The Effects of Musical Training on Bimanual Control and Interhemispheric Transfer

by

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Abstract

The present study tried to determine the effects of musical training on interhemispheric interactions. Nine younger adults were trained for 30 minutes a day for one month using the drum controller on *The Beatles*™: *Rock Band*™ and compared to 8 controls. Pre- and post-tests included unimanual and bimanual tapping tasks as well as a letter matching task. These tests aimed to measure unimanual stability, bimanual coupling, and interhemispheric transfer time, among other features of interhemispheric interactions. Significant differences were found between some pre- and post-tests, but none were found between groups. Due to some problems with initial data collection and the small sample size, further testing and increased sample size are needed before conclusions may be drawn.

The Effects of Musical Training on Bimanual Control and Interhemispheric Transfer

The brain has shown itself to be a versatile organ, capable of change and adaption to environmental fluctuations through experience and training even during adulthood. For example, as covered in the review by Draganski & May (2008), when adult participants practiced juggling for three months, there was an increase in brain volume in area hMT/V5(middle temporal area of the visual cortex). They also found increased grey matter in the left frontal cortex, the cingulate cortex, the left hippocampus, and the right gyrus precentralis. The degree of change in grey matter correlated with skill. In other words, with improved performance there was increased grey matter. The participants were then scanned again after 3 months of no practice. In conjunction with a decrease in juggling performance, there was also a loss of grey matter in the areas that had previously experienced growth. Not only did young adults show these plastic changes, but so did elderly participants. It is worth noting that while 100% of the young adults were able to achieve the goal of juggling for at least 60 seconds, only 23% of the older adults were able to reach this goal. However, the authors state that this may have been due to other factors. Juggling requires the ability to integrate visual, sensory, and motor systems, which all decline as one ages. It also may have been due to age-related declines in hand-eye coordination in the older adults (Boyke, Driemeyer, Gaser, & Büchel, 2008).

Bimanual training (like juggling) may also lead to changes in brain areas related to interhemispheric transfer such as the corpus callosum. Interhemispheric interactions are primarily mediated via the corpus callosum, the principal white matter fiber bundle connecting the two hemispheres of the brain. Of particular interest to the current study is how the corpus callosum connects the motor cortices of both hemispheres. One motor cortex can send either an inhibitory or an excitatory signal to the other cortex, depending on the desired movement. Nordstrom & Butler (2002) demonstrated this by inducing inhibitory and excitatory circuits in the motor cortex using transcranial magnetic stimulation.

Interhemispheric transfer time (IHTT) is one measure used to describe the transfer speed of information between the two hemisphers via the corpus callosum, and is affected by the size and microstructural quality of the corpus callosum (Schulte, Sullivan, Muller, Oehring, & Adalsteinsson, 2005; Jancke & Steinmetz, 1994; Westerhausen et al., 2006). IHTT can be measured using tests such as the Poffenberger paradigm (Poffenberger, 1912) where the participant must respond with one hand to a stimulus that appears in either the left- or right-visual field or using a letter matching paradigm (Cherbuin & Brinkman, 2006) where the participant must respond to a match that happens either within or across visual hemifields, which they used as a behavioral measure of interhemispheric interaction. The difference in reaction time between crossed (stimulus in opposite hemifield as response hand) and uncrossed (stimulus in same hemifield as response hand), known as the crossed-uncrossed difference (CUD) is usually seen as a measure of IHTT (Iacoboni & Zaidel, 2004; Cherbuin & Brinkman, 2006). Cherbuin & Brinkman (2006) used a letter-match task like the one used in the present study as their measure of interhemispheric interaction. They found that IHTT was a better predictor of interhemispheric interaction than other measures they took including handedness, sex, age, and functional lateralization.

As the main conduit of information between the two hemispheres, the corpus callosum is also involved in bimanual coordination. Bonzano et al., (2008) showed bimanual control deficiencies in patients who had suffered damage to their corpus callosum from multiple sclerosis. Shim et al., (2005) showed changes in interhemispheric inhibition when participants practiced a two-hand finger force production task. Interhemispheric inhibition (IHI), the ability to stop the spread of excitability in the brain from one hemisphere to the other, is particularly important for performance of asynchronous bimanual tasks. Each motor cortex is able to inhibit the other via the corpus callosum as demonstrated by transcranial magnetic stimulation (TMS) studies. IHI can be measured by using a paired-pulse TMS technique which involves applying a conditioning pulse to one motor cortex and then recording the motor-evoked potential elicited by a test pulse applied to the opposite motor cortex a few milliseconds later. IHI is strongest when the test pulse follows the conditioning pulse by about 10 ms (Duque et al., 2007).

Abnormalities arise in interhemispheric interactions when there is damage to the brain structures involved. As mentioned before, Bonzano et al., (2008) studied bimanual coordination in patients with multiple sclerosis. As a part of their study, they had participants perform a bimanual tapping task and measured the onset and offset time of each hand. Interhand interval (IHI) onset and offset were defined as the difference between the onsets/offsets of the taps of both hands. MS patients who exhibited the most corpus callosum degeneration, as assessed with diffusion tensor imaging, were slower compared to controls in these tests and also had larger IHI onset and IHI offset times (Bonzano et al., 2008). MS patients also had a longer tap duration than controls. Bonzano et al. (2008) proposed that this is due to MS patients needing a longer time to confirm that a tap had occurred.

