

Author



If you look up *interdisciplinary* in the dictionary, you might find a picture of Benjamin Johns. He is a rare triple-major, studying Chemistry, Dance and Music. His current project draws on theories from these fields as well as psychology and neuroscience. In the hopes of improving upon his research and perhaps influencing the way music and dance are taught in the future, he plans to pursue a Ph.D. in Neurobiology. Immersing himself in these fields proved especially rewarding for Benjamin, but his favorite part of the research process was discussing his work with his wife. In his spare time, Benjamin sings and dances professionally and enjoys spending time with his wife and their pets.

Key Terms

- ◆ Dalcroze-type Methods
- ◆ Eurhythmics
- ◆ Motor Equivalence
- ◆ Motor Program
- ◆ Tonal Loop
- ◆ Transfer Effect
- ◆ Vocal-Kinetic Effect

Exploring the Neurobiological Basis for the Effect of Movement on the Voice: Quantifying Dalcroze-type Methods

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Chemistry, Dance and Music

Abstract

Dalcroze-type movement while singing has been shown qualitatively to have various musically enhancing effects in a choral music context. These effects are generally known and employed by teachers of professional musicians, but have not yet been defined and understood from a neurological standpoint. The musician's pedagogical term for a musical quality is not easily translatable into scientifically measurable quantities. This research begins to elucidate the elements of music-movement transfer effects by measuring changes in trial length, peak loudness per trial, and number of breaths taken per trial when singers are subjected to movement and non-movement conditions while singing. It was found that trial length increased during movement trials. Though the neurobiological explanation for the trial length effect could be a simple task-load problem, further experimentation is required to find decisive cause.

Faculty Mentor



The importance of research in the creative arts cannot be overstated. The basic fundamental expressions of mankind are universal and cross all boundaries of cultural differences. The act of singing, one such universal act of expression, is common to cultural ritual. For countless generations we have seen the influence of movement upon singing and have understood that the nature of singing intrinsically caused movement. Benjamin Johns' research shows a direct relationship of movement upon singing and how one form of expression influences and, indeed, enhances another. The synergy created between two seemingly diverse disciplines begs for more extensive research into basic artistic expression and the fundamental common influences of each. The understanding of natural creative principles through scientific research could undoubtedly enhance communication between people seeking common goals. Research of the abstract nature of art may help influence the nature of science into a more creative expression of art.

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Introduction

The use of movement while singing is deeply ingrained in the history of vocal music performance and pedagogy. The ancient Greeks saw music and dance as a single entity, inseparable components of one performing art. There are accounts of highly stylized movement specifically used by opera singers in the Baroque era. In today's opera and solo performances, singing virtuosos regularly incorporate certain body movements. For example, Plácido Domingo will often touch the side of his face in mid-performance or subtly rise on his toes to hit a high note. These body gestures may be related to more than simply the drama of the music. The point of interest is if and how movement affects the sound a singer produces. There appears to be at least some technical utility to these physical gestures, as well as an expressive one. A study conducted by Chagnon (2001) found that singers who incorporated movement with singing believed they could memorize music faster than when they did not use movement. In what ways does movement affect the voice? How can these vocal-kinetic effects be explained from a psychological, neurobiological and philosophical basis? This project seeks to quantifiably assess and use current theories to evaluate the existence of these effects.

Successful choral conductors and researchers tout movement as having enhancing effects on the singing voice when an individual or choir simultaneously moves and sings. Chagnon's dissertation explores the effect of movement on choral singers' ability to learn their music. After studying five choral conductors who employed innovative movement-singing techniques, Chagnon qualitatively found that three things generally happened when singers moved in these choirs: the singers learned better and faster, acquired better singing techniques, and became more expressive (2001). More specifically, Chagnon believes the following eight technical effects, observed on the singers he studied, can be applied to all singers who move while singing: 1) activation of an energetic management of breath; 2) improved singing posture; 3) refined tone quality; 4) improved tone projection; 5) improved intonation (singing in tune); 6) internalized rhythm and tempo; 7) ability to modify musical articulation, diction attacks, releases, and timbre; and 8) refined phrasing. These eight effects are the primary ingredients for excellent singing.

