Effect of Music Synchronization on Runners' Foot Strike Impact

Valerio Lorenzoni[1], Edith Van Dyck[2], Marc Leman[3]

IPEM, Ghent University, Belgium
[1]valerio.lorenzoni@ugent.be, [2]edith.vandyck@ugent.be, [3]marc.leman@ugent.be

ABSTRACT

Running with music is becoming increasingly popular and software has been developed that provides music at the runners' tempo. This work aims at investigating the effect of different music synchronization strategies on runners' foot strike impact. Tests were performed in the Flanders Sports Arena in Ghent with 28 participants. The impact on the tibia was measured by accelerometers. Participants were asked to run in five different synchronization strategy conditions, each starting with a thirty-second no music reference. Speed during each condition was kept constant. Results showed no significant difference in impact among the different synchronization strategies regarding both impact level and SPM. However, a non-negligible average increase of foot strike impact could be observed when running with music compared to running without music.

I. INTRODUCTION

Running is a widespread and growing physical activity with known positive effects on health. However, the severity of foot strike impact on the ground while running is a known cause of lower limb injuries (van Gent, 2007). The Department of Movement and Sport Sciences of UGent in collaboration with IPEM, performs research on the reduction of foot strike impact, through music and sonification of movements**.**

Positive results towards impact reduction have been achieved by Clansey (2014) on treadmill running using audio and visual feedback, without influencing running economy. When compared to visual feedback, advantages of the audio feedback were reported by participants in this specific case.

The use of music while performing sports has proven to have positive effects in terms of reduction of perceived effort and pleasantness by several authors (Bood, 2013; Fritz, 2013). Specifically, music was shown to improve time-to-exhaustion and oxygen consumption, mainly because of its rhythmical structures rather than the motivational aspect of the music itself. Music with a prominent beat synchronized with the runner's tempo was considered to yield the most optimal performance output regarding perceived exertion and running economy (Therry, 2012).

This work aims at investigating the effect of different music synchronization strategies on runners' foot strike impact, or more specifically, the effect of the alignment of musical beats with footfalls. It is hypothesized that synchronized music would generate higher levels of foot strike impact compared to non-synchronized music. The mechanism underlying this hypothesis is based on the theory of embodied music cognition (Leman 2007), which formalizes the twofold link between music perception and movement. In the case of synchronization of the music tempo (BPM) and phase with footfalls, entrainment with the musical beat emerges and a feeling of agency is generated. This feeling of agency is known to have an empowering effect on the listener-agent (Leman 2016). For some people, the empowering effect might reflect into accentuation of the movement (Leman 2013), which was also reported by some subjects in preliminary tests. Since speed is kept constant in this specific experiment, it is expected that empowerment would have a direct effect on the landing mechanisms of the runners. In particular, it is hypothesized that the latter would increase the vertical heel velocity, directly leading to an increase in foot-strike impact.

II. METHOD

An experiment was performed on the indoor running track of the Flanders Sports Arena in Ghent. Different synchronization (and non-synchronization) strategies were implemented to test the above hypothesis.

A. Ethics Statement

The study was approved by the Ethics Committee of the Faculty of Arts and Philosophy of Ghent University, and all procedures followed were in accordance with the statements of the Declaration of Helsinki. All participants voluntarily participated. They were informed about the physical effort required for the experiment and that questionnaires could have contained personal questions.

B. Participants

Participants consisted of 28 non-professional runners with an average age of 24 +/-5 years. The distribution between sexes was relatively balanced with 46% women and 54% men. 61% of the participants were trained in music. Most of them (82%) were educated in an academy, 12% was self-educated, and 6% took private lessons. A majority of 86% went jogging at least once a month; 21% once a month, 25% once a week, and 52% several times a week.

C. Technology and Set-up

The runners were equipped with 3-axes digital accelerometers, one for each leg attached to the tibia, for detection of impact strength and cadence. Prior to the attachment of the sensor, the skin on the tibia was pre-stretched with tape to minimize oscillations. The accelerometers were connected to a Teensy 3.2 micro-controller and passed via USB to a Roughpad Panasonic tablet mounted on a backpack carried by the runners. The step detection was performed in real-time using in-house JAVA software (Low Impact Jogger) running on the tablet. The music alignment strategies were implemented in the commercial software Max/MSP from Cycling74' and played by the same tablet through headphones.

Speed measurements were performed in real-time using a sonar system (MaxBotix, LV-MaxSonar-EZ: MB1010) connected to the tablet. The sonar detected marker rods of 1.90 m height, placed at a regular interval of 10.1 m around the running track. Through computation of the time interval run between the marker rods, absolute speed was determined.