Natural deterioration of the brain due to age also affects bimanual coordination. Bangert, Reuter, Lorenz, Walsh, & Schachter (2010) found that older adults had difficulty with temporally asynchronous, discrete bimanual tasks. One test used in the study was a tapping task similar to the one used in the current study, described in detail below. While there were no significant age differences in performance for the synchronous condition, in the asynchronous condition older adults had disproportionately more variation in their tapping than younger adults.

Musical training is a relatively common bimanual skill that can produce changes in the brain. Among children, musical training can induce changes in brain organization leading to a larger anterior corpus callosum compared to those who have no such training (Schlaug, Forgeard, Zhu, Norton, & Norton, 2009). Hughes & Franz (2007) showed that musicians have faster reaction times under both unimanual and bimanual conditions than nonmusicans, and that there are even some small differences among musicians depending on when their musical training started. Those who began earlier (around age 7-8 years on average) exhibited a larger bimanual cost than those who began at a later age (around age 12 years on average). Hughes and Franz (2007) postulate that this is due to a more efficient corpus callosum, allowing for more effective inhibition during bimanual responses. Conversely, Ridding, Brouwer, & Nordstrom (2000) concluded that musicians had *reduced*interhemispheric inhibition between motor cortices. Ridding et al., (2000) tested six adult professional musicians who had been trained from an early age. They performed conditioning transcranial magnetic stimulation (TMS) to the hand area of the motor cortex of one hemisphere followed by a test stimulus applied to the other hemisphere 4-17 ms later. They performed this both when the subject was at rest and when the first dorsal interoseous (FDI) muscle was active. They found that TMS conditioning was 29% less effective at reducing the size of motor-evoked potentials at rest and 63% less effective in the active condition. As will be explained further, several of the tests we used include a bimanual condition, where participants use both hands at the same time to perform some task. This suggests that if the task is similar for both hands, the participants will perform more accurately and more quickly once they have received music training. Conversely, if a task is dissimilar for both hands, they may perform worse.

Nordstrom & Butler (2002) used TMS to test intracortical inhibition (ICI) and facilitation (ICF) of musicians and nonmusicians. By doing a subthreshold TMS pulse and waiting either up to 5 ms or 8-15 ms to deliver a suprathreshold pulse, an inhibitory or excitatory circuit, respectively, can be activated. The inhibitory circuit reduces the size of the MEP evoked by a suprathreshold pulse while the excitatory circuit increases it. Since motor thresholds were identical between musicians and nonmusicians Nordstrom & Butler (2002) concluded that the corticospinal neurons themselves were unchanged by music training. Instead, they said that ICI and ICF circuits in the motor cortex had less influence on corticospinal neurons in musicians than in nonmusicians.

Although there are seemingly contradictory results whether there is increased or decreased inhibition in musicians, Shim et al., (2005) note that the differences in the reported changes of the interhemispheric inhibitory pathways might be due to different levels of voluntary muscle activation and the type of muscle contraction used in the different studies. There may even be differences among musicians depending on what kind of instrument they play.

In the present study, we propose to evaluate plastic changes in the adult, nonmusician brain due to musical training. Because bimanual coordination and control is important for many daily activities throughout life (e.g. dressing, eating, driving, etc…), it may be beneficial to understand what kind of cortical changes a focused musical training intervention can induce and how they may help interhemispheric interactions and bimanual control. Additionally, studying training-induced changes associated with musical training may help us understand how to reduce age-related declines in brain function. Therefore the aim of the current study is to assess changes in interhemispheric function of young adults following a 30 day musical training intervention in comparison to a 30 day music listening control group.

We hypothesize that following music training participants will have improved interhemispheric transit time, which will be tested by the letter-match task described below. Also, participants are expected to have improved performance on bimanual tasks that require a high amount of interhemispheric inhibition, but will not significantly change on bimanual tasks that require relatively low amounts of interhemispheric inhibition. This will be tested by the motor tapping tasks, as described below. Finally, we predict that following music training, participants will have improved performance on tasks designed to quantify bimanual performance, such as the Purdue Pegboard test, also described below.

Methods

Participants

A total of 19 right-handed younger adults aged 18-30 years were recruited to participate in the study. Participants were randomly assigned to either a control group (n = 8, 3F, 23.125 ± 4.19 yrs) or a musical training intervention group (n = 9**,** 6F, 24.33 ± 2.74 yrs). One participant failed to complete training. Participants were screened for prior musical experience, filled out a health history questionnaire, and performed the Digit-Symbol Substitution task from the WAIS-R. Individuals who played a musical instrument more than 1 hour a week were excluded from participation. Additionally, any participants with a history of epilepsy or who have taken medication for depression within the last 6 months were excluded from participation.

