The Effect of Spatial-temporal Reasoning Ability on Pitch Retention and Recall

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Introduction

For hundreds of years choirs have been singing music that fills the mind with images that take the listener to far off places and back again in a few short minutes; however, the thought comes across one's mind to wonder how do these singers recall all of those pitches out of the vast capability of the human voice? This study focuses on the possibility that the ability to place and recall pitches happens in the spatial-temporal ability of the performer.

It is a well-understood fact that some of the world's top choirs do not limit their repertoire to just one genre but perform the whole gamut of time, from plainsong to post-20th century works, and within this repertoire the singer must be able to recall and produce these complex sequences of notes and rhythms. Even the veteran conductors of the world today are always searching for a way to help their ensemble sing more accurately; the first small step is to understand the ability to recall pitch over time and link it to the ability to form and manipulate visual-spatial images, which are made in the auditory cortex.

Physiologically, it hasn't been until recent increases in technology that deep study of the brain and the auditory cortex has been possible. In a study in the *Journal of Neuroscience* by Rinne, Koistinen, Salonen, and Alho (2009) a high-resolution functional resonance image of the auditory cortex (AC) yielded the ability to compare activations during pitch discrimination and pitch memory tasks. This study found that activations of the AC were between the anterior/posterior AC and while performing pitch discrimination/pitch memory tasks, respectively. Lastly it found that the activation of the AC is strongly dependent during musical tasks.

The AC is located in the right hemisphere of the brain and it is a recognized fact the dominant side of the brain is an opposite relation of the dominant hand (right handed-left brained and vice-versa). A study by Byrne and Sinclair (1979) on tonal sequence and timbre harvested the conclusion that familial left-handed subjects (subjects who were left-handed and had family members who also were left-handed) were significantly more superior on timbre tests and slightly more superior on sequential tests than control subjects that were right-handed. Consequently, this shows that spatial and musical abilities are affected by cerebral specialization; however a study presented later will offer a different view on the factors of predictability of spatial and musical abilities.

Another hemispheric study found in *Psychological Science* reported that it found that hemispherical differences in auditory and visual perception are similar (Ivry and Lebby, 1993). This study presented low-frequency and high-frequency sounds to the left and right ears and found their relation to be linked not only auditory (low-freq. & left ear, high-freq. & right ear) but also visually, which found the correlation to be the same formula of the dominant hand.

Research on music's effect on the brain is a relatively new area and Schulze, Gaab and Schlaug (2009) performed a study to compare the abilities of subjects with absolute (AP) and relative pitch when performing a pitch memory task and found that the only difference between the groups is an increased activation of the superior temporal gyrus and sulcus. The increased activation indicates that the relative pitch subjects were using a tonal working memory network or a multimodal encoding strategy (i.e. a visual-spatial activity like internally mapping notes on a staff). The last strict cognitive study is one that references an article by C.C. Pratt in 1930. Pratt wrote:

> "...The results are clear-cut and unequivocal. *High tones are phenomenologically higher in space than low ones.* ...The fact that on any place-theory of hearing the lowest tones would fall at the apex and the highest tones at the cochlea opposite the oval window no more means that we hear the world upside down than the inversion of the retinal image forces us to stand on our heads to see the world right side up. The experiments were done, however, not so much with auditory theory in mind as with the query as to whether the results would throw any light on the moot question of the apparent auditory movement which is set up by tones of different pitch when presented in succession." (p. 113-114)

This rather comedic quote used in a study found in *Cognition* aptly sums up the need for studies on sound once it leaves the cochlea and reaches the eighth cranial nerve to begin the process of perception. The original study by Rusconi et al. (2006) found that there in fact is an internal representation of pitch height that was linked to be spatial and in musically inclined participants had a response that was either horizontally or vertically associated. This study is one of the most recent on music's spatial relationship, as it also deals with place theory.

All of the above articles are all from science-based journals. Because of the neurological stance of this study, a good understanding of previous studies on this topic and ones similar to it is much needed; even just these brief studies have shown a strong bond between spatial-temporal activity and music.

Educators and conductors are always worried about staying "in tune"; however, many probably have not looked at the musical research that has targeted topics such as visual-spatial added cues, aural discrimination and musical imagery, to name a few to add to their rehearsal pedagogy. Most of these topics (and ones similar not listed) are not topics that will be blatantly addressed in a normal rehearsal setting, nonetheless, when incorporated into one it can actually make the ensemble better.

