Towards Absolute Pitch Training With Wearable Technology That Incorporates Tactile Stimuli Based on Auditory-Tactile Simulated Synesthesia

Japheth Duane C. Samaco, Ateneo de Manila University, Philippines
Andrei D. Coronel, Ateneo de Manila University, Philippines

The Southeast Asian Conference on Education 2024
Official Conference Proceedings

Abstract
This study intends to tackle the challenge of Absolute Pitch (AP) training through multisensory stimuli. Recent studies have investigated new methods of AP training; however the results were not satisfactory when compared to the output of natural AP possessors in the context of both success rate and closeness to pitch recognition. This study intends to tackle this challenge with an innovation in auditory learning through the design and development of a technology that will provide tactile sensation to add another stimulus in AP ear training. This will be done by adding haptic feedback as vibrotactile stimuli for participants, alongside tones, simulating an auditory-tactile synesthetic experience. The training design will be conducted for two groups: the experimental group will be trained using both auditory and tactile stimuli while the control group will be trained with the isolated auditory stimuli only. Both the hardware components and software will be developed to accommodate the new training design and the haptic feedback stimuli. A comparative analysis of the results will be performed to determine the effectiveness of the multisensory training as compared to isolated auditory training. The results may validate not only the effectiveness of a multisensory approach to learning, but more so give insights on the effectiveness of both the specific technology and adopted methodology that is used.

Keywords: Absolute Pitch, Perfect Pitch, Synesthesia, Multisensory, Multimedia, Tactile-Auditory Synesthesia, Music, Ear Training, Haptic Feedback

Introduction

Absolute Pitch (AP), also known as perfect pitch, is defined by Deutsch (2013) as the ability of a person "to name or produce a note of a given pitch in the absence of a reference note". On the other hand, an alternative to pitch recognition called Relative Pitch (RP), wherein persons can name the note if a reference note is given by recognizing "the musical interval (pitch distance) between any pair of tones (e.g., perfect fifth, major third), which enables them to name the second of two tones when the first is named" (Trehub, 2003). One could argue that persons with AP have an advantage over those with RP by having the ability to instantly recognize notes, as opposed to those with RP who need a reference note first.

However, according to Deutsch (2013), as much as people have Implicit AP, meaning they can recognize well-known melodies, it is difficult for people to associate individual sounds to their names as notes. As an example, a person can hear the first few notes of "Twinkle Twinkle Little Star" and be able to associate and recognize the song, yet isolated notes are harder to process and name, which is what AP possessors can do. In fact, AP has been known to be incredibly rare for people to possess, with only around 1-5 in every 10,000 people possessing it (Takeuchi & Hulse, 1993). There have also been multiple studies in the past which suggest that AP possessors have some genetic variable tied towards it (Baharloo et al., 1998) or that AP should be learned and trained during a critical period of childhood of around 3-7 years old, stating that "none of [the] survey respondents who began musical training after the age of 9 years possessed AP," (Takeuchi & Hulse, 1993) or a combination of both. However, more recent studies (Van Hedger et al., 2019; Wong et al., 2019) have refuted these claims by training adults in AP with different auditory training methods resulting in successful tests in accuracy of note classification, albeit with low success rates in training.

These researchers have proven that AP can be learned but will need to be refined to be more efficient and have a higher success rate. A good method is to use multimedia to enhance this learning process. Multimedia learning is the use of multiple senses to enhance this learning (Moreno & Mayer, 2007). According to John Medina (2014) in his book "Brain Rules," which uses some of Mayer's work as basis, the use of this multimodal perception can significantly increase recall and transfer rate of students as compared to unimodal learning. This works because of how our senses generally functions, which is that humans process the world with multiple senses working at the same time, which "takes advantage of the full capacity of humans for processing information," allowing us, for example, to not just process the world with just our eyes, but also with our ears, or even with touch (Medina, 2014).