Procedure

As mentioned earlier, a variety of tests were used to measure interhemispheric transit time and bimanual coordination. The following battery of tests were performed by all participants at pre- and post-test sessions. First, the participants completed the Edinburgh Handedness Inventory, which is a short questionnaire to determine the direction and degree of handedness of an individual. A rating is assigned from -100 to +100, with -100 being complete left-handedness, +100 being complete right-handedness, and 0 being complete ambidexterity.

Next, they performed the Purdue Pegboard test, which measures manual dexterity. There are 3 portions to this test: unimanual, bimanual, and construction. In the unimanual portion, the subject uses one hand to place small metal pegs into holes. This is done 3 times for both hands. In the bimanual portion, the subject puts the same pegs into holes 2 at a time using one hand for each peg, and it is also performed 3 times. In the construction portion, the subject uses both hands to make “thimbles” out of pegs, cylinders, and washers. This is done 3 times as well. Each trial is 30 seconds long, with performance being measured as the number of items the participant completes during this time period. A laterality index can be calculated from the difference between the participant’s right and left hand scores divided by the combined right and left hand score.

Digit-symbol. In the digit-symbol substitution task, the subject must translate a string of Arabic numerals into a string of symbols. There are 9 symbols, one assigned each to the numbers 1 through 9. The subject performs only one trial which lasts 2 minutes. The performance measure is the number of translations performed during this period and reflects psychomotor processing speed.

Letter-match. The letter-match task was used to test interhemispheric transit time, and was similar to the one used by Cherbuin & Brinkman (2006). The stimuli were seven capital letters and their lowercase counterparts: Aa, Bb, Ee, Ff, Gg, Hh, and Tt, which were displayed in a square formation in Arial 34-point bold font. A central fixation cross was displayed before and during stimulus presentation at which the participants were instructed to look. They also were instructed to place their chin in a chin rest which was 40 cm from the screen. In order to reduce eyestrain, stimuli subtended a maximum of 1.0° of visual angle and were displayed in white font against a black background. Each letter was presented 2.0° of visual angle to the left or right of the central fixation cross and 2.0° above or below the central fixation cross for 200 ms. The two conditions that were used were the no-match and match conditions. Participants had to determine if two of the letters displayed matched, which always occurred between an uppercase letter in the upper visual field (VF) and a lowercase letter in the lower VF. Half the matches occurred within the left or right half of the VF (within-hemisphere condition) and the other half occurred across the two hemifields (across-hemisphere condition). In the across-hemisphere condition, matches always occurred on one of the diagonals. This was done to decrease the influence of scanning habits, which would increase for horizontal matches. If a match was found, the participant had to press a button, whereas if there were no matches, no response was to be made. For each trial, a fixation cross would appear in the middle of the screen first for 700 ms, after which the stimuli were presented for 200 ms. Trials were timed out after 1,700 ms if no response was made. Following each trial was a 500 ms intertrial pause. The responding hand was randomized across blocks of trials. At the end of each block and after each incorrect trial feedback was given to encourage higher accuracy. A variation of this behavioral task has previously been validated by multiple studies as an accurate measure of interhemispheric interactions (Belger & Banich, 1992; Reuter-Lorenz, Stanczak, & Miller, 1999; Reuter-Lorenz & Stanzcak, 2000). This particular variation was chosen in an effort to decrease the amount of time participants spent performing the test battery.

Motor-tapping. The motor-tapping tasks are comprised of five different finger-tapping conditions: unimanual right hand tapping, unimanual left hand tapping, synchronous bimanual tapping, asynchronous right-finger-leads bimanual tapping and asynchronous left-finger-leads bimanual tapping. In all conditions, participants tapped with their index finger(s) at 1 Hz paced with visual cues. Participants were asked to focus on a fixation cross in the center of a monitor. Red circles appeared lateral to the fixation cross indicating when a tap should take place and with which hand. For example, if the condition was right hand only, a red circle would only appear on the right side of the screen. Participants were instructed not to use the circle appearance as a cue to tap; instead they were to tap in synchrony with its appearance. In the asynchronous conditions, the following finger was paced at a 180 ms delay as compared to the leading finger, but each remained at a within-hand tapping rate of 1 Hz. This asynchronous phase delay was chosen as it has previously been shown to be among the most difficult patterns to maintain (Semjen & Ivry, 2001). For all conditions (both unimanual and bimanual), unimanual stability was defined as the standard deviation of the intertap interval for that hand. Additionally, bimanual coupling was defined as the standard deviation of the between-hand lag for all bimanual tapping conditions. Therefore, for both measures, a lower value was indicative of better performance. These are typical measures used to describe tapping performance for unimanual stability (Helmuth & Ivry, 1996, Ivry & Hazeltine, 1999) and bimanual coupling (Kennerley, Diedrichsen, Hazeltine, Semjen, Ivry, 2002). In our recent research with these tasks we have shown that young and older adults' unimanual stability on these tasks falls along a continuum: simultaneous bimanual tapping is performed with the least amount of variability, then unimanual tapping, and finally performance on asynchronous tapping is the most variable. Each tapping condition consisted of four, 30-second tapping trials (30 taps per hand), with 10 seconds of visual fixation at the start, end, and in between each 30-second tapping session.

