delivered to students with a computer and Internet access anywhere in the world.

The Internet means that a Web-based approach to ear training is increasingly viable. The WBMI would enable students to practice ear training from home, without having to be physically present on campus. Advances in sampling technology, better recording technique, and faster computer processing power have made it easier to include high-fidelity instrument sounds in WBMI. The use of a sound file that was independent of the quality of sound chip would help in eliminating the discrepancy in instrument sounds between learning in school and at home, so that every student would have access to the same instruction with instrument sound of similar quality.

Instrument of c hoice

Historically, the acoustic piano rose to dominance through the nineteenth and early twentieth century based on its advantages over other acoustic instruments. These advantages include the abilities to produce: (i) over seven and a half octaves of musical pitches; (ii) multiple notes simultaneously (thus forming harmonic intervals and chords), and (iii) a wide range of musical styles. As the piano gained acceptance among both professional and amateur musicians, it also became the *de facto* instrument for general music instruction in the classrooms, including aural training.

Interestingly, from a psychoacoustic point of view, the sound produced by an acoustic piano was not ‘pure’ at all. Compared with other string instruments such as the guitar, musical pitches produced by the acoustic piano are much more complex—being produced through the combined vibration of several strings. Because a single vibrating guitar string produced fewer harmonics and overtones than the piano, it is acoustically less complex. An interesting side note was that Guido d’Arezzo’s teaching tool was also a single string instrument (Cottrell, n.d.;

Table 1. File size comparison between transform coders (MP3 vs OGG)

	WAV file	MP3*	OGG*
File size (kB)	12,274	1122	880
Download time (56k Modem)	3 min 39 s	20 s	16 s

*At CD-quality: MP3 (128 kbps), OGG (100 kbps).

Fels & Manzolli, 2001). Could he have picked the *monochord* because of its psychoacoustic clarity and simplicity over other acoustic instruments of his time?

Furthermore, the sound produced by an acoustic piano was also 'fuzzy' because each note was, in effect, a composite sound, and because each string which made up the note could be slightly out of tune with the others. Walker (1990) described how professional piano tuners, who tune by ear, can achieve aural trickery by tuning the pitch of individual string within a set to be slightly off-pitch from one another to create 'warm' tones. Whereas amateur tuners who used electronic tuning devices to produce identical and exact pitch for all strings within a set to often end up with 'colder' tones.

The problem—research questions and hypothesis

Despite numerous effectiveness studies on CBMI for aural training, it appeared that the effects of psychoacoustics and choice of instrument sounds employed in CBMI have seldom been explored. Before progress could be made in WBMI, there was a need to address this issue. The research question was: Would a psychoacoustically less complex sound make any difference to college music students in the learning pitch discrimination? For this study, piano and guitar sound were chosen to represent psychoacoustically complex and less complex sound, respectively. The hypothesis of this study was that there was no difference in pitch discrimination achievement between college music students trained using psychoacoustically complex (piano) or simple (guitar) sound. The study investigated the effects of psychoacoustically different instrument sound on first-year college music students' achievement in pitch discrimination.

Because there is a possibility that students' prior instrument playing and/or formal music training experience might also have some effect on the findings of this study, a secondary research question had been included: Does prior instrument playing or formal music training experience have any effect on pitch discrimination achievement? The second hypothesis was therefore: prior instrument playing and formal music training have no effect on pitch discrimination achievement. The independent variables include the following:

- *Instrument playing experience (IP):* the standard in US public school music programs is now so low that it would not be possible for high school graduates to pass the college music program aptitude test without private music training. A portion of those who made it through the aptitude test did so by joining a high school band, which provided enough musical training in the form of learning an acoustic instrument or singing. The high school band learning experience often did not include extensive music theory and aural training. This constituted the instrument playing experience variable.
- *Formal music training experience (FT):* Because of the low standard of public school music education, parents with more music awareness would have engaged professional musicians to tutor their children privately. Many of these students

received formal music training from a very young age. They were also likely to have performed in recitals and music tests, including aural training, long before they reached college age. This constituted the formal music training variable. Naturally, these students were expected to perform better in aural training because they have had many years of practice than the other students.

The major difference between the two groups was this: while FT students could be expected to play an instrument or sing, IP students might not all have the same rigorous music training; some were yet to encounter aural training or pitch discrimination.