To develop this Multimodal process for AP training, the studies on synesthesia and the experience of synesthetes can be used as a model. Synesthesia is defined as an experience where one stimulus of a sense evokes an experience in another sense (Banissy et al., 2014). Some occurrences are when synesthetes tasting food might trigger a simultaneous experience of sound, or the imagining of words can cause experiences of feelings of touch (Moreno & Mayer, 2007) or seeing visual words can evoke the experience of taste (Banissy et al., 2014). This experience of the "merging of the senses", is known to be incredibly rare, and affects only a small number of people with various kinds of manifestations due to the different combination of sense activation (Simner 2011), and yet there has been a study that shows a significant population of synesthetes are also AP possessors, and vice-versa (Loui et al., 2012).

Context of the Study

AP has always been thought to be an untrainable skill once a certain age has passed, or that it can only be acquired through genetics (Baharloo et al., 1998; Takeuchi & Hulse, 1993) However, recent studies have proved that AP can be trained even past the age of childhood (Van Hedger et al., 2019; Wong et al., 2019). It is now a question of how one can create and design effective training programs to improve AP learnability.

To attempt this, an AP training will be conducted, similarly modeled after the previous training studies done, with the addition of a tactile stimulation to enhance this training process through multisensory activation and learning. This tactile stimulation will be done, along with auditory prompts, using wearable devices to simulate a synesthetic experience.

Research Objectives

The objective of this study is to design and implement technology that will enable the simultaneous stimulation of both tactile and auditory senses to train AP for non-possessors and, at the same time, investigate the effectiveness of multisensory stimuli (auditory-tactile) in training AP. This training aims to recognize whether a multisensory approach to learning and training AP will be an improvement compared to an unisensory auditory training approach that most studies have conducted. In the end, this study hopes to provide another method for training AP and provide an alternative to the norm of ear training, RP training.

Research Questions

The primary research question for this study is: Will participants trained with multisensory auditory-tactile stimuli lead to better pitch recognition compared to participants trained only with unisensory auditory stimuli?

Secondary research questions are the following:

1. How will the multisensory and unisensory AP training programs be designed?
2. What technologies will be used to simulate the auditory-tactile multisensory stimuli?
3. Will the multisensory participants be able to recognize notes based on their AP training using only tactile stimuli?

Scope and Limitations

The study will only concentrate on AP training and not include other types of pitch training. This AP training will also be focused on individual notes played from a selected number of octaves using the recorded sounds of a single source (digital piano) through earwear. Because of this, the target participants for the experiment should be familiar with basic musical terminology, especially the 12 notes of the chromatic scale (C – C#/Db – D – D#/Eb – E – F – F#/Gb – G – G#/Ab – A – A#/Bb – B). In this regard, the study will not be discriminatory to people who already possess RP, as the nature of learning of the two different ear training are still inherently different. The study will not be able to include nor solve issues of people who have amusia, or tone deafness. This study will be conducted on adults around 18-26 years old. The study will not handle long term retention to see if the participants are able to retain AP months after the experiment.

This training will only focus on two senses – hearing and feeling. The training will be conducted using a wearable device providing the tactile and auditory stimulus connected and controlled to a mobile phone. An application will be designed to control the auditory and tactile stimulus for pitch training.

Significance of Study

Due to the low passing and success rates of the previous isolated sensory (auditory) trainings for AP (Van Hedger et al., 2019; Wong et al., 2019), this study could potentially be used as an alternative to AP training. If proven effective, this opens an alternative for ear training for people, especially musicians who tend to train their ears to improve their craft. People would only default to RP training due to how previous studies denied AP trainability. This study would allow another option to ear training: to have effective AP training as an alternative to RP training. Finally, this research could also show the effectiveness of synesthesia-modeled multisensory training, which could lead to further developments in learning and education using multimodality.

Methodology

The Experiment Design of this study will mostly be using the AP training design of the study "Is it impossible to acquire absolute pitch in adulthood?" (Wong et al., 2019) with some differences. This study will be using an experimental group for the multisensory training, which would mean double the number of participants to create a control and experimental group. The experiment will also be using a custom-made application to play and control the stimuli, as well as record the responses and return feedback for both the tests and the training sessions.

The experiment will be divided into four parts- The Questionnaire, the Pre-Test, the Training Program, and the Post-Test. The questionnaire at the beginning, and the post-UX test for the experimental group will both be accomplished through pen and paper. Everything else will be handled by the application.