Musical training. Musical training occurred for 30 min a day, 4 days a week, for 4 weeks (16 total training sessions). Participants (n = 9) came in to the Neuromotor Behavior Lab and trained on a modified drum set controller using *The Beatles™: Rock Band™* on a Nintendo Wii™ gaming console. *The Beatles™: Rock Band™* is a rhythm/music video game where players use controllers modeled after instruments to simulate a musical performance. As the music plays, “notes” appear on the screen with rhythms that correspond to the music and the player must hit the corresponding buttons on the controller using mock drum sticks. The drum controller has a total of 5 contact pads. Four of them represent the snare drum, toms, and cymbals of a real drum set and the 5th pad is a pedal, which represents the kick pedal of the bass drum. The player uses drum sticks to hit the 4 contact pads and their foot to depress the kick pedal, much as a real musician would play a normal drum set. Training was tailored to each individual’s performance on any given day so that the difficulty level was modulated both within and between sessions to ensure that the participants remained actively engaged and received the highest benefit from training. A total of 60 levels were used for the training. A particular song on a particular difficulty level (Easy, Medium, Hard, or Expert) was chosen for each level based on both the rating of the difficulty for the drum set and a personalized evaluation of performance. Level advancement was based on accuracy. If the participant scored 90% or greater on accuracy, then they moved to the next level. If they achieved 75 – 89% accuracy then they stayed at the same level. If they scored below 75%, they were moved down one level. A starting level was determined for all participants by using a slightly modified version of the above advancement scheme. Starting levels ranged from 1 to 30, and ending levels ranged from 37 to 60.

A control group (n = 8) completed all pre- and post-test measures, and also came to the Neuromotor Behavior Lab for 30 min a day, 4 days a week, for 4 weeks (16 total sessions). During these sessions no musical training took place; instead, participants listened to songs from *The Beatles™: Rock Band™* in an effort to control for any performance changes that might occur from i) travel to our lab, ii) interaction with individuals within the lab, and iii) listening to music while in the laboratory.

Data Analysis

Mixed model repateated measures analysis of variance were used to analyze these data. The between subjects factor was group (experimental versus control), with variables of interest (analyzed separately) including interhemispheric transit time, Purdue Pegboard performance, Digit-Symbol Substition performance, and tapping performance. Moreover, Pearson correlation analyses were used to test for relationships among these variables. The within subjects factor was time (pre- versus post-test). Significant main effects and interactions were graphed and followed up with pairwise comparisons to determine whether the training group exhibited greater improvements in performance from the pre- to post-test session than controls. All tests were done at 95% confidence level. Due to problems in the custom programs used to run the letter matching task and motor tapping tasks, some data taken from participants was unusable and was therefore excluded from further analysis. Thus, sample sizes varied slightly between tests. Tests where a different sample size was used in calculations are marked as such.

Results

The training group and control group scored similarly on the handedness assessment (Edinburgh: training = .747 ± .137, control = .712 ± .196) and performed similarly on the Purdue Pegboard task. The training group scores were: 44.144 ± 3.82 (R+L+bimanual) 41.78 ± 6.02 (assembly), and 0.052 ± 0.319 (laterality). The control group scores were: 42.785 ± 3.753 (R+L+bimanual), 42.539 ± 5.17 (assembly), and 0.039 ± 0.457 (laterality). At post-test the training group scores were: 47.074 ± 4.5697 (R+L+bimanual), 46.29 ± 6.42 (assembly), and 0.0497 ± 0.0319 (laterality). The control group scores were: 45.901 ± 4.494

(R+L+bimanual), 43.4 ± 6.688 (assembly), and 0.035 ± 0.022 (laterality). There were significant differences between pre- and post-test values of R+L+bimanual ($p < .001$) and assembly ($p < .001$) conditions, but none between groups.

At pre-test on the digit-symbol task, the training group scored 71.55 ± 10.76 and the control group scored 65.75 ± 5.57. At post-test training group scored 76.11 ± 11.45 and the control group scored 71.525 ± 10.99. There was a significant difference between pre- and post-test values ($p < .001$), but no significant difference between groups.

All members in the training group showed marked improvement in difficulty level during the course of training (Figure 1). Figure 2 shows the average difficulty level achieved in the pre- and post-test assessment with *Rock Band*™. Baseline levels were 15.22 ± 7.23 for the training group and 13.75 ± 9.47 for the control group. Post-test assessment was 50.44 ± 8.02 for the training group and 16.875 ± 9.63 for the control group, with a significant difference between groups ($p < 0.001$).