While Chagnon's study was conducted only recently, the effects he found have been known to music teachers for the greater part of the twentieth century. The Swiss musician Emile Jacques-Dalcroze (1865-1950) developed a method

of music training known as Eurythmics, which uses rhythmic movements to enhance a student's learning of musical qualities (Caldwell, 1995). Since its conception, the idea of Eurythmics has been further developed to incorporate non-rhythmic movements. To those not familiar with Dalcroze-type exercises, Chagnon's findings may be surprising. To a neurobiologist the results are intriguing. Why and how does this effect work? What is the neurological effect of movement on a singer that dramatically influences the learning of music, vocal technique, and musical expression? One aim of this research is to quantitatively, rather than qualitatively, evaluate the effect that movement has on some of the eight performance qualities mentioned above. A second objective of this research is to better understand the neurobiological basis of how movement and music affect each other by using existing theories about cognitive function. With this knowledge, any learning system potentially could become more efficient, with immediate applications to vocal and dance pedagogy. Additionally, physical therapy could be enhanced for patients with lost or limited vocal, movement, learning, or memory ability.

Because the amount of literature on this specific movement-singing effect is limited, music and/or movement related articles from neuroscience, psychology, dance, and pharmacology were used to provide some thought-provoking insight. The ideas fostered by these articles apply to this research project in three ways.

The Neurobiology of Voluntary Movement: The Mind's Eye View

Human movement is made possible by a jointed skeletal frame, muscles and connective tissue, motor neurons that signal muscles to contract, and a central nervous system that controls which muscles fire, when, and with how much intensity. Therefore, coordinated movements are fairly complex considering how many voluntary muscles humans have. In "The Organization of Movement," Ghez and Krakauer (2000) teach rules for voluntary movement. They state that all voluntary movement begins in the brain with an internal representation, a mind's eye view, of the desired bodily movement. The mind's eye imagines environmental factors surrounding the body (motor kinematics) and how much force to give muscles in order to accomplish a desired task (motor dynamics). This internal view is evident in the following phenomenon.

A person can write his/her name with either hand. Assuming the subject is not ambidextrous, the attempt with the hand not normally used for writing will be unkempt, but generally recognizable as writing. One can also write

his/her name with the pen held in the teeth or between the toes. Again, the result may be unkempt, but the product is usually recognizable as writing. Writing is an example of one motor program that we have learned using the muscle groups controlling our writing hand and arm. The fact that we can still write with other muscle groups, a phenomenon known as motor equivalence, indicates that the motor program is not located in the muscles performing a coordinated movement, but is instead somewhere in the mind. This motor equivalence has exciting implications for a theory explaining the results of the present research.

Ghez and Krakauer elucidate another rule governing voluntary movement: moving voluntarily takes longer with a more complex movement. Since there are more muscle groups and associated neurons to consider firing, it is logical that complex voluntary movement takes more time than simple voluntary or involuntary movement. Like an old computer that takes less than a second to calculate 3×3 , but takes 10 seconds to open a word processing program, humans take longer to process more complicated movements. This rule provides an explanation for one result of this research.

The Psychology of Singing in Tune

A psychologically-based perspective also explains results of this research. The tonal loop theory (Figure 1), as described in *The Psychology of Music* (Deutsch, 1999), shows how singers are able to sing in tune and provides fuel for a hypothesis that explains the Dalcroze vocal-kinetic effect. The tonal loop theory assumes two working memory areas communicate with each other: one area temporarily remembers what tonality the singer performs (the tonal store) and the second area rehearses and maintains the tonality (the fundamental frequency control process). Silent rehearsing is also called “inner singing” because the singer does not