Participants

20 participants aged 18-26 will be invited to partake in the training experiment. All participants will be checked via an information form to make sure that they do not exhibit any levels of neuropathy (e.g., impairment or disfunction of sensation in their fingertips), a form of amusia (i.e., the inability to recognize changes in pitch, or tone-deafness), or that the participants do not already possess AP. The participants will also be checked for basic knowledge of music, i.e., knowledge of the 12 notes of the chromatic scale, as well as music and instrument experience.

These participants will be divided into two groups: 10 participants for the multisensory training (henceforth called the experimental group) and 10 participants for the unisensory (auditory) training, henceforth called the control group. Equal number of males and females (three males and three females) will be assigned to a group. The group assignment shall be handled such that the musical experience of the two groups will be balanced.

Participants will be given monetary compensation for each completed training day with additional payment for completing the whole experiment.

Technology Design

The training program will be using a desktop application to facilitate the experiment. The experimental group will be conducting training sessions using both the vibrotactile haptic glove and headset simultaneously for tactile and auditory stimulus respectively. The hardware devices will be connected via wires to the computer and used through the application to create the simultaneous integration of the two senses and calibrated to create a connected and simultaneous experience of the two senses. The control group will be conducting the training sessions using only a headset for the auditory stimulus.

To simulate the tactile experience, a glove will be designed and developed that simulates various kinds of haptic experiences. In a survey (O'Toole et. Al., 2021) conducted on people and their emotional responses to sounds, the study was able to find out that people have associated the 12 pitches of the chromatic scale to various emotions (Joy, Fear, Anger, Sadness). The table below shows the distribution, where the survey shows more people choosing the emotion association to the pitch, while some pitches are mixed results (noted as Neutral). Using these emotions, sounds that are known to reflect such emotions will be played through the haptic controller to be translated to tactile feedback. These sounds will be pitch shifted to fit the associated pitch as well. The sounds chosen for the haptic feedback of the pitches are arbitrary and are designed for more diversity of tactile stimuli.

Pitch	Emotion
C	Joy
C#	Joy
D	Joy
D#	Joy
E	Anger
F	Sadness
F#	Sadness
G	Sadness
G#	Neutral
A	Neutral
A#	Neutral
B	Neutral

Table 1: Emotions Associated to Pitches

The glove will contain aluminum vibration motors on the five fingertip areas of the participants chosen hand (the other hand will be used to control the application). These disc-shaped motors, connected to an Adafruit Haptic Motor Controller, will create the haptic sensations based on the audio played. These will be connected to an Arduino board, which is then connected to the computer with the training application.

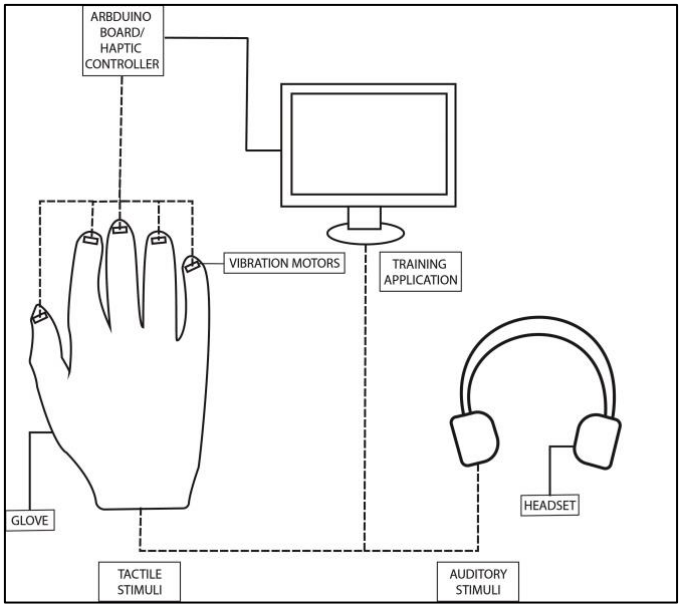


Figure 1: Technology Design for the Experiment

A headset will be used to play the auditory experience. This headset will also be connected to the computer via wired connection.