Unimanual stability (variability for within-hand tapping, lower is better) for the training group ($n = 5$) in the unimanual condition (left and right hand data combined) was 78.6 ± 17.1 ms at pre-test and 74.2 ± 15.5 ms at post-test. In the simultaneous condition it was 66.1 ± 11.1ms at pre-test and 64.8 ± 10.6 ms at post-test. In the asynchronous condition it was 74.6 ± 16.4 ms at pre-test and 70.4 ± 17.7 ms at post-test. Unimanual stability for the control group ($n = 8$) in the unimanual condition (LH+RH) was 75.4 ± 20.5 ms at pre-test and 61.3 ± 21.6 ms at post-test. In the simultaneous condition it was 81.5 ± 24.1 ms at pre-test and 60.1 ± 19.4 ms at post-test. In the asynchronous condition it was 84.4 ± 25.9 ms at pre-test and 59.3 ± 18.4 ms at post-test. There was a significant difference within-subjects between pre- and post-measures ($p = .006$) as well as between pre- and post-measures by group ($p = .021$). However, there was no significant difference between groups overall. Figure 3 shows the pre- and post-measures of unimanual stability in the unimanual and asynchronous condition

Bimanual coupling (variability of between-hand lag, lower is better) for the training group (n = 5) in the simultaneous condition was 17.5 ± 5.2 ms at pre-test and 18.6 ± 6.6 ms at post-test and in the asynchronous condition was 63.9 ± 22.7 ms at pre-test and 45.6 ± 12.1 ms at post test. For the control group (n = 8), bimanual coupling in the simultaneous condition was 21.8 ± 11 ms at pre-test and 15.1 ± 5.2 ms at post-test and in the asynchronous condition was 63.4 ± 24.4 ms at pre-test and 37.1 ± 9.5 ms. A significant difference was found between pre- and post-tests (p = .011), between conditions (p < .001), and between pre- and post-tests by condition (p = .002), but there was no significant difference between groups. Figure 4 shows the pre- and post-measures of bimanual coupling in the simultaneous and asynchronous conditions.

In the letter-match task, right and left hand data were combined to create a single, unimanual value. At pre-test the training group (n = 4) had mean reaction times of 734.2 ± 112.2 ms (across match), 750.8 ± 133.7 ms (within match), and 740.9 ± 122.6 ms (overall), and an average difference of -16.7 ± 23.9 ms between conditions (across – within). Their mean accuracies were 85.16% (across), 83.85% (within), and 88.5% (overall). The control group (n = 5) had mean reaction times of 808.8 ± 98.7ms (across), 805.9 ± 121.9 ms (within), and 806.4 ± 108.8 ms (overall), and an average difference of 2.9 ± 32.3 ms (across – within). Their mean accuracies were 89.65% (across), 87.99% (within), and 91.74% (overall). At post-test, the training group had mean reaction times of 711.1 ± 116 ms (across), 710.5 ± 122.2 ms (within), and 710.4 ± 118.7 ms (overall), with an average difference of 0.57 ± 15.5 ms (across – within). Their accuracies were 94.53% (across), 90.80% (within), and 94.47% (overall). The control group had mean reaction times of 775.6 ± 116 ms (across), 774.3 ± 110.5ms (within), and 774.6

± 112.3 ms (overall), and an average difference of 1.3 ± 22.1 ms (across – within). Their accuracies were 94.38% (across), 94.93% (within), and 95.59% (overall). There was a significant difference between pre- and post-tests in across accuracy (p = .016), within accuracy (p = .003), overall accuracy (p = .009), but no difference between groups in any condition. There were no significant differences in reaction time between pre- and post-tests as well as between groups (across: p = .104; within: p = .075; overall: p = .082). Figure 5 outlines reaction times and the overall accuracy of the letter-match task.

Discussion

The goal of this study was to determine if music training in adult nonmusicians had an effect on interhemispheric interactions. The brain remains plastic well into adulthood (Draganski et al., 2008), retaining its ability to adapt to new experiences, such as juggling. Bimanual tasks such as juggling require great interhemispheric coordination, and thus use the corpus callosum to relay information between the two hemispheres. Though bimanual coordination declines with age (Bangert et al., 2010) it is still possible for older adults to learn complicated bimanual tasks (Draganski et al., 2008).

Music is a common bimanual task that is known to cause changes in the developing brains of children (Schlaug et al., 2009), while adult musicians have been shown to have faster reaction times (Hughes & Franz 2007) and differences in their intracortical inhibition and facilitation (Nordstrom & Butler 2002) compared to nonmusicians. The present study tried to determine if some of these effects on reaction time and intracortical inhibition would occur if adult nonmusicians began musical training.

The letter-match data that we obtained seems to be in concurrence with data gathered by Cherbuin & Brinkman (2006). They report an average reaction time of 839 ± 88 ms and accuracy of 92.00 ± 0.05% for the within condition and a reaction time of 873 ± 80 ms and accuracy of 91.50 ± 0.05% for the across condition. Our subjects had slightly faster, reaction times, ranging from about 710 to about 810 ms. Whether or not this is significantly different is difficult to tell, although the significant difference in accuracy from pre- to post-test in this study suggest that it is possible that post-test results may be significantly different from Cherbuin & Brinkman's (2006) results. However, because there was no significant difference between groups, we are unable to conclude that training had an effect. This task, however, had a smaller sample size (training n = 4, control n = 5) than the original set due to problems with the custom program used in this task which may have affected results. Also, while reaction times for this task were not significantly different, their p-values showed a possible trend (across: $p = .104$; within: $p = .075$; overall: $p = .082$). Using a larger sample size may show that there is a significant difference in reaction time between pre- and post-tests, and possibly between groups.