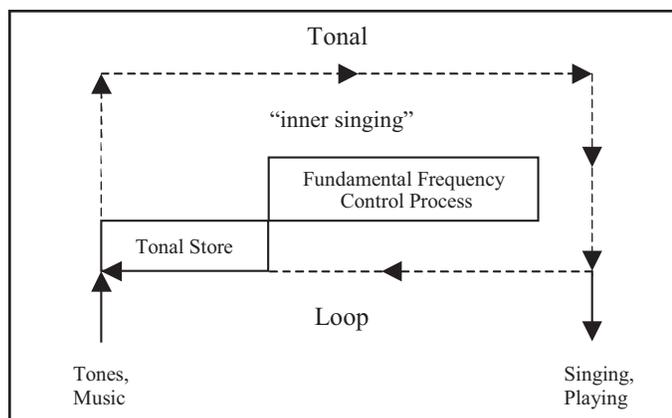


Figure 1

A model of the tonal loop theory rationalizing a musician’s ability to sing or play in tune (Deutsch, 1999)

make noise; the song is silently sung in the mind. This concept of internal processing follows from the motor equivalence rule previously described.

Another interesting aspect of the tonal loop theory is that it was modified from a theory developed for linguistics, the phonological loop theory. The reason for interest in these related theories is the idea that they represent parallel processing systems in the brain. A present hypothesis for the vocal-kinetic effect employs parallel processing as a means for enhancing cross-system learning. Moving enhances the learning of vocal techniques because movement and singing are parallel systems that communicate with each other. Applying a concept embodied in movement potentially allows the singer to understand that concept in the language of movement. Once the concept is learned, the singer then translates it from movement language into vocal language. This is similar to the motor equivalence discussed earlier. The concept of “smooth,” for example, can be applied not only to different parts of the moving body, but to the singing voice as well. Learning in this manner of awareness then becomes a function of interdisciplinary exploration and translation.

The Psychology and Neurobiology of Optimized Learning

The learning of infants, which we know to be amazingly efficient, is psychologically described by Stern in his book, *The Interpersonal World of the Infant* (1985). Stern proposes that amodal perception is key to an infant’s learning abilities. The infant is able to translate between modes of sight, sound, touch, smell, and taste by perceiving the world through a unified lens. In other words, infants can literally see, hear, feel, smell, and taste the quality of their mothers rocking them to sleep through one global sensory organ. The baby’s senses have not yet differentiated. By paying more attention to rhythms, shapes and intensities, babies can capitalize on perceptual synesthesia to learn at incredible rates.

The ability to translate across modes of learning is not limited to babies or perception. Zatorre reviewed interesting research that points to the brain’s ability to “grow” one sensory modality into the region of another (2001). Weinberger reports a significant amount of research-based evidence for the positive effect of music on learning, memory and creativity (MuSICA archive, online). Indeed, music effect research has been considered and performed in Germany by Gruhn, who describes two experiments that parallel the intent of the present paper (2000). He concludes that applying what is known neurobiologically about these transfer effects to educational practice is yet prema-

ture: “Empirical data cannot be directly transferred to educational practice because scientific descriptions are essentially different from educational prescriptions...Judgments in education...are value judgments to a large degree” (Gruhn, 2000). Gruhn’s assessment is accurate insofar as music transfer effect data are presently limited to the handful of experiments that have been performed on the topic, but as the effects become better understood, the value judgments of educators will potentially be influenced by the empirical data. Nonetheless, “we may expect new insights into neuronal developments and cognitive effects related to music learning” (Gruhn, 2000).

Development of the Present Research Method

Unfortunately, Gruhn’s article was not available to the author when the present research method was devised. Pre-existing models of motor behavior provided suitable research guidelines. In the *British Journal of Clinical Pharmacology*, Hindmarch presents a model of “psychomotor performance” that counts personality, motivation and memory as fellow contributors to movement behavior (1980) (Figure 2). Hindmarch’s model illustrates how motor behavior can influence motivation, memory and personality as well as sensory/primary coding and central organization of output. The article focuses on the design of experiments involving drug interaction with motor function, but most of what Hindmarch says can also be applied to physical task interaction with motor function. For example, he mentions that experiments involving motor and sensory systems will be subject to learning and practice effects. He advises choosing subjects that have all reached a plateau in their learning curve, a suggestion that influenced the method of subject selection in the present experiment.