Method

Materials

An online ear-training module named Mona Listen© (Loh, 2004) was developed for this study with the dual purpose of pitch discrimination training and data collection. Permission to collect data from first-year music students at a major research university in the United States was obtained from the Institutional Review Board at the host institution prior to the study. The training module was subsequently field and pilot tested to ensure external validity before the commencement of actual data collection.

Sampled piano and guitar sounds of high fidelity were incorporated as sound sources (MP3s) to provide a better musical context, and to maximize the pedagogic values of ear training. The Web-based training modules required student-participants to memorize, recall, and identify melodic intervals in both ascending and descending orders. In order to facilitate online tracking, the WBMI was designed with the support of online database architecture. Students were issued unique combinations of user IDs and passwords to authenticate them as valid users of the site. The login procedure enabled the online database to unobtrusively keep track of students' online activities, which included their login frequencies, time-on-task, response times to test items, number of times they accessed the training materials, if and when they repeated an ear training exercise, as well as the scores attained after each exercise and assessment.

All participants took a pretest when they logged in to the Web site for the first time. They were then allowed a two-week period to learn pitch discrimination of four melodic intervals using the online music instructional module developed. At the end of the two-week period or after the students had completed all the tutorials and quizzes (whichever came first), they were required to take a post-test to conclude their training.

The study

A total of 65 first-year students completed both pretest and post-test. (A follow-up post-test was also administered and took place one week after the first post-test and conclusion of the online data collection, and was meant to measure the post-treatment retention of pitch discrimination skills). All test items used in the assessments were drawn from a pool of 20 carefully counterbalanced items. These items consisted of melodic intervals in two instrument sounds (piano and guitar) in five interval classes [perfect 5th (P5), perfect 4th (P4), major 6th (M6), minor 3rd (m3) and a distractor] and two playing orders (ascending and descending), as shown in Table 2.

Distractors were included (by request of the music instructors) to reduce guessing, and consisted of melodic intervals other than P5, P4, M6 and m3. For both tests, participants were given five choices for each multiple-choice test question: A = P5, B = P4, C = M6, D = m3, and E = none of the above. Students were allowed to listen to an interval twice, but must answer the question within a time limit of 30 s.

A counterbalanced design was employed in this study to control for carryover effects in pitch discrimination training using a particular instrument sound. Participants were randomly assigned to one of two 'instrument-sequence' groups, to be trained using (i) piano sound for P5/P4 and guitar sound for M6/m3 (PN-GT), or (ii) guitar sound for P5/P4 and piano sound for M6/m3 (GT-PN), as shown in Table 3.

Participants were not aware of the assignment nor were they informed of the differential treatment. Achievement scores of college music students in pitch discrimination served as indicators (data) for this study.

Findings

The data collected from the instruments were examined using directional *t*-tests and multivariate analysis with repeated-measure design. Statistically significant differences in this study were reported at the $\alpha = .05$ level. Effect size for repeated measure studies were reported as Eta and partial Eta squared (η_p^2) values (Thalheimer & Cook, 2002), with .01, .06, and .14 (or 1%, 6%, and 14%) representing represent small, medium and large effect sizes, respectively (Green *et al.*, 2000).

Hypothesis 1

A high reliability coefficient (measured as Cronbach's alpha), $\alpha = .906$, attested to the high inter-item correlation among test items. Pretest and post-test pitch discrimination

Table 2. Melodic intervals by class, order, and instrument sound

Interval class	Piano/ ascending	Piano/ descending	Guitar/ ascending	Guitar/ descending	Total items
Perfect 5th	1	1	1	1	4
Perfect 4th	1	1	1	1	4
Major 6th	1	1	1	1	4
Minor 3rd	1	1	1	1	4
Distracters	1	1	1	1	4
Total test items	4	4	4	4	20

Table 3. Counterbalanced 'instrument sequence' grouping of participants

Group	P5 training	P4 training	M6 training	m3 training
PN-GT	PN	PN	GT	GT
GT-PN	GT	GT	PN	PN

PN, piano sound; GT, guitar sound; P5, perfect 5th; P4, perfect 4th; M6, major 6th; m3, minor 3rd.

achievement score means of melodic intervals, recorded in different instrument sounds (piano or guitar), were compared using paired sample *t*-tests. The significance level was reduced to $\alpha = .025$ using appropriate Bonferroni adjustment in order to control for the experiment-wise error rate. Table 4 presents the results of the analyses.