Hayward and Gromko (2009) made an applicable study when they looked at sight-reading, technical proficiency, spatial visualization and aural discrimination. They found that subjects with higher spatial-temporal ability were better sight-readers because they could recall pitches better, however they found that sometimes the technical ability of the subject hindered their ability to reproduce the correct pitch.

Taking out the factor of ability, Long (1977) focused on finding a relationship between pitch memory in short melodies when related to melody length, tonal structure, melodic contour and music perception ability. The study found that all the former factors influenced pitch memory but the most was perceptive ability because of its close tie to previous learning and tonal structure. Two last correlations were made when memory for pitch improved as the number of pitches in the melody increased and that certain intervals caused variations in pitch memory recall.

A focus on short-term memory, pitch sequence and pitch position by Williams (2009) shows that a loss of short-term memory in music is a result of delay time to reproduce the sequence, the position of the pitch in the sequence and the length of the sequence. Short-term memory is the key in this study because it was done over a length of time in multiple sessions, which can actually increase the frequency of positive data because of the repetition.

The previous studies have all been post-test only tests, which limits some of the applicable ability to classrooms. The next studies are ones that have been used in a classroom and are designed in a pre- and post-test manner.

Visual-spatial cues (such as Curwin hand-signs) are often thought of as one of the best ways to coordinate the voice and melodic contour. In a study in the *Journal of Research in Music Education*, Forsythe and Kelly (1989) set out to find if added visual-spatial cues do aid in melodic discrimination. Subjects were placed into groups where they heard 30 melodies played twice either aural-visual both times, aural-visual first and aural only second, and aural only for both. The study determined that when visual cues were paired with melodies it was generally an effective aural discrimination aid.

In the continuing fight to keep funding in the schools for music, educators are always striving to find ways to show that music is interrelated with all the subjects and effects all parts of the learner. Gromko and Poorman (1998) sought out to find the effect of musical training on preschooler's spatial-temporal task performance. After analyzing the data they stated that while theories of spatial ability cannot predict the effect of music training and ability, research in spatial memory could give some rationale for its inverse or the effect of music on spatial knowledge. Knowing this Gromko and Poorman wrote a suggestion of this study for music education as follows:

> "We believe that early music training with an emphasis on sensory motor activity, visual and aural perception of space and sound, and the improvement of memory for space and sound nurtures a young child's intrinsic love of learning, helps them move expressively and perceptively within their

> environments, and sustains and encourages their intellectual growth up to the point that they enter school." (p.178)

It is this thought that sums up the need to study the cognitive process of music that can ready students, even at the pre-school level to continue in school and instill intellectual growth. It is in reading through the data and seeing it is possible impact on the future that makes these studies vitally influential to what we do as educators.

Lastly, in a study published in the *Journal of Research in Music Education* by Bergan (1967) began to investigate a topic similar to this; however, because MRI technology was not yet invented a complete physiological connection could not be made. Even with the inability to investigate cognitive implications, Bergan did find that a positive correlation exists between pitch judgment and imagery, and that positive correlation exists between pitch judgment and musical memory. Terminology like musical imagery and musical memory are used where this study plans to be in terms of spatial ability (in place of musical imagery) and musical memory (pitch memory).

Method

This study is an attempt to find the effect of spatial-temporal ability and repeated exposure to a simple melody on pitch memory as measured by the correctness of intervals and accuracy of starting and ending pitch. Participants were a volunteer population (N = 30) of music majors at the University of Alabama consisting of eight graduates and twenty-two undergraduates, sixteen vocalists and fourteen instrumentalists, and fourteen males and sixteen females.

Participants first completed a spatial-temporal task on the Nintendo Wii™ game Big Brain Academy™ that has a section that requires the participant to complete ten exercises where a three-dimensional two-colored object that looks similar to a Rubik's cube with a few pieces taken out is placed on the screen and rotated clockwise and the participant matched one of four possible figures to the initial object. After the exercises were finished, the game indicated how much time it took the participant to complete the exercises and the percent of the exercises that the participant got correct. For data analysis, the percent correct was inverted to show the percent incorrect and added to the amount of time it took to complete the exercises to create the Kyle Spatial Factor (KSF), which was the factor used to evaluate the spatial ability of participants.