The present experiment investigates claims made by Dalcroze and others in the vocal arts regarding the effects of movement on a singer’s sound. To measure potential effects, subjects were recorded singing a memorized melody three times in no specific order: once without moving, once while simultaneously copying the movement of the researcher, and once while copying the movement of the researcher but with a specific concept behind the movement. The audio and video recordings were subjected to analysis to identify effects that movement had upon the singers. The current research sought to evaluate the following effects of movement on vocal performance: 1) better tone projection (louder singing), 2) improved posture, 3) more expressive presentation (testable by timbre analysis), 4) more in tune (testable by pitch analysis), and 5) better breath control (testable by counting the number of breaths taken).

Methods and Materials

The National Anthem Experiment

Test subjects were selected on a volunteer basis from choirs at UCI. An important feature of the choral program at UCI is that it uses Dalcroze-type instruction. At the close of the academic year, students in these choirs were chosen with the hope that Hindmarch’s learning plateau for Dalcroze-type concepts would already be reached. The only other prerequisite for participation was familiarity with the song “The Star Spangled Banner” (the United States’ national anthem, chosen because it is well known). This study was approved by the Institutional Review Board (IRB) of UCI under protocol #2002-2427.

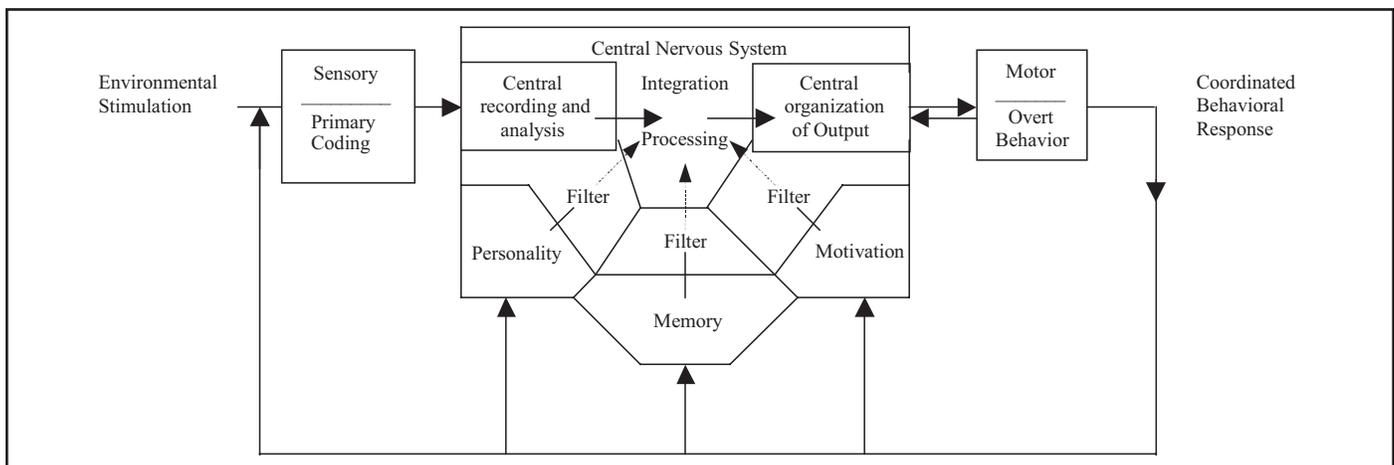


Figure 2
Hindmarch’s model showing the balance between the sensory and motor systems as being influenced by personality, memory, and individual motivation (Hindmarch, 1980)

Subjects (N = 13) were recorded singing *a cappella* onto digital video and audio tapes. After taking a short survey of the singer's background in vocal performance, the singer was instructed to sing in the following manners in random order:

- I. "The Star Spangled Banner" without moving more than needed (emphasizing that substituting "la" for forgotten words is better than stopping).
- II. "The Star Spangled Banner" while copying live demonstrated movements (again emphasizing that words are not necessary). All of these movements were, in general, similar in quality to tai chi: very smooth, connected, and not too fast.
- III. "The Star Spangled Banner" while copying demonstrated movements that are connected to a specific concept (e.g., imagine you are pushing a 100-pound block across the room while singing).

