Rhythm Rangers

an evaluation of beat synchronisation skills and musical confidence through multiplayer gamification influence

Kjærbo, Rasmus Emil Reffstrup; Parpal, Ramon Romeu; Pérez, Marco González; Correia, Francisco Manuel Soares de Almeida Rosado; Guruvayurappan, Vatsal; Overholt, Daniel; Dahl, Sofia

Published in:
Proceedings of the 17th Sound and Music Computing Conference

DOI (link to publication from Publisher):
10.5281/zenodo.3898765

Publication date:
2020

Document Version
Publisher's PDF, also known as Version of record

Rhythm Rangers: an evaluation of beat synchronisation skills and musical confidence through multiplayer gamification influence

Rasmus Kjærbo, **Ramon Romeu**, **Marco González Pérez**, **Francisco Rosado Correia**, **Vatsal Guruvayurappan**, **Dan Overholt**, and **Sofia Dahl**

Aalborg University Copenhagen,
{rkjar19,rromeu19,mgonza19,frosad19,vguruv19}@student.aau.dk,
{dano,sof}@create.aau.dk

ABSTRACT

Musical confidence and beat synchronisation skills are explored before and after playing the custom made multiplayer game, Rhythm Rangers. Timing variability is evaluated comparing scores from a repeated baseline test, pre- and post-game. A qualitative questionnaire assessing musical sophistication, behaviours, and confidence is used for correlation. Participants synchronise claps at quarter-note level to audio loops of varying rhythmic complexity from metronome, to complex syncopated break-beat. The setup comprises bespoke wearable controllers and software integrating multi-sensor microcontrollers (ESP32), a microcomputer (Raspberry Pi), and a visual programming language (Pure Data). Baseline test results indicate better overall beat synchronisation to drum loops compared to a metronome—similar results were found for game scores where the average standard deviation (SD) was highest for the metronome. Average drift variability showed a downward trend for both baseline test loops (metronome and simple drum loop). Total average SD decreased with relation to the amount of rhythmic information in the loops until the complex break-beat. Little correlation between the qualitative data and the participant's performance during the experiment was found. Dependant samples T-test for the simple drum loop showed a significant effect ($t = -2,48, p < 0.05$). No significant effect for the metronome ($t = 0.03, p < 0.05$) when comparing the baseline test before and after the game. Participants with least or no improvement found the game most challenging; higher game scores showed the least improvement; less experience with rhythm games showed the most improvement. All participants claimed to have had fun and enjoyed themselves while playing the game.

1. INTRODUCTION

Rhythmic coordination is an essential part of everyday life (e.g. during walking) and it is involved in higher order cognitive tasks like dancing and performing music. Rhythm can also be helpful in rehabilitation of people suffering from neurodegenerative disorders like Parkinson's disease [1] and moving to the beat can increase your sense of happiness and well-being. It seems there is good evidence supporting the benefits of training and exercising rhythmic skills. However, the benefits of rhythm is also dependent on perceptual and sensorimotor rhythmic skills [2]. Fortunately such skills can be both tested [3] and trained [4].

Gamification is a great way to promote learning and skill development [2, 5] and can help create incentives for progression and to motivate skill development [6]. Bégel et. al [6] set up criteria for rhythm training and reviewed 27 rhythm-based games available on the market. Albeit presenting good grounds for rhythm training, none of the games fully met their criteria. Poor precision of temporal movement recordings constricted measurements of motor performance variability (drift) and testing the precision of beat synchronization (local) [6]. Issues on level handling and difficulty increases were also reported.

The aim of this work was to evaluate participants' beat synchronization skills and musical confidence through rhythm training with a multiplayer game. A baseline skill evaluation test was constructed along with a four-player rhythm game in which the players synchronize their clapping to 2-bar audio / drum loops, each repeated 4 times to a total of 8 bars. The loops vary in rhythmic complexity, ranging from quarter-note metronome to syncopated break-beat. Additionally the player devices record the action and movement of each player. Baseline tests were performed before and after each game to evaluate training effect. The game data is correlated with a qualitative pre-game and post-game questionnaire in order to evaluate the effect of the game and experiment as a whole.