Comparing our bimanual coupling data from Bangert et al. (2010), it seems that our participants at pre-test tested similarly to their participants in the simultaneous condition, but our participants performed worse in the asynchronous condition at pre-test. At post-test, our participants became significantly better than pre-test in the asynchronous condition, and seemed to score similarly to the participants from Bangert et al. (2010), though there were no differences between groups in the present study. Bangert et al. (2010) gave participants feedback after each tap, which may have helped them concentrate and adjust their taps, becoming more accurate. Our participants may have been less accurate pre-test because they had no such feedback. They did, however, become much more accurate post-test, but since there were no significant differences between the groups at post-test we cannot conclude that training had an effect. However, this test also had a reduced sample size for the training group (n=5) due to data collection problems. An increased sample size may solve some of these problems.

Ultimately, while there were significant differences between pre- and post-tests, there were no significant differences found between groups in any of the conditions except for the difficulty level achieved and unimanual stability. It was expected that after a month of training that participants would become good at the game and achieve higher difficulty levels than the control group. With the unimanual stability, it appears that the control group, not the training group, showed a statistically significant improvement. This may indicate that there were not enough participants for that test to balance out some controls doing particularly poorly on the pre-test and/or particularly well on the post-test as it would be expected that the control group would perform similarly at two distant time points. The other statistically significant differences between time points do not suggest that music training had an effect on any of the other measures (bimanual coupling, letter-match reaction times and accuracies, bimanual coordination, etc) as there were no significant differences between groups. However, due to data collection problems with the custom letter-match and tapping programs, some data was unusable and reduced the already small size of the participant groups even further. A larger sample size is definitely needed before any conclusions may be drawn.

Besides an increased sample size, other options to pursue further study might include different testing paradigms to more carefully determine interhemispheric transit time and interhemispheric interaction or a different training paradigm possibly using a different instrument (e.g. piano, though care must be taken in which instrument is chosen due to differences in the role of each hand). Because of the nature of the "notes" in *Rock Band*™ (they come from the horizon and move down the screen towards the player), perhaps using a different motor-tapping paradigm would show a difference between groups. An example would be a paradigm where the circles would be moving towards a target line with taps occurring when a circle reaches that line, or vice versa with stationary circles and a moving line. This might be comparable to a musician reading notes on a page, and would be similar to the “falling” notes present in *Rock Band*™. Another possibility is adding tempo-matched music or even simply a metronome sound to the motor-tapping task. Training subjects may have been relying on auditory clues to maintain tempo during training and the lack of it in the motor-tapping task used may have affected this.