The analogue signal was sampled at 30 Hz, digitized by a dedicate Teensy 3.2 micro-controller and sent as OSC message via a local network created by a TPLink router, also placed on the backpack.

The OSC speed message was received by 3 Raspberry PI's placed along the track at about 100 m distance from each other and displayed on screens, to provide feedback to the runners. In particular, the current speed was displayed and the screen turned blue if the speed dropped below the initial reference velocity (first 30 seconds). A red screen indicated that the speed was above the reference velocity and a green one implied a running velocity within 10% of the initial reference velocity.
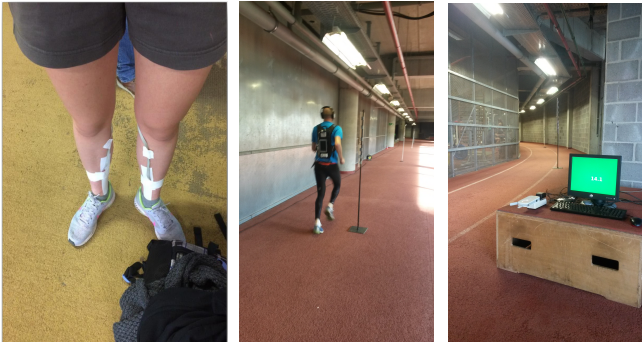
Figure 1. Picture of the experimental set-up. Accelerometers installation and pre-stretching (left), backpack and poles positioning (middle), speed feedback system: Raspberry pi and screens (right).

Three network extenders were also placed along the track to maintain overall network coverage.

D. Procedure

The participants were asked to run five times, in five different conditions presented in random order. The first 30'' of each condition featured no music and were used to calculate the average runner's velocity and cadence (SPM) (which served as a reference throughout the experiment). The runner was then requested to keep this speed constant throughout the condition. Each condition had a duration of 3'30'' (of which 3' with music).

The 5 conditions consisted of (in alphabetic order):

1. *Adaptive Sync*: An adaptive BPM and phase synchronization based on the D-Jogger technology (Moens, 2014).

2. *Initial Sync*: A tempo synchronization condition based on the initial SPM of the runner.

3. *Min 30%*: A non-synchronized condition with music BPM adaptively 30% lower than the runner's SPM.

4. *No Music*: A reference condition without music.

5. *Plus 30%*: A non-synchronized condition with music BPM adaptively 30% higher than the runner's SPM.

Condition 2 and 3 are synchronized conditions; specifically, in condition 2, synchronization is externally imposed by the system, while in condition 3 (commercially available), synchronization depends on the user. Conditions 4 and 5 are non-synchronized conditions in which the alignment of the foot strike with the music beat is not regular and cannot

continuously be achieved. Conditions were randomized across participants to minimize fatigue effects.

E. Music

In all conditions the same music piece was played. The piece was specifically composed for this experiment by Myrthe van de Weetering (www.myrthevandeweetering.com). The music had to meet the following requirements: to be unknown, instrumental (no lyrics), and to have a clear beat in order to highlight the difference between synchronized and non-synchronized conditions.

F. Data Acquisition

For each condition, the 3D force measured by the accelerometers was converted into resultant non-dimensional g-force and SPM by the JAVA software and was stored locally on the tablet, together with the speed measurements from the sonar.

The g-force and SPM (moving average over 5 steps) were continuously transmitted as OSC to an in-house MAX/MSP program running on the same tablet, which provided the sonifications.

After each trial, participants were asked to fill out BORG, PACES, and BMRI questionnaires to respectively rate perceived exertion, enjoyment, and the motivational qualities of the music.

G. Data Analysis

The median values of the g-force, SPM, and speed were calculated respectively after 10 seconds from the start of the experiment to the start of the music (20 seconds) (part 1) and after 30 seconds from the start of the music for a duration of two minutes (30 seconds before the end of the song) (part 2) for each participant. The differences and ratios of the medians (with music / without music) were used to evaluate the effect of the different synchronization strategies for all participants separately. Different time intervals for calculation of the medians with music were tested and provided analogue results.

Due to technical problems during the acquisition, some conditions were not reported for a number of participants. Participants with missing conditions have been excluded from the analysis. Therefore, the final number of usable participants for the analysis was 22.

The acquired .txt files were first processed in MATLAB, while statistical analyses both for impact levels and questionnaires were performed in SPSS.