2. RELATED RESEARCH

Research related to the coordination between perception and action has seen a surge in the last 20 years, especially when it comes to music [7]. The coordination of actions (e.g. finger tapping) with a rhythmic event sequence (e.g. music) is commonly referred to as *sensorymotor synchronization* (SMS) [8]. SMS studies have traditionally used simple metronome clicks or pure tones as stimuli and many apply a synchronization-continuation paradigm, where a participant synchronize finger taps to a stimuli and continues at the same rate when the stimuli disappears [8, 9]. However, some studies on SMS have used actions other than finger tapping [4, 10, 11], as well as other modes of stimuli; ranging from simple drum loops to excerpts of full compositions, or using visual stimuli; and to the form of coordination; either on-beat or off-beat, in-phase [down beat synchronization] or inverted-phase [up-beat synchronization] [9]. With respect to rhythmic skills, several studies have found optimal beat reproduction (e.g. tapping to the beat) is obtained with an interonset interval (IOI) around 600 ms (100 BPM). According to [9], minimal variability was observed with IOIs between 200 ms and 1200 ms. Similarly, Getty [12] found that between 300 and 900 ms there was a linear increase of variability with interval duration [9]. The variability can be both short-term (local) and long-term (drift). A study [4] investigated isochronous serial interval production (ISIP, classic continuation tapping) by measuring the difference between individual intervals respectively (per beat, local variability), and by looking at changes in long-term variability (drift). According to the authors, analysis of the variance can be further elucidated by decomposing the ISIP task into local variability - which could reflect random neural noise according to the authors - and the slower evolving drift variability - which could reflect some aspect of participants' short-term memory. During the first hour of practice, their participants showed a substantial decrease in variability, but not much afterwards. The effect of training was similar for different mode of response, amount of feedback, and interval duration, they found similar effects, suggesting that the observed improvement in variability is mainly an effect on motor implementation [4].

For multimodal SMS there is a general tendency for auditory dominance where participants show lower variability for auditory metronomes as opposed to visual [10]. However, for continuous motion there is less dominance. Hove et al [13] found that visual stimuli of a periodically bouncing ball can be as effective as an auditory metronome in producing stable tapping movements. When participants were asked to synchronize with one modality only and the other acted as a distractor, the effect on performance differed with the expertise of participants. Video gamers displayed higher variability and were more influenced by both auditory and visual distractors. Musicians, who also had experience in following conducting, had lower variability but also a tendency to be distracted by the auditory events when tapping to the visual metronome [13]. The influence of rhythmic expertise on the sensitivity for asynchrony in multisensory stimuli has also been shown in other studies [14].

A few rhythmic games with the aim of training studying SMS already exist. Rhythm Workers was the final product of a research project [2] and used rhythmic patterns and musical stimuli as a tool to trigger cognitive abilities in people having neurological disorders [2]. To evaluate player training, the game comes in two versions; a perception and a tapping version. In the perception version of the game, training is carried out using an adjusted version of the Beat Alignment Test [3]. The main goal is to construct a building by detecting whether a metronome is aligned to the beat of an audio loop or not. In the tapping version, the goal is to tap to the beat of the stimulus as accurately as possible. Successful fulfilment of either tapping or judgement task results in a building which appear better structured and more aesthetically appealing than with bad performance.

Many game designers have looked to Csikszentmihályi and his conditions for optimal flow experience [15]. A good flow task should be balanced in regard of difficulty and participant skill level and there should be instant feedback on how well you are performing the task. When the skill-to-task balance is optimal the player can experience a merging of action and awareness. With varying difficulty levels in the auditory stimulus, we hope to engage various levels of skill. Coupling clear and concise goals with immediate visual feedback to grab the players' concentration on the task at hand, we aim to achieve flow states like transformation of time (immersive engagement) and loss of self-consciousness (decrease of negative personal assumptions towards musicality). [6] remark that Guitar Hero for example increases the difficulty by adding more events that you need to respond to, this without affecting the auditory stimulus (you play along to the same song). An important aspect of the rhythm training protocol in [6] is varying beat salience as a control for levels and difficulty. A commercially successful rhythmic game is Beat Saber [1], which is a VR rhythm game where the goal is move your hands to 'cut' or 'slice' beats as they fly towards you as small cubes. Every cube indicates which hand you need to use and the slice direction. The tasks are designed so that players appear to be dancing or moving to a choreography. Beat Saber is a good example on how body movements can be used in a rhythm game. All actions in the game are strongly supported by sound and visual effects emphasizing the rhythm and flow.

A game or rhythmic training device can also be wearable. Soundbrenner Pulse is a tactile vibrating metronome that allows the user to follow a beat without hearing sound. The user feels vibrations on either chest, wrist, or ankles depending on where the device is strapped. The device is coupled with a mobile app and can be controlled via app or directly on the device [2]. GripBeats is a device created to explore non-traditional ways of making and interacting with music in the shape of a bracelet strapped around your wrist and hand [3].

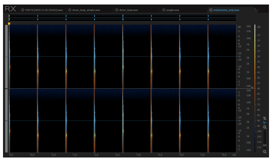
3. GAME DESIGN & IMPLEMENTATION

3.1 General Game Design

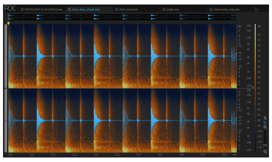
Players enter the game by strapping a wireless custom made game controller to the back of their hand (see Figure 2) and follow the game instructions. Four players compete by synchronizing claps at quarter-note level to four audio loops with increasing rhythmic complexity.