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Figures

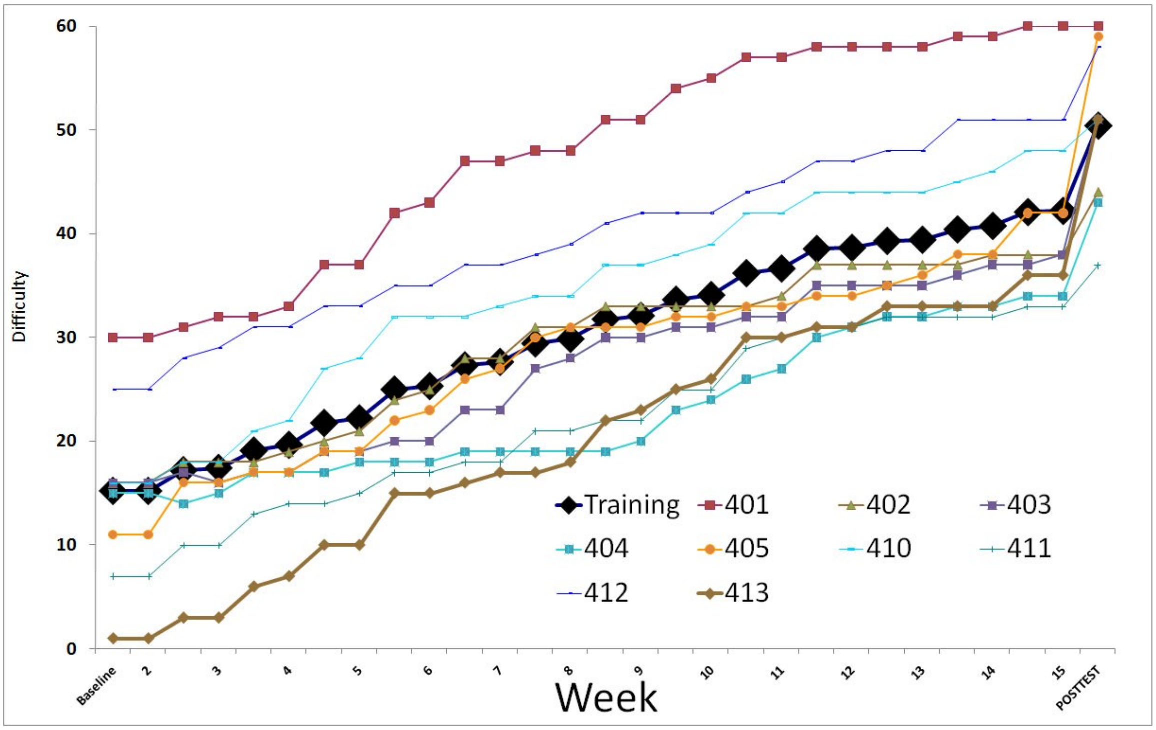

Figure 1. *Difficulty level achieved by participant. Each line represents a single participant and the black line represents the average level of all trainees.*

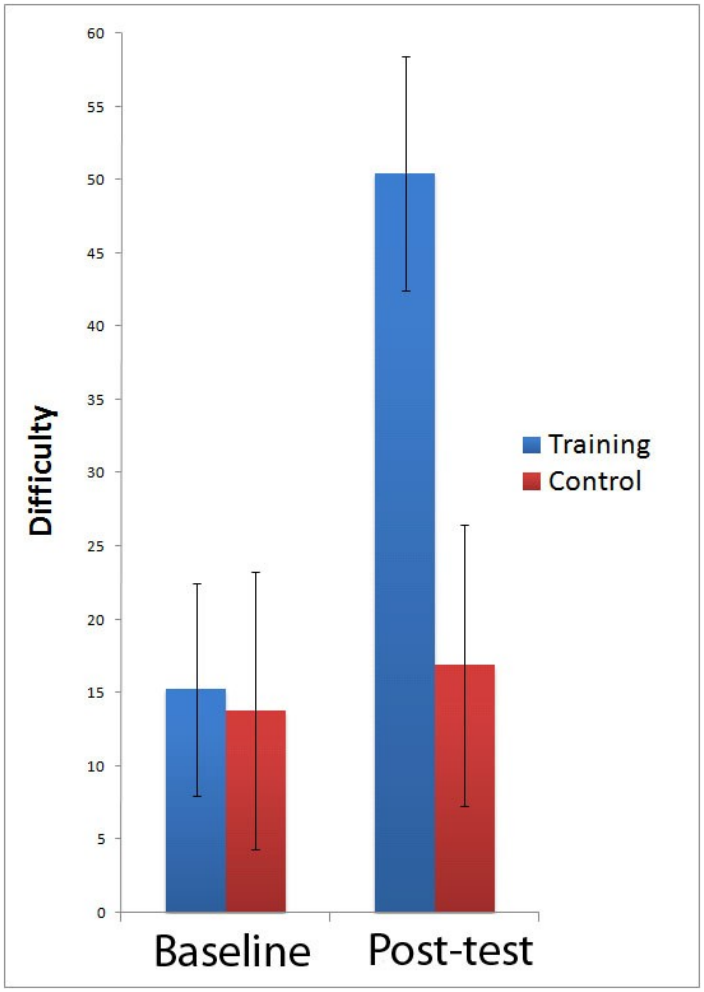

Figure 2. *The baseline and post-test measure of difficulty level achieved in The Beatles™: Rock Band™. Levels ranged from 0 to 60. Error bars represent ± 1 standard error from the mean.*

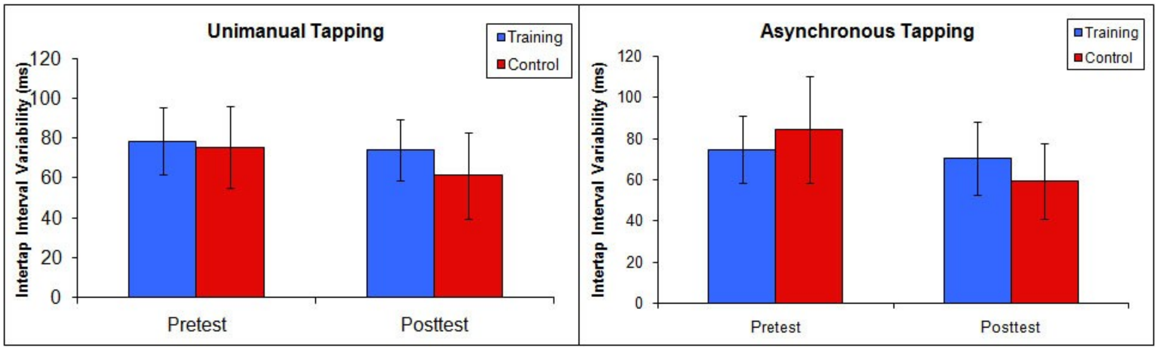

Figure 3. *Pre- and post-test unimanual stability measures for the unimanual (LH & RH combined) condition and asynchronous condition. Error bars represent ± 1 standard error from the mean.*