After this portion of the experiment, the subjects were asked what they thought during the three performances. For example, some subjects admitted that they did not focus much on the concept given to them, which is valuable for interpreting the recorded results of that trial.

Audio recordings were analyzed by Pro Tools® Free for peak volume and trial length. The results were tabulated and Wilcoxon's Sum of Ranks tests were run on the data. The number of breaths taken per trial were also recorded. Video recordings were analyzed for changes in posture. Timbre and pitch analyses have not yet been conducted, as they are not possible using software presently available to the author. However, many of the subjects appeared to stay in tune, a phenomenon predicted by the tonal loop theory.

Results and Discussion

The following results were found:

- 1) Copied movement trials, including the "movement only" and "concept with movement" trials, took more time than "no movement" trials.
- 2) "Movement only" and "concept with movement" trials showed no significant difference in length.
- 3) A comparison of peak loudness per trial showed no significant difference.
- 4) A comparison of number of breaths taken per trial showed no significant difference.
- 5) Posture effects may have been influenced by experimental design.

The results of this experiment demonstrate an effect that movement has upon the duration of each song trial. Table 1 shows the duration of each trial per subject with the average noted at the bottom. The length of each trial was taken to be from the glottal attack on the first word, "Oh," to the cutoff on the last word, "brave." The concept given to each subject is shown in parenthesis. Again, the order of trials was randomized.

By comparing averages visually, it is evident that the trials during which the subjects were instructed not to move were shorter than the trials that used movement. However, merely comparing averages does not take into account the overlapping variations between subjects. The Wilcoxon's Sum of Ranks tests were used to test for a statistically significant effect. Three statistical evaluations were run comparing the following: 1) "no movement" to "movement only" ($p < 0.01$), 2) "movement only" to "concept with movement" ($p > 0.1$), and 3) "no movement" to "concept with movement" ($p < 0.05$). Both tests against "no move-

Table 1
Trial lengths

| Subject Number | No Movement Trial (min:sec) | Movement Only Trial (min:sec) | Concept with Movement Trial (min:sec) |
|----------------|-----------------------------|-------------------------------|---------------------------------------|
| 1 | 1:12.0 | 1:26.6 | 1:28.4 (frisbee toss) |
| 2 | 1:16.7 | 1:36.4 | 1:30.6 (balloon pump) |
| 3 | 1:23.0 | 1:33.1 | 1:42.0 (thick air) |
| 4 | 1:09.8 | 1:34.9 | 1:25.4 (balloon pump) |
| 5 | 1:32.0 | 1:44.0 | 1:38.8 (frisbee toss) |
| 6 | 1:31.0 | 1:47.0 | 1:34.0 (cotton toss) |
| 7 | 1:25.0 | 1:47.0 | 1:41.0 (balloon pump) |
| 8 | 1:39.2 | 1:42.9 | 1:43.3 (block pushing) |
| 9 | 1:12.1 | 1:24.9 | 1:22.1 (balloon pump) |
| 10 | 1:07.6 | 1:20.1 | 1:14.7 (weight lifting) |
| 11 | 1:25.4 | 1:23.0 | 1:28.1 (cotton toss) |
| 12 | 1:26.6 | 1:37.2 | 1:59.3 (frisbee toss) |
| 13 | 1:09.5 | 1:27.1 | 1:12.8 (chopping) |
| Avg. per Trial | 1:20.8 | 1:34.2 | 1:32.3 |

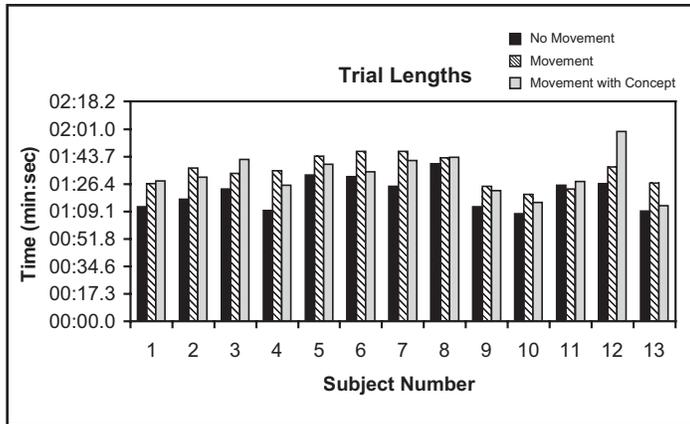


Figure 3
Length of trial per subject

ment” showed significant differences ($p < .05$). No significant difference was shown for “movement only” to “concept with movement.” Therefore, movement apparently significantly increases the length of singing, but an applied concept may not enhance this effect.