Levels and difficulty handling in Rhythm Rangers varies beat salience with loops of varying rhythmic complexity. First level is metronome sound, then a simple drum loop

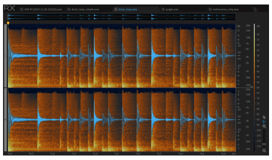
[1] https://beatsaber.com
[2] https://www.soundbrenner.com
[3] https://www.gripbeats.com



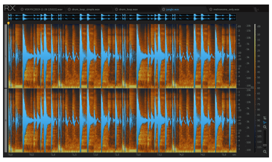
(a) FFT metronome



(b) FFT simple drum loop



(c) FFT syncopated drum loop



(d) FFT jungle break-beat

Figure 1: Spectrograms of the different sound samples used for the experiment.

with kick drum, snare drum and hi-hats on straight eight-notes only. The following level adds syncopation and more subdivisions. Final level is a break-beat with many syncopated subdivisions. All audio loops are only rhythm based, with no melody. Figure 1 shows an FFT of the four loops.

The players should maintain clapping with equal spaced rhythmic division for 32 beats except at randomly placed beat locations where they should avoid to clap. These "no-go" tasks occured four times per game. Two tempo levels was chosen to be 90 BPM (IOI = 666.67 ms) and 100 BPM (IOI = 600.00 ms) based on [9, 12]. Each game comprise eight trials; four audio loops at tempo 90 BPM (666.67 ms) and four similar audio loops time-stretched to tempo 100 BPM (600.00 ms).

3.2 Designing and building the wearable device

3.2.1 The main case

The TTGO T-Audio board is fastened to a wooden laser-cut base plate using nuts, bolts and spacers. The space between the board and the base plate house a 3.7V Li-Po battery. An elastic band attaches the device to the back of your hand. Figure 2 shows the final case design.

Figure 2: Final case design. Case with device and battery strapped to player's hand.

3.3 Technical specifications and game implementation

3.3.1 Hardware and programming

The game was implemented using the microprocessor ESP32 on TTGO T-Audio v1.6 board[4]. The ESP32 is an affordable micro-controller with built-in Bluetooth and WiFi support, several GPIOs and analog inputs. The chip is capable of running real-time DSP applications[5]. The chip is mounted on the TTGO T-Audio board which also houses a MPU9250 3-axis acceleromenter and gyroscope. The board has 19 built-in RGB LEDs and battery management. Altogether adequate to analyse movement data with a decent size, weight, and built-in technology. Four boards were used in the project as wearable devices for the players while one was used as a visual metronome (VM) depicting the game rules, indicating when each player should or should not clap, since the main cue for following the tempo are the audio loops. The VM also hosts a web-server which displays the score of each round accessible via a web browser over http.

Communication between all devices was handled with WiFi network hosted on a household router with messages sent via the Open Sound Control (OSC) protocol over the User Datagram Protocol (UDP). OSC is supported by both the ESP32 and Pure Data (Pd), which brought the benefits of modern networking technology to our game and testing environment[6]. Lower latency was preferred over reliable packet delivery and handshaking, so UDP was chosen instead of the Transport Control Protocol (TCP). UDP resulted in minor loss of packets during transmission, but was chosen for its superiority in real-time interaction and communication. Packet loss was most prominent in areas with high amounts of wireless network traffic. To mitigate, the WiFi channel with the least measured activity was selected before each run of the experiment, and Ethernet capable devices (RPi and researcher laptop) were connected with CAT-5 cables to the router. Messaging between the ESP32 boards via OSC is handled by a Pd patch (programme) hosted on the RPi. Arduino IDE was used to program the ESP32 chip with two main programs implemented; clap detection and LED feedback for the baseline test and game running on the wearable game device, and the other, the visual metronome and game rule indicator, loaded onto the VM.

3.3.2 Inter-device communication

Establishing a reliable communication between all the TTGO T-Audio boards and the Pd patch on the RPi was a challenge. Bluetooth was considered, but discarded due to higher latency and shorter range compared to WiFi [16]. The most challenging part of the setup was synchronizing the VM and the wearable game devices. Accurate synchronization is crucial as players have to follow the VM. In order to correctly detect local variability for each clap, the wearable game devices need to have the same tempo and

[4] https://github.com/LilyGO/TTGO-TAudio
[5] https://faust.grame.fr/doc/tutorials/index.html
[6] http://opensoundcontrol.org/introduction-osc

start time as the Pd patch. After testing different methods, we decided to follow the procedure described in Figure 3.