Pitch discrimination training using melodic intervals recorded in guitar sound has a larger positive effect [$t(65) = 6.418$; $p < .001$; $\eta_p^2 = .392$] than piano sound [$t(65) = 3.075$; $p < .005$; $\eta_p^2 = .129$] on achievement of melodic intervals identification. The variance between pretest and post-test achievement plots suggested that melodic intervals coded in guitar sound had a greater effect than intervals coded in piano sound on pitch discrimination achievement.

Overall, students showed a statistically significant improvement after training, indicating that the WBMI was effective. While students were more likely to answer correctly test items recorded in piano sound during the pretest, the pitch discrimination training reversed the trend. After training, participants were more likely to answer correctly test items recorded in guitar sound during the post-test. Figure 2 shows the plot for the overall effect of pitch discrimination training on achievement by instrument sounds. Students achieved a greater increase in achievement score for items recorded in guitar sound.

Guitar sound was found to have a larger positive effect on achievement than piano sound in pitch discrimination training. While pitch discrimination had traditionally been provided by the acoustic piano, the findings suggested a psychoacoustically less complex instrument (such as the guitar) may be an easier (better?) instructional medium for students. Music educators might want to consider replacing the psychoacoustically complex piano sound with instrument sounds that were psychoacoustically *less complex* for pitch discrimination training.

Table 4. Paired samples *t*-tests of contrasts by piano/guitar sound

Contrasts	n	Mean	SD	95% CI of the difference Lower	95% CI of the difference Upper	t-value	Sig.*	Eta^2
Pos_GT–pre_GT	65	1.154	1.449	0.795	1.513	6.418	.000	.392
Pos_PN–pre_PN	65	0.662	1.735	0.232	1.091	3.075	.003	.129

PN, piano sound; GT, guitar sound. *$p < .025$; pre, pretest scores; pos, post-test scores.

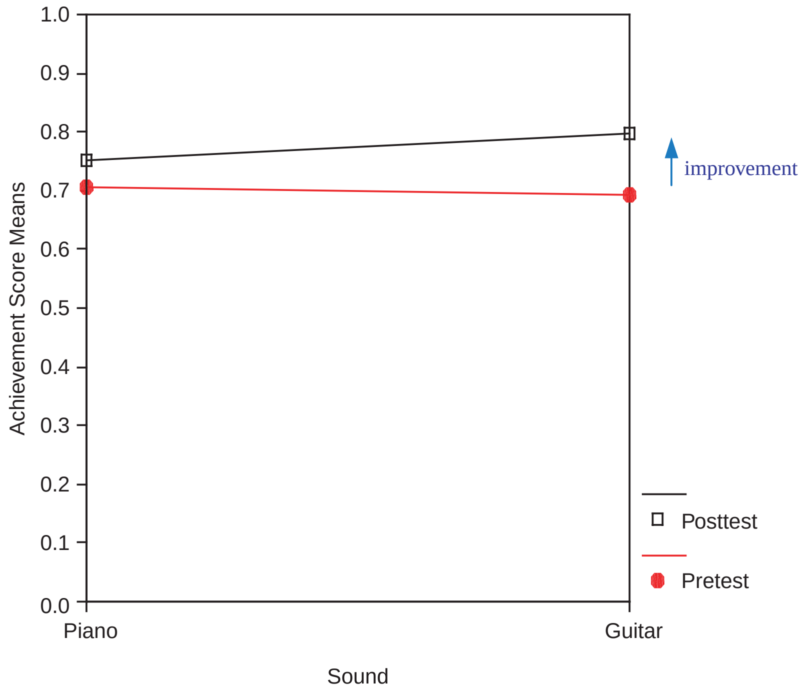

Figure 2. Improvement in achievement by instrument sounds

Hypothesis 2

It was expected that IP participants who had prior instrument playing experience before college might possibly perform better in pitch discrimination tasks than participants with no prior instrument playing experience (i.e. voice majors). However, analysis showed that neither prior instrument playing experience [$F(2, 59) = 2.218$; $p = .118$] nor the types of instruments played (brass, wind, percussion, string, keyboard, and voice) were significant at the $p = .05$ level [$F(7, 57) = 1.638$; $p = .143$]. As most of these students learned either through informal study or high school band, they were, at best, hobbyists. It was expected that high school band teachers would not have the time to do aural skill training in addition to regular band practice.

A homogeneity test using Tukey's HSD verified that FT participants in the study were of similar standing in term of pitch discrimination achievement at the time of pretest, regardless of the amount of formal music training experience received before entering college. Participants were separated into two categories based on self-reported data as having received: (i) some (1–15) years of formal training ($n = 42$), and (ii) no formal training ($n = 23$). Table 5 presents the means, standard deviations, and standard errors of the achievement scores according to participants' formal musical training experience.