A computer, through a designed application, will host the training sessions and control the different devices.

Application Design

Software will be developed using the Unity Game Engine. This software will contain both the pre-test and post-test for the participants, as well as the training programs for both control and experimental groups. The software will be able to communicate with the haptic glove through the Arduino Board and the headset to send the information on what tactile and auditory stimuli will be received by the participants simultaneously. The application will also collect the data based on the inputs and responses of the User.

Pre-test & Post-test

The participants from both groups will have the same pre-test and post-test, except for an additional tactile test for the experimental group and post-UX survey regarding the tactile experience.

Test Proper

Participants will be using the custom-made application for their testing. The Pre-Test will be performed by the participants after answering the Information Questionnaire and before starting the Training Program to assess their learning performance after the training program.

The Post-Test will be performed at least a day after the participant's last training session. No tactile feedback will be used for these tests, even for the experimental group.

The test will require the participants to name the pitch based on a tone played. The tone will play for 1 second and, afterwards, the participant has 5 seconds to name the pitch. The mapping of the pitch names will be set up either horizontally (from C-> B), or via a keyboard layout with the notes placed on the keyboard key. Participants may take a break anytime by pressing a pause button, but there will be mandatory breaks during the test, in which the participant may decide when to continue. The test, however, should be finished within the day.

The test will use a total of 120 unique tones twice, leading to a total number of 240 tones to be named by the participant. The 96 of the 120 tones are composed of 48 tones from octaves 3-6 (C3-B7, 12 tones per octave) for both the synthetic and piano tones. The last 24 tones are going to come from violin tones of octaves 4-5. It should be noted that participants were not trained in octaves 3 and 6, nor in violin tones. For violin tones, only trained pitches (octaves 4-5) will be used. Overall, the test will only use tones that are under either trained Octaves and Trained timbres, Trained Octaves and Untrained Timbres, or Untrained Octaves and Trained Timbres. The pitches will be presented in a randomized order.

	Octave 3 (C3-B4)	Octave 4 (C4-B5)	Octave 5 (C5-B6)	Octave 6 (C6-B7)	Total per Instrument
Synthetic	12	12	12	12	48
Piano	12	12	12	12	48
Violin		12	12		24
Total per Octave	24	36	36	24	Total Tones: 120

Table 2: Pitches Used for Testing

Before the test proper, the participant will be given a practice test consisting of 10 randomized tones to familiarize oneself with the layout, and to adjust the volume of the tones.

The number of correctly named pitches will be recorded. Incorrectly named items will be recorded as well for relative distance to the correct pitch. Time in between the tone being played, and the participant inputting an answer will also be recorded.

Additional Post-test and Questionnaire for the Experimental Group

The experimental group dealing with the multisensory stimuli will be given an additional questionnaire and test at the end of the experiment, after the post-test. The additional post-test will test whether the participants retained the connection between the haptic feedback and the pitch that they associated with.

The test will require the participants to name the pitch based on haptic vibration played. The vibration will occur for 1 second and, afterwards, the participant has 5 seconds to name the pitch. Like the pre-test and post-test proper, the mapping of the pitch names will be set up either horizontally (from C-> B), or via a keyboard layout with the notes placed on the

keyboard key. Participants may take a break anytime by pressing a pause button, but there will be no mandatory breaks during this test due to the shortened length.

The test will use the haptic feedback from the trained pitches of octaves 4-5 for a total of 12 unique tactile experiences, with only the vibration level changing based on the octave of the pitch. Overall, the test will amount to a total of 48 items, using the 24 pitches twice.

The number of correctly named pitches will be recorded. Time in-between the tone being played, and the participant inputting an answer will also be recorded. Incorrectly named items, however, will not be recorded as the different haptic effects are not associated with the relative distance of the pitches.

The questionnaire will be a post-UX survey on their experience using the vibrotactile haptic glove.