1. When the Game Start button (I/O 36) is pressed on the VM, it sends an OSC message to the RPi stating that the game is starting.
2. The RPi sends an OSC message with the interbeat interval in milliseconds (90 BPM = 666.67 ms) to the VM and to the wearable game devices. Immediately afterwards, the RPi sends a metronome start message to the VM which flashes its LEDs in time with the count-in before the game starts. The game begins after the count-in on the following quantised beat (5th quarter-note from count-in). When the game start OSC message is sent to all the devices - after the respective audio sample has been selected - either a baseline test run or game run commence. Depending on selected mode (baseline test or game) the VM flashes accordingly and the game player devices start detecting claps.
3. During the game, each wearable device sends a score for each clap to the RPi which stores it for future data analysis. At the end of the game, each wearable game device sends the average (drift) score of all claps to the RPi.
4. Once the game finishes, the RPi calculates the final score (with game penalties) from each player and sends it to the web server hosted by the VM. Final scores are then displayed on the web server (and in the Pd console) and is subsequently shown on a screen to the players.

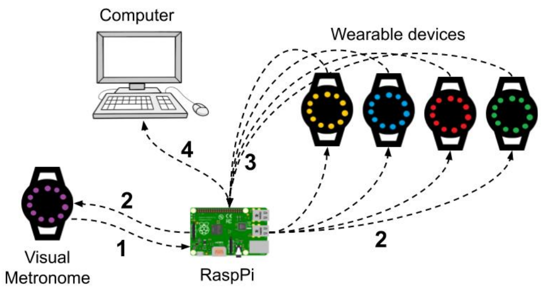


Figure 3: Scheme of the communication between devices during a game.

Hard syncing the devices was attempted by sending tempo clock at tick level (24 PPQ, parts per quarter) from the RPi to all devices. It worked somewhat, but with a noticeable and odd desynchronisation observed between the devices, so the method was ultimately discarded.

3.4 Game scores

When a clap is detected the score is calculated by the following expression:

$$Score = (1 - \frac{abs(x)}{y}) \cdot 100 \quad (1)$$

where x represents how early or late the player clapped to the closest beat, and y is half the interbeat interval in milliseconds. By computing the absolute value of x, only positive clap scores will be computed. The downside of this approach is the loss of timing information; the algorithm is ignorant of whether a clap happened before or after the beat. It only computes how close it was to the beat. Clap scores are normalized and thereby made independent of the tempo so that a clap score value is obtained as an integer between 0 and 100; where a score of 100 is equivalent to a perfect clap on beat and 0 is a perfect off-beat clap.

4. EXPERIMENT

To further investigate the link between gamification in a multiplayer setting and rhythm training, we designed an experiment.

4.1 Aims and Predictions

We predict that players of our game can improve their synchronisation skills in a multiplayer game. This improvement is in the detection of the tactus while at the same time clapping as accurate to the tactus as possible, minimising local and drift variability. We predict that players with higher clap scores will feel an increase in their musical confidence, which might result in an increased engagement in future musical activities. Participants claiming to have rhythmic experience (e.g. drumming, playing rhythm games, etc.) might elicit higher scores during the game, hinting at some rhythmic skill present.

4.2 Participants

A total of 20 participants (one female, ages 21 to 47) were recruited at Aalborg University Copenhagen campus and participated in five groups of four persons each. The game is designed for a target group of non-musically trained individuals, but we decided not exclude participants based on musical ability. Compensation given in form of food and beverages. Participants all agreed to being filmed and photographed during the experiment.

4.3 Setup and Procedure

The experiment took about 25 minutes and was divided into three stages: pre-intervention baseline test, game (intervention) and post-intervention test. Before and after the experiment, the participants filled out a questionnaire.

A group of four participants was brought to an isolated room where they were instructed how to operate the wearable devices. Before carrying out the pre-intervention baseline test, they were asked if the wearable device felt comfortable and were encouraged to move the device around to ensure it is non obtrusive. Ensuring comfortability before moving on to the actual experiment helped mitigate performance issues which otherwise may arise. It was made sure that none of the participants suffered from any kind of colourblindness, so that they could follow the game rules without any problem.

Participants were made aware of the scoring system. Each wearable device's LEDs light up whenever a clap is detected, with scores ranging from 0 to 100 being paralleled in the LEDs lighting up from red to green (greener meaning positive results). The flow of the game is presumed to improve by providing the participants with instant feedback on their performance. Figure 4 illustrates the scoring system described.

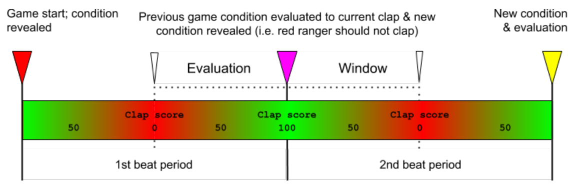


Figure 4: Scoring system for rhythm game. Red arrow indicates game condition 'Red player do not clap on the next beat' with the LEDs on the VM flashing red on the first quarter-note. The following quarter-note, a pink arrow indicates when the red player's 'do not clap' condition gets evaluated while also showing the next game condition; pink colour indicating that everyone should clap on the following quarter-note.