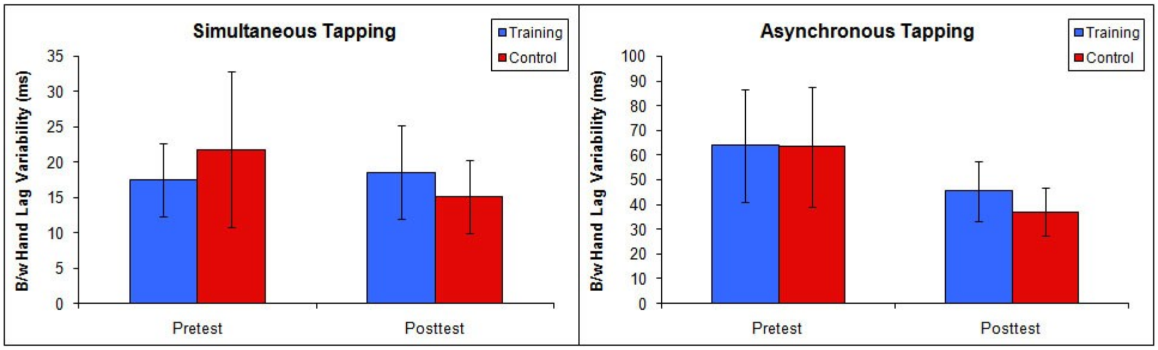

Figure 4. *Pre- and post-test bimanual coupling measures for the simultaneous and asynchronous conditions. There was a significant difference between pre- and post-tests, but not between groups. Error bars represent ± 1 standard error from the mean.*

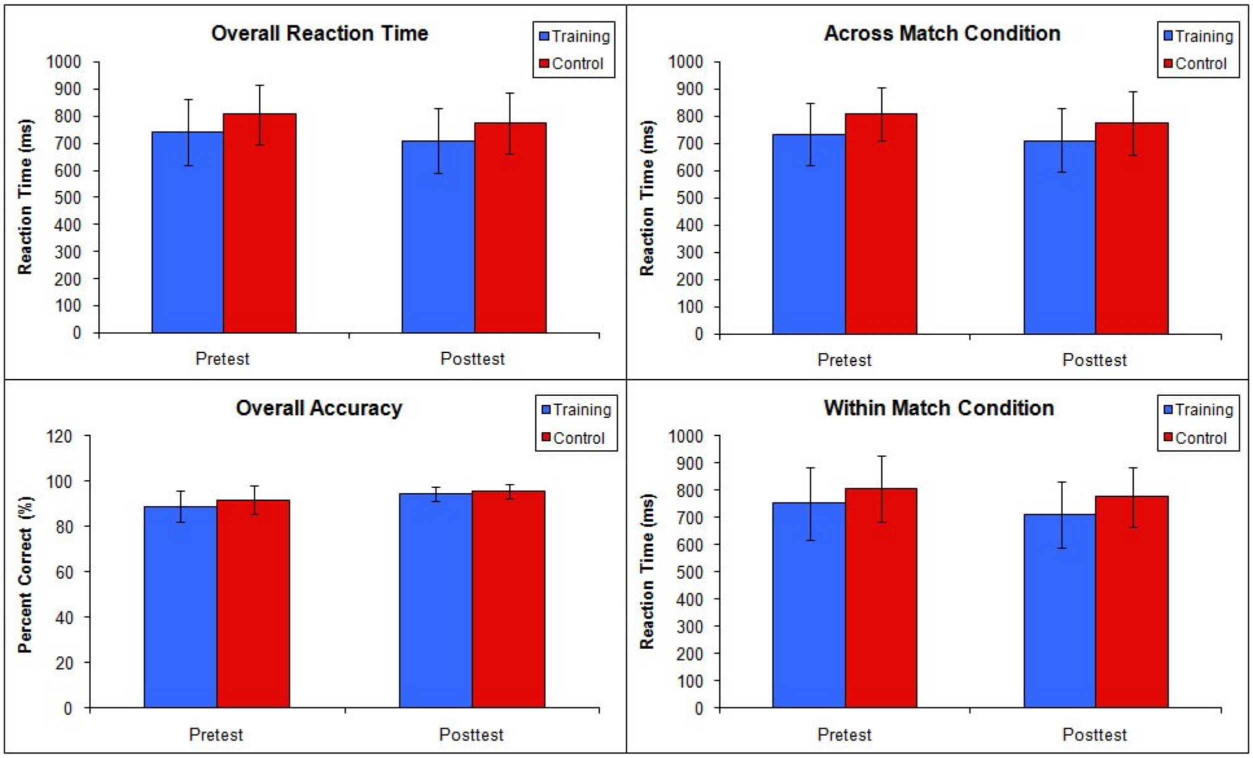

Figure 5. *Across and within reaction times, overall RT, and overall accuracy for the letter match task. Error bars represent ± 1 standard error from the mean.*