Training Design

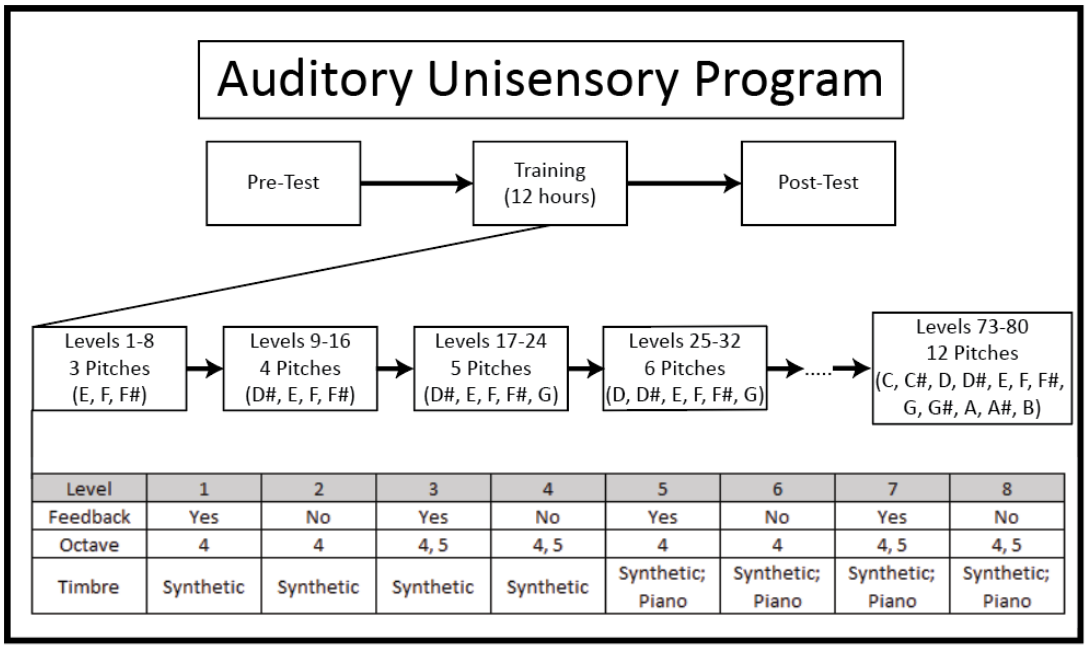
The training design, as modeled in the study (Wong et al., 2019), will be structured and organized using different levels, with the experimental group having a different system from the control group to account for the additional tactile stimuli. For every level, the participant will be given a total of 20 tones based on the given pitches and characteristics of the level. If the participant can correctly name at least 90% of the tones, or 18/20, they may move up a level, but they may visit any level previously done.

Control Design

Participants of the control group will be trained using a program with 80 levels in total. The 80 levels will be divided into 10 groups. The groups determine the number of pitches to be used for training. Every group is divided into 4 subgroups. These subgroups have different characteristics to target specific kinds of training.

Initially, only 3 pitches will be introduced, and the number of pitches will increase every 8 levels, until level 73 where all 12 pitches are being used for training. For the four subgroups, divided into levels 1 and 2, 3 and 4, 5 and 6, and 7 and 8, all odd numbered levels will show the participant immediate feedback on whether their answer is correct or not. Even levels will only show the results after all tones have been named to determine whether the participant is moving on to the next level. For the first subgroup, only one octave (octave 4) will be used. For example, for level 1 and 2, only pitches E4, F4 and F#4 will be used. For the second subgroup, two octaves of the pitches will be used. Hence, in our example, E4, F4, F#4, E5, F5, F#6 will be used. For the third subgroup, we will return to using only one octave, but will introduce a timbre using the same pitches. Synthetic timbre will be used throughout the 80 levels, but a piano timbre will be added for the third and fourth subgroups. For the fourth subgroup, it will use both octaves 4 and 5, and timbres synthetic and piano. After the eight levels, the combination will reset again to using only one octave and one timbre, but a new pitch will be introduced. The figure below illustrates the different combinations per group, with a more detailed table in Appendix A.

After any levels with feedback, a 15 second glissando clip will be played in order to erase any memory of existing referential tones from the previous level for the no feedback levels.