Table 5. Achievement scores by formal musical training

		Pretest			Post-test		
Group	*n*	Mean	SD	SE	Mean	SD	SE
Some formal training (1–15 years)	42	67.02	20.750	3.21	79.88	16.135	2.67
No formal training (0 year)	23	71.30	20.901	4.34	75.22	19.216	3.60
Total	65	68.54	20.743		78.23	17.285	

A positive interaction with moderately large effect was detected in pitch discrimination training in relation to formal music training experience [$F(1, 63) = 8.555$; $p = .005$; $\eta_p^2 = .12$]. Compared with participants without formal music training, participants with formal music training experience received a larger boost in pitch discrimination achievement from Pretest to Post-test. Figure 3 presents a plot of the difference in achievement score means between participants with and without formal music training experience.

Results from this study indicated that music students with some formal musical training managed to learn pitch discrimination at a faster rate than students with no formal training. The formal musical training apparently laid some kind of foundation to provide support and scaffolding for subsequent pitch discrimination training. Experience in playing instruments did not appear to yield the same effect as formal music training. The WBMI developed for this study appeared to be a fairly effective learning tool and the first-year college music majors were found to have improved significantly in pitch discrimination ability.

Suggestions for future study

Pitch discrimination through ear training is important for beginning college music students because the aural skill developed will allow them to better understand the musical pitches they hear and help them to become better musicians. From a pedagogic point of view, having the piano as the only instrument for sound production in ear training is of little practical value to non-piano players, or players of other instruments. As most music students would already have a primary instrument of study, or an acoustic instrument (including voice) in which they specialize, it makes good pedagogical sense to use the student's primary instrument for pitch discrimination purposes. Because these instruments are likely to become the students' livelihood, many students will spend hours practicing and perfecting their skills on the instruments. For example, many violinists have professed to an internal imprint of the pitch of A_4 (Bachem, 1937), having developed some sort of a phantom tuning fork from the repeated listening and tuning exercises (Ward, 1999). Hence, it might be more appropriate for the violin majors to practice pitch recognition using their primary instrument, the violin; and for the flautists, the flute, and so on.

More importantly, because different types of sound can assert different psychological effects on the hearers (Siegel & Siegel, 1977), the choice of instrument sounds

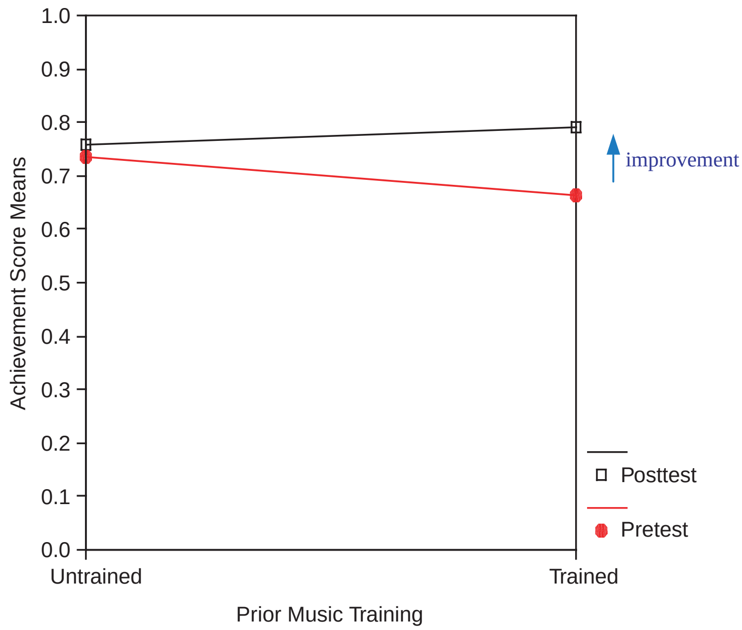

Figure 3. Improvement in achievement by formal music training experience

used in pitch discrimination could actually affect learning outcomes. So, rather than requiring non-keyboardists to recognize intervals or chords played on the piano, it might be better to use the students' instrument of study as sound source for pitch discrimination.