The implications of this effect are not clear, but three possible explanations present themselves. First, the effect could be a result of complex processing. Considering that most subjects were not selected for their ability to mimic, their brains may have taken longer to process copying the given movement. Second, the tai chi mode of movement may have influenced the singers by slowing their tempi, which would provide an example of one mode (movement) translating to the other (singing). Finally, the absence of movement could have caused anxiety, thereby promoting faster singing. Other explanations are also possible. Worthy of notice is that one subject, subject 11, has a “movement only” trial shorter than the “no movement” trial. Subject 11’s trial lengths were in general the second most consistent, having a differential of 5.1 seconds compared to the average subject differential of 16.5 seconds. Figure 3 shows the data of Table 1 in graphical form.

The National Anthem Experiment shows no effect of movement on the peak volume of singing. Peak volume is reported in Table 2 using a relative decibel scale by Pro Tools® Free, rating a greater volume for less negative decibels. The data reported is the result of the “find peak” function in Pro Tools® Free when the song trial was highlighted. No trials were normalized after the digital audio was recorded into the computer under constant conditions as .wav files.

Visual examination of the data shows that loudness does not vary as much per trial of the subject as it does across subjects. After running the Wilcoxon tests no significant

Table 2
Peak volume of each trial, measured in decibels

| Subject Number | No Movement Trial (dB) | Movement Only Trial (dB) | Concept with Movement Trial (dB) |
|----------------|------------------------|--------------------------|----------------------------------|
| 1 | -0.3 | -0.5 | -0.5 (frisbee toss) |
| 2 | -3.1 | -3.4 | -2.8 (balloon pump) |
| 3 | -3.0 | -1.7 | -1.9 (thick air) |
| 4 | -1.7 | -2.3 | -2.3 (balloon pump) |
| 5 | *NA | NA | -2.1 (frisbee toss) |
| 6 | NA | NA | NA (cotton toss) |
| 7 | NA | NA | NA (balloon pump) |
| 8 | -1.8 | -2.7 | -2.3 (block pushing) |
| 9 | -15.2 | -12.9 | -9.7 (balloon pump) |
| 10 | -3.8 | -8.1 | -1.7 (weight lifting) |
| 11 | -2.7 | -8.6 | -7.9 (cotton toss) |
| 12 | -2.7 | -3.0 | -1.7 (frisbee toss) |
| 13 | -0.7 | -0.5 | -0.6 (chopping) |

*NA data represents data not yet analyzed.

difference was evident between the three trials ($p > 0.1$). Therefore, movement probably does not affect the overall peak volume of the singers, but this result does not necessarily contradict Chagnon’s findings. Perhaps a study of singers over a longer period of time would show an increase in the intensity of the movement trials, or perhaps the average volume increases instead of the peak volume. Average volume might be greater for movement trials, but this quantity was not measurable using the software programs available to the author.

In order to examine the effects of movement on breath management, the number of breaths per trial were counted. The results showed no significant difference. Number of breaths were tallied per trial not including the first breath before “Oh” or the last breath after “brave.” No significant effect was shown using Wilcoxon’s test ($p > 0.1$). Table 3 shows the tabulated data for the number of breaths taken per trial.