Level	1	2	3	4	5	6	7	8
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

Figure 2: Auditory Unisensory Program

Similar to the pre-test and post-test, every item in a level will play a tone for 1 second. The participant will have 5 seconds to identify the correct name of the pitch of the presented tone. For training, incorrectly identified pitches will be considered wrong, and their relative distance to the correct answer will not be acknowledged.

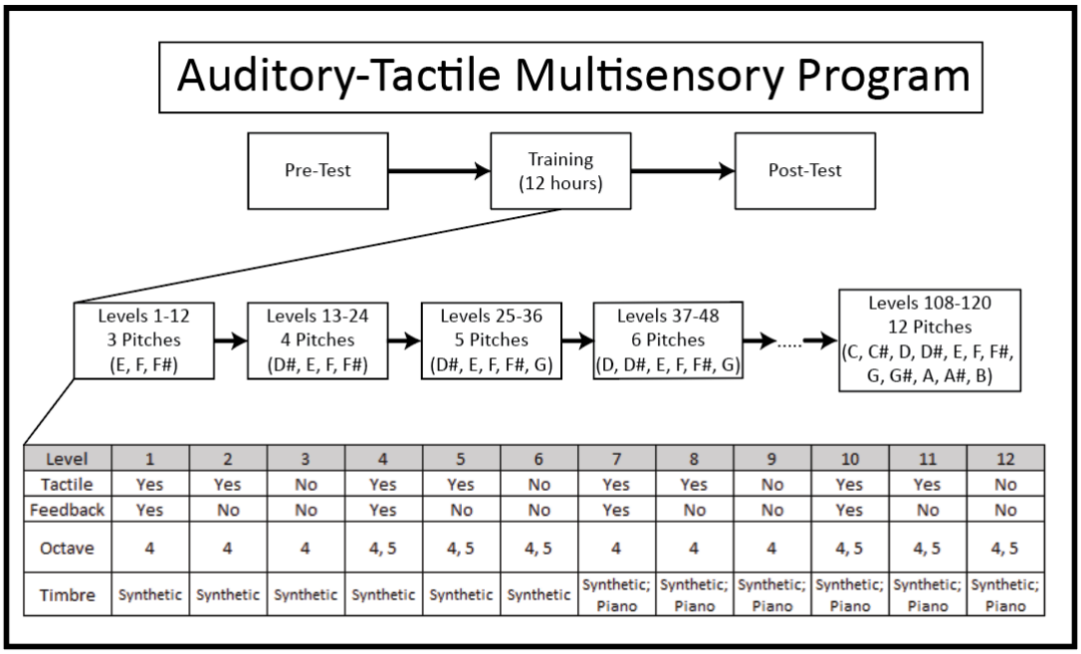
Participants may also freely listen to sample tones before entering the training level.

The training will be completed once the participant has completed all 80 levels, or 12 hours of training have passed. Participants may complete 1 hour of training per day but should be finished with the whole experiment within a month and a half.

Experimental Design

The experiment design acts similar in structure to the control design, but with 4 additional levels within the groups due to the inclusion of the tactile feedback, for a total of 120 levels.

Rather than having 8 levels per group, it will now have 12 levels, with 3 levels per subgroup. The first level in a subgroup works similar to the control design, with immediate feedback on whether the answer is right or wrong, but the played tone will also be accompanied by a tactile stimulus. The second level in a subgroup will include the tactile stimuli as well, but the feedback will only be revealed at the end of the level. The third level in a subgroup will not include the tactile stimulus. Instead, only the tone will be played, and the feedback will all be revealed in the end as well. This is to make sure that the participants are not completely reliant on the tactile stimulus during the whole training program. The other subgroups work similarly to the groupings in the control group. The figure below shows the different combinations based on the levels, with a more detailed table in Appendix B.



Level	1	2	3	4	5	6	7	8	9	10	11	12
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

Figure 3: Auditory-Tactile Multisensory Program

Similar to the control design and the tests, every item in a level will play a tone for 1 second along with a haptic response (depending on the level). The participant will have 5 seconds to identify the correct name of the pitch of the presented tone.