The participants were instructed to attempt to clap on beat as close as possible to a series of repeating audio loops which are played during the two tests and the rhythm game. The audio files were time stretched from their original tempo of 90 BPM using Ableton Live Suite 10.1.5 utilising the Beats Mode time-stretch algorithm and were presented in 44.1kHz 16Bit normalised WAV format through a wired JBL Charge 3 loudspeaker.

4.4 Baseline test; pre-intervention

Prior to beginning the initial baseline test, we asked the participants to fill out the first questionnaire with demographic data (age, sex); their experience with music and rhythm related activities (e.g. do you play an instrument; do you play rhythm games; do you dance) and music genre preferences. This questionnaire was based on the Goldsmith's Musical Sophistication Index (Gold-MSI [17]) querying musical and rhythmic abilities. Participants were asked if they knew anyone in the group, as it could be an interesting factor to explore the effect of interpersonal connections on performance. However, in the acquired sample most participants knew at least one other participant in the group, not allowing for a proper evaluation of this parameter.

Each participant took the baseline test individually in the order of their assigned player number. In the baseline test each participant clapped on tempo to two audio loops for eight bars (32 beats) at 90 BPM in a 4/4 meter: a basic metronome loop and a simple drum loop with little syncopation. The order was randomised for each group. Participants clapped to the sound of the audio loops without the visual metronome.

Each trial had a 4 beat vocal count-in (*one, two, three, four*) before clapping commenced. The remaining participants stayed outside the room, with the researchers not conducting the experiment, until called for.

4.5 Rhythm game

Upon completion of the first test, all participants were called into the room to begin the multiplayer rhythm game. Participants were again asked if there were any comfortability issues and if they were ready to proceed. The rules of the game were then explained. Eight rounds of eight bars of four distinct sounds were then played; metronome and simple drum loop (same as in the baseline test) as well as a more syncopated drum loop and finally a break-beat with many syncopated subdivisions (see Figure 1) all in 4/4 meter, ordered, at 90 BPM, then repeated at 100 BPM. In game mode, the VM was introduced to the players, with flashing LEDs in six distinct colours, each with a different game rule serving as a warning to what action is to be taken on the following beat. When the VM flashes one of the participant's respective colours (red, blue, green or yellow) that participant should skip the following beat (i.e. if red flashes, the participant representing the red colour should not clap on the next beat) while the remaining participants clap as normal. A pink flash = every participant claps on beat. A white flashes = all participants should skip the following beat (i.e. they should not clap on the beat following the white flash). Participants were gently introduced to the game by running a test-round allowing them to completely grasp the game rules. Figure 5 provides an explanation of the game conditions.

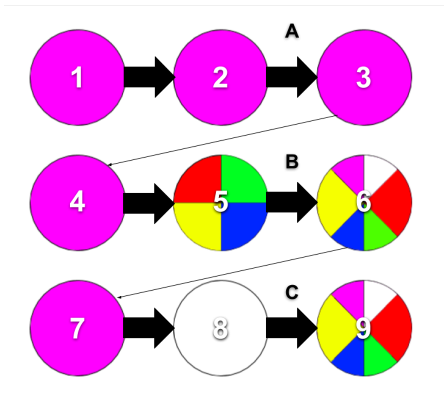


Figure 5: The conditions for the rhythm game; colours represented are displayed in the VM: condition A displayed on beat 2 = every player claps on beat 3; condition B displayed on beat 5 = the player that had their colour flash on beat 5 does not clap on beat 6, regardless of the colour that shows up on beat 6, every other player claps; condition C displayed on beat 8 = no player claps on beat 9, regardless of the displayed colour on beat 9.

The researchers checked that everyone understood the rules to the best of their abilities before proceeding. Two more conditions were presented for the scoring system: when a participant misses a clap (true miss) or claps when not supposed to (false positive), two game points are deducted from their final score per erroneous action. The final game score was calculated from participant's drift scores with the penalties scores subtracted. At the end of every round, all scores (drift, total game score, and penalties) were shown on the dedicated web server for everyone to see.

The go/no-go task involved in the game makes it demanding in that participants need to attend to the VM and learn to make the right response depending on the colour of the flash. While the challenge makes the game more interesting for participant to train their rhythm keeping skills, the demand on attention is high. We are aware that some participants have more difficulties to divide their attention between keeping the beat and following the game rules, compromising their scores. However, the experiment follows a within participant design comparing the pre- and post- intervention tests without the VM.

