Derek Tingle, Jennifer Hsu
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INTRODUCTION

Our goal was to design an interactive and engaging game to improve players rhythmic timing. Rhythm plays a strong role in music, and rhythm seems to be strongly influenced by motor movement. Instrumentalists must perform precise movements and precise timing of those movements in order to play their instruments well. People also naturally synchronize their movements to music, as is evident in dancing or tapping one's foot to a song. Previous studies on rhythm have shown that many areas in the brain related to motor processing are also active during music listening [4,6]. Further research have shown that rhythmic accuracy increases more when trained with movement as opposed to passive listening and that rhythmic perception is influenced by movement [4]. We have created an interactive and entertaining training game that allows people to "air drum" different rhythms in attempts to improve their rhythmic accuracy. The movement-triggered sounds should further increase the players' rhythmic accuracy. We hypothesized that players would show improvement in the synchronization of motor movement with musical rhythm, the accuracy of timing intervals between beats, and also the memorization of rhythmic sequences. We begin by giving a more detailed description of the neural correlates involved with the integration of rhythmic and motor movement processing followed by an explanation of the training game, and lastly a discussion of our results. We found unexpected results from our pre-training and post-training tests. We discuss the reasons for this outcome and improvements on the experimental design after our analysis of the results.

BACKGROUND

Zatorre et. al point out several neural correlates in their review regarding movement and its relation to rhythmic processing [6]. The cortical areas pertinent to our research are derived from this review, with additional citations supporting these findings, and summarized below.

Because we are training participants on rhythmic accuracy through motor movements, we are interested in the interaction between the neural processes behind movement and rhythmic processing. Previous cognitive neuroscience research has shown that brain areas important for motor movements involved with rhythm include the cerebellum, the basal ganglia, the supplementary motor area (SMA), and the dorsal lateral premotor cortex (dPMC).

The cerebellum is important for feedforward control as well as feedback control, which we can think of as error correction. The cerebellum is also involved in accurate timing for movements, which means that it must be involved in some type of rhythmic processing. The cerebellum also plays a role in learning a sequence of movements. These sequences of movements are chunked together by the SMA. In purely perceptual tasks with no active movement by the participant, the cerebellum has been shown to be active [1,6]. The basal ganglia is involved with movement timing as seen through experiments with timed finger tappings [1,6]. The dPMC integrates auditory features with the motor response in the premotor cortex and is important in the integration of complex rhythmic sequences [1,2,3,6].

With prolonged training, we can expect that players will exhibit some type of cortical plasticity. Several studies have shown that increased training in musical tasks leads to anatomical and functional plasticity of auditory and motor areas, as well as somatosensory areas [1]. Anatomically, intense training increases the grey matter volume for the above mentioned cortical structures. Functionally, piano playing novices have exhibited cortical activity that becomes increasingly similar to that of professionals as a result of intense training [referenced in 1]. Experts have shown stronger activations of these areas as opposed to novices [1,4]. It has also been suggested that rhythmic training through motor movement may also affect representations in the auditory cortex [4].

From our training task, we can expect that players who train for long periods of time may show some type of plasticity in the cortical areas involved with the processing of rhythm and movement, feedback of rhythmic accuracy, and memorization of rhythmic sequences. We can expect to see an increase in grey matter volume in these areas as well as cortical magnification of rhythmic representation in the auditory cortex. These areas will will most likely begin to have stronger activations and tend towards the cortical activity exhibited by people who have high rhythmic accuracy.

DESCRIPTION AND DEMONSTRATION OF METHODS

To play the game, players listen to and try to repeat a reference drum beat using a natural interface that mimics how one may play a physical drum kit. The task is to play back the reference beat as accurately as possible. Accuracy is measured as the sum of the squared time difference between when the true timing of each note onset in the measure should be triggered and when the user actually triggers the corresponding drum hit. The system uses the ChucK audio programming language to interpret players’ input signals and to play back a selection of drum loops, and the Processing visual programing language to provide visual feedback. Open Sound Control (OSC) is used to interface between the two programming languages.