After any levels with feedback, a 15 second glissando clip (no tactile feedback will be attached) will be played to erase any memory of existing referential tones from the previous level for the no feedback levels.

Participants may also freely listen to sample tones before entering the training level. They may also include or exclude the haptic feedback to their preference.

The training will be completed once the participant has completed all 120 levels, or 12 hours of training have passed. Participants may complete 1 hour of training per day but should be finished with the whole experiment within a month and a half.

Analysis

Once all participants have completed the training and post-tests, the results of the tests will be collected and analyzed. One-Way ANOVA will be used to analyze the differences between an individual's pre-test results and their post-test results, using both metrics of correctly named pitch, or relative distance between the correct pitch and the answers of the participants. This will determine whether the training program was successful in having the participants learn AP or not, whether under the control or experimental group. The scores of the two groups will also be compared to examine whether one group's program, either the auditory unisensory program or the auditory-tactile multisensory program, was more successful in training AP.

The results of the additional tactile post-test will also be analyzed using Mean Absolute Deviation to determine whether the participants have developed a link between a specific pitch and the haptic feedback used to reinforce its AP learning.

Conclusion

Absolute Pitch training has always been in the backseat of ear training, second to Relative Pitch due to various reasons. Various designs and training methodologies need to be implemented to make the training worthwhile and have more positive results. The results of this experiment aim to create a methodology in learning the skill with better end results. This study hopes to also encourage more studies using synesthesia-designed multimedia in training various other skills. There are hopes to invigorate further studies in AP training for musicians, with varying designs in technology and implementations.

Acknowledgements

I would like to thank my Advisor for holding my hand throughout this endeavor, Dr. Andrei Coronel, my mentors for the project who gave so much help and insight, Dr. Didith Rodrigo, Mr. Toto Oppus, Mr. Cesco Amante, and Mr. Neith Casano, and the secretary of DISCS, Mrs. Elisa Agbay and Mrs. Joannie Ereno for bearing all the headaches for assisting me through all the problems.

Appendix A: Table of Levels for Auditory Unisensory Training Program

AUDITORY UNISENSORY STIMULUS								
3 Pitches (E, F, F#) - Levels 1-8								
Level	1	2	3	4	5	6	7	8
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
4 Pitches (D#, E, F, F#) - Levels 9-16								
Level	9	10	11	12	13	14	15	16
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
5 Pitches (D#, E, F, F#, G) - Levels 17-24								
Level	17	18	19	20	21	22	23	24
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
6 Pitches (D, D#, E, F, F#, G) - Levels 25-32								
Level	25	26	27	28	29	30	31	32
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
7 Pitches (D, D#, E, F, F#, G, G#) - Levels 33-40								
Level	33	34	35	36	37	38	39	40
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
8 Pitches (C#, D, D#, E, F, F#, G, G#) - Levels 41-48								
Level	41	42	43	44	45	46	47	48
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

9 Pitches (C#, D, D#, E, F, F#, G, G#, A) - Levels 49-56								
Level	49	50	51	52	53	54	55	56
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

10 Pitches (C, C#, D, D#, E, F, F#, G, G#, A) - Levels 57-64								
Level	57	58	59	60	61	62	63	64
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

11 Pitches (C, C#, D, D#, E, F, F#, G, G#, A, A#) - Levels 65-72								
Level	65	66	67	68	69	70	71	72
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

12 Pitches (C, C#, D, D#, E, F, F#, G, G#, A, A#, B) - Levels 73-80								
Level	73	74	75	76	77	78	79	80
Feedback	Yes	No	Yes	No	Yes	No	Yes	No
Octave	4	4	4, 5	4, 5	4	4	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