4.6 Baseline test; post-intervention

After the game, the baseline test was redone by each participant. Before taking the test, the participants were asked to fill out the second questionnaire regarding the game itself and their overall experience playing the game. The questions covered issues during gameplay making the experience less enjoyable or if there was any especially difficult part during the game, 5-point scale questions (from strongly disagree to strongly agree) regarding the comfortability of the device, the fun and difficulty factors of the game, and if instructions were properly explained.

5. ANALYSIS & RESULTS

Drift scores from pre- to post-intervention tests were compared and cross-referenced with answers to the perceived difficulty of the game. Linear regression revealed the following trends; participants with least or none-to-negative improvement (difference between the post- and pre-test intervention) found the game most challenging; participants with high game scores were also found to have the least improvement; participants claiming to be less experienced with rhythm games also with fewer interactions with rhythmic performance showed most improvement.

When analysing the difference in average local scores between both baseline tests for the metronome sound, a decrease of 0.14% was found. In contrast, the difference in average local score for the simple drum loop showed an increase of 5.83%. A dependant samples t-test showed the game to have a significant effect on scores for the simple loop, $t = -2,48, p < 0.05$ but no significant effect with the metronome results $t = 0.03, p < 0.05$. An interesting result is that the scores were higher and less fluctuating for the simple beat drum loop than the metronome sound. On average, the difference between the simple beat and the metronome was 17 % (12 point difference out of the 100 point scale) in the pre-intervention test and 24 % (17 points) for the post-intervention test. The standard deviation (σ), comparable to the consistency of even claps between all participants, a score related to the overall drift, was lower for the simple beat drum than the metronome.

	Pre-intervention		**Post-intervention**	
	Metronome	Simple beat	Metronome	Simple beat
Average	69.77	81.99	69.67	87.07
σ	4.98	4.02	5.26	3.99

Table 1: Average score and standard deviation for pre & post-intervention tests with different sound samples.

Participants showed an improvement in performance (difference between post-intervention and pre-intervention test) for the simple beat drum loop opposed to the metronome (see Figure 6). A difference of around 10% was found between the two sounds. An interesting tendency was found where player performance decreased over time as seen in Figure 6. This tendency was consistent throughout all trials between both tests, however the decline was more pronounced in the post-intervention trials, especially for the metronome sound.

The majority of first claps, immediately after the initial count-in were usually very accurate. The average value for the first clap was close to 90 points. Since the stimuli were presented in randomised order for each group, we assume this difference in results between sounds is a matter of the sound itself and not the order of presentation. Error bars of ±1% are shown on the graphs, since the score values are captured as decimals and then rounded to the nearest integer.

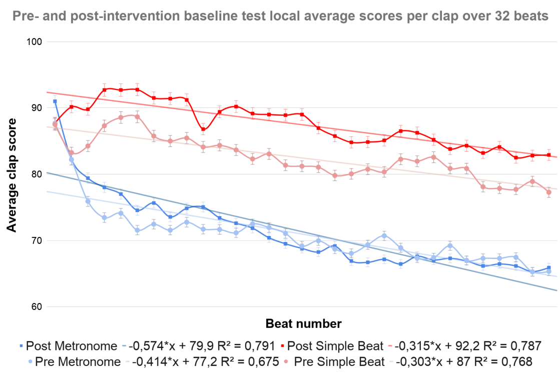


Figure 6: Tendency over time of local scores decreasing for all trials in both baseline tests. Error bars of ±1%.

Comparing players' average performance between the trials at 90 and 100 BPM (Figure 7), shows that players generally perform better at the higher tempo. This could be due to entrainment from the previous rounds at 90 BPM as players get more accustomed to the game and its conditions. Players again score generally lower for the metronome sound. At 100 BPM, the general scores for drum beat audio loops increased with 20 points on average approximately compared to scores from the metronome rounds.

For both tempi, the performance in the first beats for the metronome trials were high (around 90 points) but after about 4 beats, the scores started to decline to around 65 points. One group performed relatively well compared to the other groups during the metronome rounds, however these results are skewed by their overall performance, as

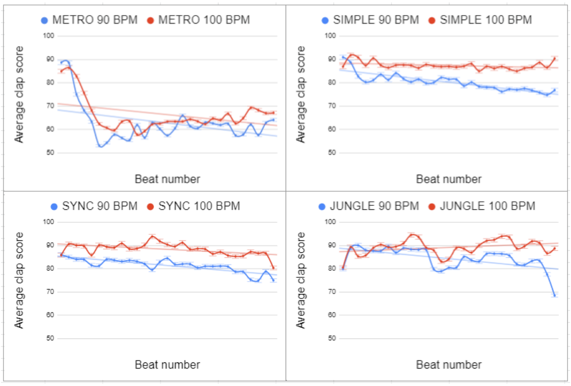


Figure 7: Player performance between game trials at 90 BPM (Blue) and 100 (Red) BPM. From top-left to bottom-right: metronome, simple drum loop, syncopated drum loop and jungle drum loop. Error bars indicate standard deviation.

this was the highest scoring group (overall average drift score within the group = 84.16).