The controller used to trigger note onsets the game was a crucial design decision. While taking input from a standard interface such as a mouse or keyboard is trivial to implement, we believed that the game would be much more engaging if players were able to use natural gestures to produce percussive sounds. We initially designed the game using the Microsoft Kinect controller. This interface uses a 3-dimensional camera to allow users to control software without having to manipulate a physical device. We realized after our initial testing that the 30 ms latency of the Kinect prohibited the game from feeling natural. As anyone who has worked with digital instruments knows, low latency is crucial to developing an engaging musical experience. Because of this, we chose to use a GameTrak controller. The GameTrak controller is a device with two gloves that are attached to rotating, retractable strings. It provides the 3-dimensional positions of both hands with very low latency. We also tuned the gesture recognition software to predict the point at which the player’s hands abruptly stop travelling downward before they actually do so. This affords users to play the game in much the same way that one would play the “air drums.”

The game is structured as a repetition task. The player is first played a randomly-selected reference drum beat, then attempts to recreate it. The player is given a visual countdown indicating when they should begin playing back the reference beat. The ‘playback’ measure immediately follows the reference beat’s measure. The tempo is fixed at 120 BPM and each reference beat is four quarter notes in length. The number of note onsets varies from 4-12. While the difficulty of each individual rhythm is difficult to measure quantitatively, a wide variety of subjectively easy and complex reference rhythms exists.

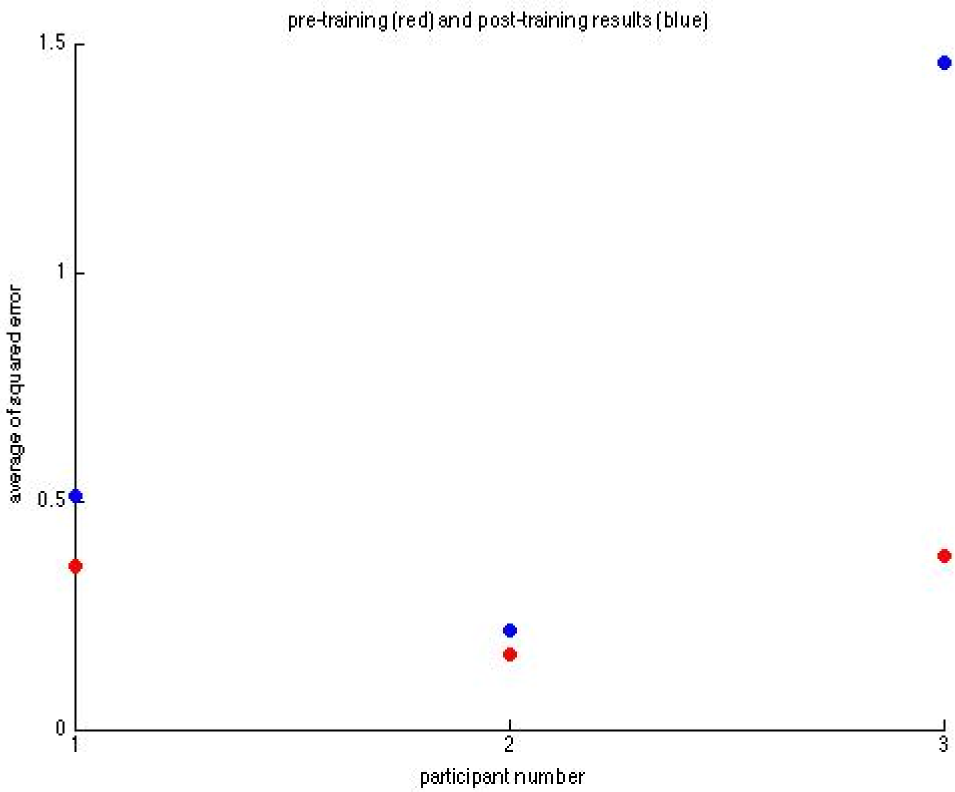
The accuracy of each note onset is calculated in real-time. Instantaneous visual feedback is provided to the player in several ways. If the triggered onset is within some threshold of the true note onset, a vertical feedback bar will appear on screen relative to a fixed bar in the center of the screen. If the triggered onset comes before the true note onset, the feedback bar appears to the left of the fixed bar, and if the triggered onset is late the feedback bar appears to the right of the fixed bar. The distance between the feedback bar and the fixed bar is proportional to the temporal distance between the true and triggered note onsets. If the player triggers a note outside of this threshold, a red ‘X’ appears on the screen, indicating that their timing was far from correct. If the triggered note falls within a smaller threshold of about 50ms of the true note onset, it is counted as being triggered at the correct time. When this occurs, the vertical feedback bar is green, and the score in the upper right hand corner is incremented. If the triggered note falls outside of this range, the vertical feedback bar is red. We were motivated to provide visual feedback as previous research has shown that visual and rhythmic binding in perception is a crucial part of the feedfoward and feedback control of movement in musicians [5]. It is important to note, however, that while a player’s timing relative to the true onsets was displayed, we did not provide visual or audio feedback to explicitly indicate the true tempo.