The findings of the study suggest that psychoacoustics of instrument sound, and hence, the choice of instrument used, can have an important role in aural training achievement. Music educators may wish to re-examine the piano as the 'only' instrument of choice for pitch discrimination training. Researchers could examine other instrument sounds to further ascertain the effect of psychoacousticity on aural training and music instruction. Additionally, college students with formal music training experience appeared to have an accelerated rate for pitch discrimination learning and higher achievement score means than those without formal music training. This seemed to confirm the 'rich get richer' phenomenon, as students who have engaged professional music teachers for private lessons would attain better results. Additional research studies would be necessary to fully investigate the extent of this interaction. Psychoacoustics of instrument sound could have been just one of several factors that affect pitch discrimination achievement, and further research in this direction is necessary to provide a better understanding.

Although pitch and timbre are defined quite differently, the relationship between pitch and timbre is less clear (Thompson & Schellenberg, 2002). Because timbre has a 'profound influence' on a person's appreciation of music (p. 481), it is possible that timbre could have some effects on pitch discrimination achievement. Further research is needed to ascertain if there is any effect or interaction between timbres and psychoacoustics of instrument sounds on pitch discrimination.

Conclusions

Even though WBMI has many advantages over the older CBMI, there is currently a wide gap in the literature on the use and effects of innovative technology and WBMI at the college level. This study informed the literature by examining the effects of psychoacoustics and the choice of instrument sound on achievement in pitch discrimination. The Web-based aural training module developed for this study employed realistic instrument sound to provide not only the musical context for music learning, but also maximize the pedagogic values of ear training for music students other than piano and keyboard majors.

WBMI liberates the music students from having to congregate at a music laboratory for 'drill-and-practice' exercises in ear training. Because many college students now have easy access to the Internet and Web resources there will be more opportunity for music students to improve their ear training skill should online ear training become more readily available.

The time has come for an update of pitch discrimination training using new technology. More importantly, more research is necessary for the re-evaluation and verification of pedagogic values of current music classroom practices. The move from CBMI to WBMI, and hence the development of new WBMI, can help pave the way for other music courses that are geared towards online certification. Even as GUIDO evolved from a set of programmed instructions to become a fully fledged aural training system; WBMI such as Mona Listen© can likewise be further developed for self-directed learning in today's music classroom.

Notes on contributor

Christian Sebastian Loh is an Assistant Professor (Instructional Design Technology) and one of two coordinators of the Collaboratory for Interactive Learning Research (CILR) in the Department of Curriculum & Instruction at the Southern Illinois University of Carbondale, IL, USA. His research interests include the instructional game development, assessment of learning using serious games, and various emerging technologies.

References

Arnone, M. P. & Small, R. V. (1999) Evaluating the motivational effectiveness of children's web sites, *Educational Technology,* 39(2), 51–55.

Bachem, A. (1937) Various types of absolute pitch, *Journal of the Acoustic Society of America,* 9, 146–151.

Berge, Z. L. (2000) Evaluating web-based training programmes, in: B. H. Khan (Ed.) *Web-based training* (Englewood Cliffs, NJ, Educational Technology Publications).

Burns, E. M. & Ward, W. D. (1982) Intervals, scales, and tuning, in: D. Deutsch (Ed.) *The psychology of music* (New York, Academic Press, Inc.), 241–269.

Coffman, D. D. (2000) Adult education, in: R. Colwell & C. Richardson (Eds) *The new handbook of research on music teaching and learning: a project of the Music Educators National Conference* (New York, Oxford University Press), 1222.

Cottrell, J. (n.d.) *A brief history of the monochord*. Available online at: http://lowbrassnmore.com/Monochord.htm (accessed 10 September 2005).

Davis, J. (2001) CAI: does it have an effect on aural skills performances?, paper presented at the *Eighth International Technological Directions in Music Learning Conference*, San Antonio, TX, 25–27 January.

Deihl, N. C. (1971) Computer-assisted instruction and instrumental music: implications for teaching and research, *Journal of Research in Music Education,* 19, 299–306.

Deutsch, D. (1999) *The psychology of music* (2nd edn) (San Diego, CA, Academic Press).

Eddins, J. (1981) A brief history of computer assisted instructions in music, *College Music Symposium,* 21(2), 7–14.

El-Tigi, M. & Branch, R. M. (1997) Designing for interaction, learner control, and feedback during web-based learning, *Educational Technology,* 37(3), 23–29.

Estrella, S. G. (1999) JavaScript and QuickTime for music educators: the Temple University aural training diagnostic tests, paper presented at the *Sixth International Technological Directions in Music Learning Conference*, San Antonio, TX, 28–30 January.