Conclusive analysis of subject posture was thwarted by the design of the experiment. Only one video camera was used

Table 3
Number of breaths per trial

| Subject Number | No Movement Trial | Movement Only Trial | Concept with Movement Trial |
|----------------|-------------------|---------------------|-----------------------------|
| 1 | 13 | 15 | 15 (frisbee toss) |
| 2 | 11 | 11 | 15 (balloon pump) |
| 3 | 13 | 11 | 11 (thick air) |
| 4 | 10 | 12 | 11 (balloon pump) |
| 5 | *NA | NA | NA (frisbee toss) |
| 6 | NA | NA | NA (cotton toss) |
| 7 | NA | NA | NA (balloon pump) |
| 8 | 13 | 15 | 14 (block pushing) |
| 9 | 17 | 16 | 16 (balloon pump) |
| 10 | 15 | 16 | 16 (weight lifting) |
| 11 | 15 | 14 | 14 (cotton toss) |
| 12 | 11 | 10 | 13 (frisbee toss) |
| 13 | 12 | 12 | 10 (chopping) |

*NA data represents data not yet analyzed.

for the purposes of recording the subject's movement, when a second camera recording the researcher's movement is also necessary. Laban Movement Analysis of the National Anthem Experiment video showed slight variations in singer posture. The variations could result either from the movement itself (posture of the researcher and the singer would differ) or from the modeled posture of the researcher (posture of the researcher and the singer would be identical). Chagnon's claim is that movement itself can affect posture. Without video of the researcher, no conclusions can be drawn.

Further quantitative tests are warranted to evaluate activation of an energetic management of breath; improved singing posture; refined tone quality; improved tone projection; improved intonation (singing in tune); internalized rhythm and tempo; ability to modify musical articulation, diction attacks, releases, and timbre; and refined phrasing. A survey study of the audio recordings is currently underway to provide support for this data and for other Dalcroze-type effects. The study uses a semi-quantitative scale that accounts for a listener's rating of the above qualities.

This National Anthem Experiment quantified some effect of movement on vocal performance. Better-designed future experiments stemming from this one should eventually resolve issues of the kinds of music and movement combinations that effect specific qualitative observations. The Dalcroze-type effects to be evaluated fall into the broader categories of transfer effects, where one cognitive ability is facilitated by learning another. Transfer effects research is still in its infancy, but is beginning to draw well-deserved attention. Though the possibility exists that Dalcroze-type methods succeed only in convincing the performer of the Dalcroze method, it would be anomalous that so many choral conductors and professional singers use them in spite of audience indifference.

Conclusion

The results demonstrate that movement can be shown to quantitatively affect vocal performance. As more experiments like the National Anthem Experiment are performed, additional effects may also be quantified. The current theoretical basis for the effect of movement on the voice exists through present theories that explain other effects in other disciplines. The rules governing motor processing are consistent with the finding here, that copied movement causes a temporal elongation effect while singing. The tonal loop theory was developed to explain musicians' abilities to stay in tune, so the ability of some singers in the National Anthem Experiment to stay in tune was as expected.

The key for future experiments is to specify and quantify the effects of certain movements. Effects such as "improved projection of tone" are too generalized to be of effective pedagogical or scientific use. It is necessary to quantify exact movements and develop a scale showing improvement of tone projection. Even more specific and valuable is understanding how the effect varies depending on the personality and aptitude of the student. Experiments that explore the fine details of a single vocal-kinetic effect may lead to understanding other transfer effects.

The legend of transfer effects has already impacted society. Schools of higher education seek "well-rounded" individuals with extracurricular activities, perhaps indicating that intelligence transfers through non-academic disciplines. The Mozart Effect has parents inundating their children with Mozart sonatas, expecting that better analytical skills will develop. There is even evidence that Mozart's music can help prevent seizures (Weinberger, Fall 1998). Various

studies link other cognitive achievements to arts disciplines, such as singing to memory, dance to memory, and music to math scores (Ginsborg, 2002; Mitchell, 2001; Weinberger). The results seem to be synergistic for Dalcroze-type effects. Chagnon does not report that a single movement effects a single consequence, but by using concept-based movements in choral rehearsals, multiple problems of choral sound can be solved. Cognitive science benefits by specifying and improving the vocal-kinetic effect. The deeper science delves into cognition, the more dramatic changes may enhance the future of human creative and performance ability.

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