Appendix B: Table of Levels for Auditory-Tactile Multisensory Training Program

AUDITORY-TACTILE MULTISENSORY STIMULUS												
3 Pitches (E, F, F#) - Levels 1-12												
Level	1	2	3	4	5	6	7	8	9	10	11	12
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
4 Pitches (D#, E, F, F#) - Levels 13-24												
Level	13	14	15	16	17	18	19	20	21	22	23	24
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
5 Pitches (D#, E, F, F#, G) - Levels 25-36												
Level	25	26	27	28	29	30	31	32	33	34	35	36
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
6 Pitches (D, D#, E, F, F#, G) - Levels 37-48												
Level	37	38	39	40	41	42	43	44	45	46	47	48
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
7 Pitches (D, D#, E, F, F#, G, G#) - Levels 49-60												
Level	49	50	51	52	53	54	55	56	57	58	59	60
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
8 Pitches (C#, D, D#, E, F, F#, G, G#) - Levels 61-72												
Level	61	62	63	64	65	66	67	68	69	70	71	72
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
9 Pitches (C#, D, D#, E, F, F#, G, G#, A) - Levels 73-84												
Level	73	74	75	76	77	78	79	80	81	82	83	84
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
10 Pitches (C, C#, D, D#, E, F, F#, G, G#, A) - Levels 85-96												
Level	85	86	87	88	89	90	91	92	93	94	95	96
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
11 Pitches (C, C#, D, D#, E, F, F#, G, G#, A, A#) - Levels 97-108												
Level	97	98	99	100	101	102	103	104	105	106	107	108
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano
12 Pitches (C, C#, D, D#, E, F, F#, G, G#, A, A#, B) - Levels 108-120												
Level	109	110	111	112	113	114	115	116	117	118	119	120
Tactile	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
Feedback	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No
Octave	4	4	4	4, 5	4, 5	4, 5	4	4	4	4, 5	4, 5	4, 5
Timbre	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano	Synthetic; Piano

References

Baharloo, S., Johnston, P. A., Service, S. K., Gitschier, J., & Freimer, N. B. (1998). Absolute pitch: An approach for identification of genetic and nongenetic components. *The American Journal of Human Genetics*, *62*(2), 224–231. https://doi.org/10.1086/301704

Banissy, M. J., Jonas, C., & Cohen Kadosh, R. (2014). Synesthesia: An introduction. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01414

Deutsch, D. (2013). Absolute pitch. *The Psychology of Music*, 141–182. https://doi.org/10.1016/b978-0-12-381460-9.00005-5

Loui, P., Zamm, A., & Schlaug, G. (2012). Absolute Pitch and Synesthesia: Two Sides of the Same Coin? Shared and Distinct Neural Substrates of Music Listening. *ICMPC: Proceedings. International Conference on Music Perception and Cognition*, 618–623.

Medina, J. (2014). *Sensory Integration. In Brain Rules: 12 Principles for Surviving and Thriving at Work, Home and School* (pp. 163–179). Pear Press.

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*(3), 309–326. https://doi.org/10.1007/s10648-007-9047-2

O'Toole, P., Glowinski, D., Pitt, I., & Mancini, M. (2021). When emotions are triggered by single musical notes: Revealing the underlying factors of auditory-emotion associations. *Companion Publication of the 2021 International Conference on Multimodal Interaction*. https://doi.org/10.1145/3461615.3485419

Simner, J. (2011). Defining synaesthesia. *British Journal of Psychology*, *103*(1), 1–15. https://doi.org/10.1348/000712610x528305

Takeuchi, A. H., & Hulse, S. H. (1993). Absolute pitch. *Psychological Bulletin*, *113*(2), 345–361. https://doi.org/10.1037//0033-2909.113.2.345

Trehub, S. E. (2003). Absolute and relative pitch processing in tone learning tasks. *Developmental Science*, *6*(1), 44–45. https://doi.org/10.1111/1467-7687.00251_1

Van Hedger, S. C., Heald, S. L., & Nusbaum, H. C. (2019). Absolute pitch can be learned by some adults. *PLOS ONE*, *14*(9). https://doi.org/10.1371/journal.pone.0223047

Wong, Y. K., Lui, K. F., Yip, K. H., & Wong, A. C.-N. (2019). Is it impossible to acquire absolute pitch in adulthood? *Attention, Perception, & Psychophysics*, *82*(3), 1407–1430. https://doi.org/10.3758/s13414-019-01869-3

Contact emails: jsamaco@ateneo.edu
acoronel@ateneo.edu