Participants were randomly placed into one of three groups using a set of numbers generated by the website randomizer.org to create the random placement list. After being placed in the groups the participant was told that they were going to listen short melody that was played once, 5, or 10 times (corresponding to their group placement), listen to 30 seconds of white noise, listen to a short narrative and then they will hum the melody back after the recording. All three items were on a continuous recording, and there was a two-second break between each section. Before the recording began, participants were asked to sit with their hands on their thighs and that singing, humming or using kinesthetic reinforcements like fingerings or hand-signs was not permissible. Upon being prompted from the study supervisor that they were close enough to the microphone, participants were then asked to hum the melody into the microphone and it was recorded. Participants were then thanked for their time and released. The recordings were listened to, analyzed using a strobe tuner to find the exact notes performed by the participant and then converted from cents +/- from the actual pitch to Hertz.

Results

After the collection of data it was put in an excel spreadsheet then organized by the researcher. The data was then imported into a data analysis program, SPSS. Four statistical tests were conducted with the assistance of an experienced researcher in the field of music education at the University of Alabama.

The first test was a two-way analysis of variance (ANOVA) arranged to evaluate the relationship between the number of repetitions of the melody heard by the participants (1, 5, or 10), participants' primary instrument (voice vs. instrument), and the number of intervals participants performed correctly. Results yielded a statistically significant overall model, F (5, 24) = 6.26, p = .001, η_p^2 = .57. The first main effect was the influence of repetitions on intervals performed correctly. Results were statistically significant, F (2, 24) = 3.64, p = .042, η_p^2 = .23 and a Tukey HSD post hoc test indicated statistically significant differences (p = .002) between the group of participants who heard the melody played once and 10 times. The group who had the melody played once performed fewer correct intervals (M = 1.17, SE = .24) when compared with the group who heard the melody played 10 times (M = 2.10, SE = .25). Participants' primary instrument, whether the subject was a vocalist or instrumentalist, was also statistically significant, F (1,24) = 14.58, p = .001, η_p^2 = .38. Examination of the mean correct intervals indicated that instrumentalists performed fewer correct intervals (M = 1.12, SE = .32) when compared to vocalists (M = 2.19, SE = .19). The interaction between the two factors (instrument and repetitions) was not statistically significant, F (2, 24) = 0.77, p > .05, η_p^2 = .06.

The second test was a one-way ANOVA arranged to evaluate the relationship between the accuracy of the starting pitch performed by the participants (in Hz), the Kyle Spatial Factor (KSF), and the number of repetitions of the melody heard by the participants. Results yielded a statistically significant overall model, $F\ (3, 26) = 3.69$, $p = .025$, $\eta_p^2 = .298$. The first main effect was the influence of the KSF on the accuracy of the starting pitch performed by the participants. Results were statistically significant, $F\ (1, 26) = 9.02$, $p = .006$, $\eta_p^2 = .26$. Also, while the overall model was significant the number of repetitions of the melody heard by the participants was not, however, there was a correlation between participants' starting pitch and the KSF.

The third test was a one-way ANOVA arranged to evaluate the relationship between the accuracy of the ending pitch performed by the participant (in Hz), the KSF and the number of repetitions of the melody heard by the participants. The results of this model were not significant, $F\ (3, 26) = 2.668$, $p > .05$, $\eta_p^2 = .235$, however, the KSF did yield a significant value that can show that it is a predictor of the ending pitch.

The final analysis conducted is the same two-way ANOVA run in the first test but this time with the KSF as a covariant; results yielded a statistically significant overall model, $F\ (6, 23) = 5.004$, $p = .002$, $\eta_p^2 = .566$. The first main effect of this model was that the KSF was not statistically significant, $F\ (1, 23) = .003$, $p > .05$, $\eta_p^2 = .000$. The second main effect is similar to the second main effect from the first test on the analysis of whether the participant was a vocalist or instrumentalist and how many intervals they performed correctly, $F\ (1, 23) = 13.659$, $p = .001$, $\eta_p^2 = .373$.

Discussion

This study is an attempt to find the effect of spatial-temporal ability and repeated exposure to a simple melody on pitch memory as measured by the correctness of intervals and accuracy of starting and ending pitch. The results overall show that spatial-temporal ability was not a significant predictor for accuracy of starting and ending pitches of a melody; however the number of repetitions of a heard melody did yield some interesting results.