EXPERIMENTAL DESIGN

In order to test how much a player’s rhythmic timing improved over the course of the game, we administered a pre-training test and a post-training test afterwards. The pre- and post-tests were similar to the training session in that users repeated rhythms with movement. The tests each contained three separate rhythms. The pre- and post-tests differed from the training section in that the players tapped out the rhythms on the space bar of the keyboard instead of using the GameTrack controller as measuring finger tapping on a computer is a widely used test for rhythm experiments [2,6]. Additionally, the reference beats during the pre- and post-tests were subjectively easier in that they contained fewer note onsets and less syncopation than many of the training reference beats. Note that the rhythms used for the pre- and post- training tests were both different from each other and also different from the training rhythms. We wanted to be sure that players’ actually improved their rhythmic accuracy through movement control and to avoid the issue where the players’ accuracy may have improved from repetition or practice of the same rhythms. For these tests we computed the average of the squared differences between the time the beat should be triggered and the time the participant actually triggered the beat.

RESULTS

We tested and trained three participants. Our surprising results are shown in the figure below. The x-axis indicates the participant number while y-axis indicates the average rhythmic accuracy across the three rhythms for the pre- or post-test. The red dots are the pre-training results and the blue dots are the post-training results. A dot with a lower average means that he or she exhibited a smaller amount of error from the correct rhythmic timing, and hence performed better. It seems that all three participants did better in the pre-training tests than in the post-training tests. This actually goes against our hypothesis and several reasons for these results are described below.



DISCUSSION

While the training should theoretically lead to improved accuracy when triggering note onsets using a drum-like interface, we specifically designed the pre- and post-tests to consider rhythmic accuracy in isolation from the specific implementation of the physical controller.

There exist several possible sources of error in our design that could have contributed to the unexpected lack of improvement. First and foremost, to be able to adequately measure the usefulness of our game in improving players' rhythmic timing we should test a much larger number of players. Furthermore, if we expect to see measurable results, we will most likely need to allow players to train for a longer duration of time. Ideally, we could allow players to play the game on their own over the course of many days and log the duration that they trained. We expect that the players' mean squared error would be inversely correlated with how long they trained for.

Another issue that we encountered was the relative difficulty of the pre- and post-tests. While this is certainly possible that players could have shown a decrease in rhythmic accuracy as a result of our training game, it is more likely that the relative difficulty of the reference beats for the pre- and post-tests are not quite equal. We could either include a larger sample of reference beats, randomize the reference beats for each test, or even attempt to empirically determine the difficulty of each individual reference beat by comparing each reference beats' mean squared error over a population of players. Any combination of these methods would allow us to conclude with more certainty how the training period affected the players' rhythmic timing. The error appeared to increase as the measure progressed. This indicates that the accumulating error of the triggered onsets made the latter part of the playback measure more difficult than the beginning. This could be addressed by providing some combination of audio and visual feedback to indicate the tempo.

IMPACT

We expected that the predicted improvements in players' rhythmic accuracy would translate to improved rhythmic accuracy in the performance of a variety of musical instruments and other tasks that involve both rhythm and motion. On a local level, players could improve their rhythmic perception, rhythmic sequence memorization, and motor movement synchronization to rhythms. On a more abstract level, because the players are training their motor control with rhythm, they could become better instrumentalists and possibly even better dancers. This might even lead to improved skills in games like Guitar Hero and Rock Band where people play instruments in a game-like setting. Furthermore, the improvement that we had wanted to show could have indicated that games like Guitar Hero and Rock Band actually improve a player's musical accuracy and performance.

FUTURE RESEARCH

In addition to possible modifications to our current design, we also discussed future experiments that could be implemented within the existing structure of the game that could provide valuable insight into how to improve players' rhythmic timing. One interesting variable that we did not explore in the current study is the effect of varying the tempos during the training period. Although we did anticipate that allowing users to trigger note onsets using a natural interface rather than a button press would yield improvement in rhythmic accuracy, we cannot definitively make this claim. In the same vein, it could be interesting to study the difference in how players' rhythmic accuracy could improve if they were to complete a more open-ended task, such as drumming along to their favorite music.

SOURCES

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