Estrella, S. G. (2001) Interactive Web development techniques for music learning, paper presented at the *Eighth Technological Directions in Music Learning Conference*, San Antonio, TX, 25–27 January.

Fels, S. S. & Manzolli, J. (2001) Interactive, evolutionary textured sound composition, paper presented at the *6th Eurographics Workshop on Multimedia*, Manchester, 8–9 September.

Green, S. B., Salkind, N. J. & Akey, T. M. (2000) *Using SPSS for Windows: analyzing and understanding data* (2nd edn) (Upper Saddle River, NJ, Prentice Hall).

Hofstetter, F. L. (1975) GUIDO: an interactive computer-based system for improvement of instruction and research in ear-training, *Journal of Computer-Based Instruction,* 1, 40–42.

Hofstetter, F. L. (1978) Instructional design and curricular impact of computer-based music instruction, *Educational Technology,* 18, 50–53.

Hofstetter, F. L. (1985) Perspectives on a decade of computer-based instruction, 1974–1984, *Journal of Computer-Based Instruction,* 12, 1–7.

Kemmis, S., Atkin, R. & Wright, E. (1997) *How do students learn?* (Norwich, University of East Anglia).

Khan, B. H. (1997) *Web-based instruction* (Englewood Cliffs, NJ, Educational Technology Publications).

Killam, R. N., Lorton, P. V. & Schubert, E. D. (1975) Interval recognition: identification of harmonic and melodic intervals, *Journal of Music Theory,* 19(2), 212–234.

Klonoski, E. (2000) A perceptual learning hierarchy: an imperative for aural skill pedagogy, *College Music Symposium,* 40, 168–169.

Kothman, K. (2000) Interactive MIDI instructional applications on the Web using JavaScript and the Beatnik player, paper presented at the *Seventh International Technological Directions in Music Learning Conference*, San Antonio, TX, 27–29 January.

Kraft, L. (1967) *A new approach to ear training; a self-instruction program* (New York, W. W. Norton).

Kuhn, W. E. & Allvin, R. L. (1967) Computer-assisted teaching: a new approach to research in music, *Journal of Research in Music Education,* 15, 305–315.

Loh, C. S. (2004) The effect of pitch discrimination training on achievement in melodic interval discrimination. Unpublished doctoral dissertation, The University of Georgia, Athens, GA.

Loh, C. S. & Williams, M. D. (2002) 'What's in a web site?'—Students' perception, *Journal of Research on Technology in Education,* 34(3), 351–363.

Peters, G. D. & Beiley, B. L. (1995) *Teaching tools in music* (Medford, NJ, Learned Information, Inc.).

Sergeant, D. (1973) Measurement of pitch discrimination, *Journal of Research in Music Education,* 21(1), 3–19.

Siegel, J. A. & Siegel, W. (1977) Absolute identification of notes and intervals by musicians, *Perception and Psychophysics,* 21, 143–152.

Spangler, D. R. (1999) Computer-assisted instruction in ear-training and its integration into undergraduate music programs during the 1998–99 academic year. Unpublished master's thesis, Michigan State University, East Lansing.

Starr, R. M. (1997) Delivering instruction on the World Wide Web: overview and basic design principles, *Educational Technology,* 37(3), 7–15.

Taylor, R. P. (1980) *The computer in the school: tutor, tool, tutee* (New York, Teachers College Press).

Thalheimer, W. & Cook, S. (2002) *How to calculate effect sizes from published research articles: a simplified methodology*. Available online at http://work-learning.com/effect_sizes.htm (accessed 18 March 2004).

Thompson, W. F. & Schellenberg, E. G. (2002) Cognitive constraints on music listening, in: R. Colwell & C. Richardson (Eds) *The new handbook of research on music teaching and learning* (New York, Oxford University Press), 461–486.

Walker, R. (1990) *Musical beliefs: psychoacoustics, mythical, and educational perspectives* (New York, Teachers College, Columbia University).

Ward, W. D. (1999) Absolute pitch, in: D. Deutsch (Ed.) *The psychology of music* (2nd edn) (San Diego, CA, Academic Press), 265–298.

Wittlich, G. (1987) Computer applications: pedagogy, *Music Theory Spectrum,* 11(1), 60–65.

Worthington, T. G. & Szabo, M. (1995) Interactivity in computer-based aural skills instruction: a research study, paper presented at the *Annual Meeting of the Association for Educational Communications and Technology*, Anaheim, CA, February.