Figure 8 displays a trend over the audio loops at both game tempi. Player performance seems to be more dispersed with the metronome loops, which is an audio loop without any subdivisions. The the most consistent scores (lower standard deviation values) are seen for the simple and syncopated beats, which had more subdivisions than the metronome. For the break-beat, consistency decreases again, as it is more difficult to be accurate in tempo as there are many subdivisions in the sound. It seems that beats with either too many or too few subdivisions are harder to synchronise to.

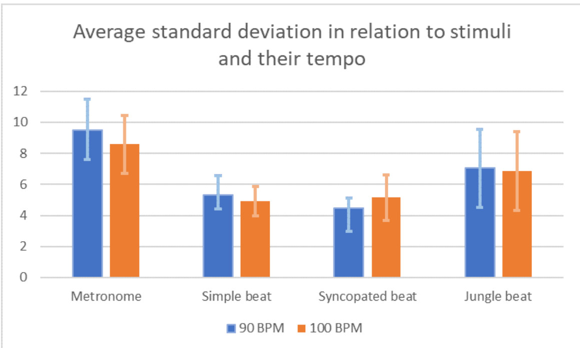


Figure 8: Average of the standard deviations for all the players during a game with different tempos and sound samples. It can be understood as the consistency of the players beat keeping ability. Error bars indicate standard deviation.

5.1 Participant feedback

From a total sample size of 20 participants; 19 participants found the provided game instructions were clearly presented; 16 of the participants found the game had some challenge to it; 17 of the participants found the game device was comfortable to wear; 11 of the participants tapped with their foot and 9 bobbed their head as an aid for keeping synchronization.

Six participants reported an increase in confidence level in musical skills after partaking in the experiment. Nine participants felt very inclined to participate in more musical activities in the future. Overall, some participants claimed they faced some difficulty when the rhythm game when the VM was introduced due to the complexity of the rules, however every participant claimed they had fun playing the game and enjoyed themselves throughout.

6. DISCUSSION

We have successfully developed a wearable, wireless game device capable of capturing high resolution real-time performance data to be played in a competitive multiplayer game. Local variability in the baseline tests for the simple drum loop showed an average standard deviation across all clap scores which decreased slightly from the pre- to post-intervention test. The overall average score increased from 81.99 points to 87.07 points. The same comparison for the metronome sound showed an increase in overall average standard deviation (4.98 for pre-intervention test and 5.26 for the post-intervention test). The overall average score was almost identical for pre- and post-intervention test (69.77 for pre-intervention and 69.67 for post-intervention).

The game at 90 BPM showed a decrease in standard deviation for the first three trials: 1. metronome ($\sigma = 9.41$) $\rightarrow$2. simple beat ($\sigma = 5.34$) $\rightarrow$3. syncopated beat ($\sigma = 4.44$), followed by the fourth audio loop, the break-beat with many syncopations (σ = 7.06). The break-beat was deliberately chosen as the hardest level. At 100 BPM, a somewhat similar tendency was observed: decrease from metronome (σ = 8.59) to simple beat ($\sigma = 4.91$), then slight increase from simple beat to syncopated beat (σ = 5.15), and a higher increase for the break-beat ($\sigma = 6.85$).

The results of the experiment hint at various interesting correlations, but given the small sample size of participants, and how and where they were recruited, a more representative experiment with a larger and more diverse sample size would be needed. In order to verify the effect of rhythm training more thoroughly, future work could have a control group whom did the baseline test twice within a couple of days without playing the game. More trials and training over a longer period (i.e. a couple of weeks) would likely show stronger overall results. Also, given that we compute the absolute value of the scores, information about whether claps are early or late in relation to the beat is lost. Signed values would likely have shown the documented tendency to anticipate the beat (negative mean asynchrony, see e.g [10]). Correlations between some of the qualitative data from the questionnaires (e.g. musical skills, behaviours, and musical genre preference) to the quantitative test and game data proved difficult, but some interesting findings were that higher pre- and post-intervention test scores correlated with higher game scores showing less improvement. The opposite was found as well.

Training in a competitive style with pseudo collaborative tasks supported group cohesiveness according to participants. Earlier research support that interpersonal entrainment tend to affect social attitudes in a positive way [10,18] but considering that the overall task of the game was competitive it is an interesting result. This supports the choice of the 'no-one clap' game condition, showing that universal task relations (all participants do not clap) increases perceived group unity.

In addition to the VM, participants also had visual temporal information from the movements of other players. It seems reasonable to assume that these sometimes acted as distractors similar to the study by [13]. It seems reasonable to assume that in the case of one player displaying more asynchrony, the influence would be larger on the performance of non-musicians players.