One of the first major observations from this study is that there was a major difference in the performance of the melody after it was heard 1 versus 10 times. This says to us that as we are teaching that repetition is a major factor in correct performance, if the participant heard the melody 10 times there is a statically significant probability that they will sing more correct intervals.

Another observation stems from the first ANOVA run that contradicts some of the usual assumptions between vocalists and instrumentalists. It is a well understood thought that because instrumentalists have a kinesthetic relationship to producing sounds that they would be better at reproducing and singing correct intervals. The data from this study shows that based on the Tukey HSD post hoc tests that vocalists actually on average performed more correct intervals. This is quite intriguing because vocalists have no kinesthetic relation to the voice (meaning that they don't have a key, button or string to press down to create a note) and that producing specific sounds is possible only by muscle memory.

Addressing the spatial impact on pitch memory, the KSF is a significant factor in predicting the ability to remember and reproduce the starting pitch, however the number of correct intervals sang by the participant is not related to the KSF. Also, even though the model was not significant, the KSF did yield a significant value that can partially show that it is a predictor in the ability to sing the ending pitch correctly.

The KSF was produced on data from the Nintendo Wii™ game Big Brain Academy™ and was used only as a means to quickly obtain data. The KSF is a number that is slightly inconsistent because the game itself was adaptive, meaning that as a participant completed the exercises quickly and more accurately or slower and less accurately the game got tougher or easier, respectively. The game's ability to adapt made the time and score from the game very questionable, in addition there was no time limitation on any individual exercise or the test as a whole which will add to the skew of the data. Another issue with the data is that only three intervals were evaluated for correctness out of the possible eight in the melody used in the study. Lastly, the use of white noise could have actually blanked the subject’s memory completely, which could have greatly effected the pitches recalled by the participant.

This study was strictly for finding data on the effects of spatial-temporal ability on pitch memory but nevertheless many other possibilities for other studies have arose. Reproducing this study with more time available and a more reliable test of spatial-temporal ability this test may actually yield better findings. Also, a study of focus during listening for recall ability is something that could come out of a future study similar to this and a study on difficulty of melodies and the ability to recall them are just a few of the additional studies that could stem from this study.

Bibliography

Bergan, J. R. (1967). The relationships among pitch identification, imagery for musical sounds, and musical memory. *Journal of Research in Music Education, 15*, 99-109.

Byrne, B. & Sinclair, J. (1979). Memory for tonal sequence and timbre: a correlation with familial handedness. *Neuropsychologia, 17*, 539-542.

Forsythe, J. L. & Kelly, M. M. (1989). Effects of visual-spatial added cues on fourth-graders' melodic discrimination. *Journal of Research in Music Education, 37*, 272-277.

Gromko, J. E. & Poorman, A. S. (1998). The effect of music training in preschoolers' spatial-temporal task performance. *Journal of Research in Music Education, 46*, 173-181.

Hawyard, C. M., & Gromko, J. E. (2009). Relationships among music sight-reading and technical proficiency, spatial visualization, and aural discrimination. *Journal of Research in Music Education*, *57*, 26-36.

Ivry, R. B. & Lebby, P. C. (1993). Hemispheric differences in auditory perception are similar to those found in visual perception. *Psychological Science, 4*(1), 41-45.

Long, P. A. (1997). Relationships between pitch memory in short melodies and selected factors. *Journal of Research in Music Education, 25*(1), 272-282.

Rinne, T., Koistinen, S., Salonen, O., Alho, K. (2009). Task-dependent activations of human auditory cortex during pitch discrimination and pitch memory tasks. *The Journal of Neuroscience, 29*(42), 13338-13343.

Rusconi, E., Kwan, B., Giordano, B. L., Umiltà, C., Butterworth, B. (2006). Spatial representation of pitch height: the SMARC effect. *Cognition, 99,* 113-129.

Schulze, K., Gaab, N. & Schlaug, G. (2009). Perceiving pitch absolutely: Comparing absolute and relative pitch possessors in a pitch memory task. *BMC Neuroscience, 10*(106), 1-13.

Williams, D. B. (1975). Short-Term Retention of Pitch Sequence. *Journal of Research in Music Education, 23*, 53-66.