A future version of the game could incorporate more modes, more levels, more sounds, advanced features like sound and timbre control, a visual metronome incorporated in a 2D platform game hosted on the RPi showed on a connected HDMI monitor. The device could also double as an OSC / MIDI compatible remote control which you could link to a Digital Audio Workstation (DAW) for expressive music performance and production (like the MI.MU Glove). If the audio engine gets ported to Faust, attaching a speaker to the device would make it usable for individual or group training for patients with neurodegenerative motor diseases or other types of rehabilitation.

Acknowledgments

The authors completed the design and implementation of the work in a semester project during their master studies in Sound and Music Computing at Aalborg University Copenhagen, supervised by authors Dan Overholt and Sofia Dahl. All authors participated in the writing of the manuscript. A special thanks goes out to Jesper Greve and Peter Williams for their continuous technical assistance and infinite supply of machinery and Razvan Paisa for his ESP32 expertise and support.

7. REFERENCES

[1] M. H. Thaut, G. C. McIntosh, and V. Hoemberg, "Neurobiological foundations of neurologic music therapy: rhythmic entrainment and the motor system," *Frontiers in Psychology*, vol. 5, 2015.

[2] V. Bégel, A. Seilles, and S. Dalla Bella, "Rhythm Workers: A music-based serious game for training rhythm skills," *Music & Science*, vol. 1, Jan. 2018.

[3] J. R. Iversen and A. D. Patel, "The Beat Alignment Test (BAT): Surveying Beat Processing Abilities in the General Population," p. 5, 2015.

[4] G. Madison, O. Karampela, F. Ullén, and L. Holm, "Effects of practice on variability in an isochronous serial interval production task: Asymptotical levels of tapping variability after training are similar to those of musicians," *Acta Psychologica*, vol. 143, no. 1, pp. 119–128, May 2013.

[5] J. Lee and J. Hammer, "Gamification in Education: What, How, Why Bother?" *Academic Exchange Quarterly*, vol. 15, pp. 1–5, Jan. 2011.

[6] V. Bégel, I. Di Loreto, A. Seilles, and S. Dalla Bella, "Music Games: Potential Application and Considerations for Rhythmic Training," *Front. Hum. Neurosci.*, vol. 11, p. 273, May 2017.

[7] N. P. M. Todd and C. S. Lee, "The sensory-motor theory of rhythm and beat induction 20 years on: a new synthesis and future perspectives," *Front. Hum. Neurosci.*, vol. 9, Aug. 2015.

[8] B. H. Repp, "Sensorimotor synchronization: A review of the tapping literature," *Psychonomic Bulletin & Review*, vol. 12, no. 6, pp. 969–992, Dec. 2005.

[9] N. Ehrlé and S. Samson, "Auditory discrimination of anisochrony: Influence of the tempo and musical backgrounds of listeners," *Brain and Cognition*, vol. 58, no. 1, pp. 133–147, Jun. 2005.

[10] B. H. Repp and Y.-H. Su, "Sensorimotor synchronization: A review of recent research (2006–2012)," *Psychonomic bulletin & review*, no. Journal Article, pp. 1–50, 2013.

[11] B. Burger, M. R. Thompson, G. Luck, S. H. Saarikallio, and P. Toiviainen, "Hunting for the beat in the body: on period and phase locking in music-induced movement," *Frontiers in Human Neuroscience*, vol. 8, 2014.

[12] D. J. Getty, "Discrimination of short temporal intervals: A comparison of two models," *Perception & Psychophysics*, vol. 18, no. 1, pp. 1–8, Jan. 1975.

[13] M. J. Hove, J. R. Iversen, A. Zhang, and B. H. Repp, "Synchronization with competing visual and auditory rhythms: bouncing ball meets metronome," *Psychological Research*, vol. 77, no. 4, pp. 388–398, Jul. 2013.

[14] K. Petrini, S. Dahl, D. Rocchesso, C. H. Waadeland, F. Avanzini, A. Puce, and F. E. Pollick, "Multisensory integration of drumming actions: musical expertise affects perceived audiovisual asynchrony," *Experimental Brain Research*, vol. 198, no. 2, p. 339, Apr. 2009.

[15] M. Csikszentmihalyi, *Finding Flow - The Psychology of Engagement*. BasicBooks, 1997.

[16] J.-S. Lee, Y.-W. Su, and C.-C. Shen, "A Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi," in *IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society*, Nov. 2007, pp. 46–51, iSSN: 1553-572X.

[17] D. Müllensiefen, B. Gingras, L. Stewart, and J. Ji, "Goldsmiths Musical Sophistication Index (Gold-MSI) v1.0: Technical Report and Documentation Revision 0.3," p. 69.

[18] P. Reddish, R. Fischer, and J. Bulbulia, "Let's dance together: synchrony, shared intentionality and cooperation," *PloS one*, vol. 8, no. 8, p. e71182, 2013.