III. RESULTS

A. Measurements

Figure 2 shows the average values of the g-force, SPM, and velocity over the 22 participants against time for two of the synchronization conditions (initial synch and no music) with the most different outcomes. The horizontal (red) lines in each plot represent the median values calculated from 10 to 30 seconds without music and from 60 to 180 seconds with music respectively.

A gradual increase of the g-force can be noticed when the music starts (30 seconds, vertical line). The transient phase lasts for about 30 seconds. This has been excluded in the analysis, as we are hereby interested in steady state values.

a)
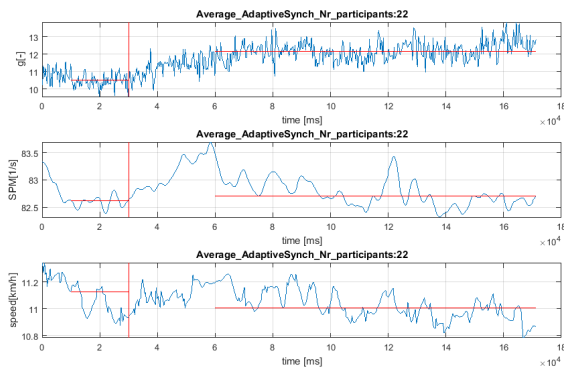
b)
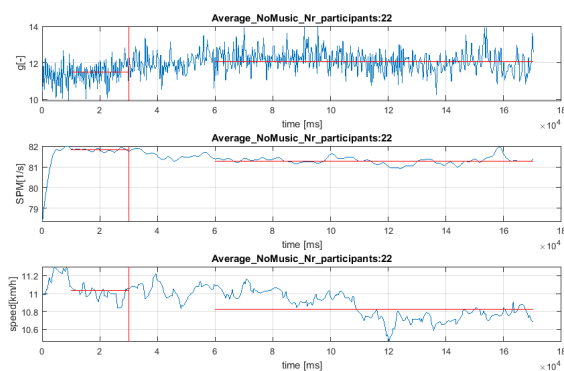
Figure 2. Plots of the average g-force, SPM, and speed over 22 participants against time (ms) for conditions: Initial synch (a) and No Music (b).

Average variations after the start of the music are shown to be much lower for the SPM and the speed (the last was an imposed constrain).

The differences and ratios of the medians (with music / without music) were used to perform statistical analysis on the effect of the different synchronization strategies. The g-ratios for all conditions were non-normally distributed, according to a KS-test ($p < 0.05$). A Friedman test showed that ratios did not differ significantly among conditions, $\chi^2 = 2.26$; $p = 0.69$.

Comparison of the g-ratios between people with music education and without music education was performed using a Kruskall-Wallis test. No significant difference was observed between the two groups either, $p = 0.13$.

Analysis of the pairwise differences between median g-force with and without music was also performed for all the conditions. A KS-test revealed that differences for adaptive sync condition was normally distributed ($p = 0.06$) as well as SPM+30% ($p = 0.20$). The conditions initial sync ($p = 0.02$), SPM-30% ($p = 0.016$) and no music ($p = 0.001$) were not normally distributed. A paired t-test was performed on the normally distributed pairs, while a Wilcoxon test was executed for the non-normally distributed pairs. A summary of the results is shown hereafter with effect size Cohen's d for t-tests and Pearson's correlation coefficient r for Wilcoxon tests:

1. *Adaptive Sync*: Paired t-test showed a significant difference in g-force between the part without music ($M = 10.27$; SE = 0.77) and the part with music ($M = 11.87$; SE = 0.93); $t = -3.66$; $p < 0.001$; $d = 0.78$.
2. *Initial Sync*: Wilcoxon test showed a significant difference in g-force between the part without music ($Mdn = 9.66$) and the part with music ($Mdn = 11.95$); $z = -3.39$; $p < 0.001$; $r = -0.51$.
3. *SPM-30%*: Wilcoxon test showed a significant difference in g-force between the part without music ($Mdn=10.05$) and the part with music ($Mdn = 11.05$); $z = -3.13$; $p < 0.01$; $r = -0.47$.
4. *No Music*: Wilcoxon test showed no significant difference in g-force between the first 30 seconds ($Mdn = 8.74$) and the second part (2 minutes) ($Mdn = 9.26$); $z = -1.77$; $p = 0.08$.
5. *SPM+30%*: Paired t-test showed a significant difference in g-force between the part without music ($M = 10.47$; SE = 0.82) and the part with music ($M = 11.81$; SE = 0.95); $t = -3.24$; $p < 0.001$; $d = 0.69$.
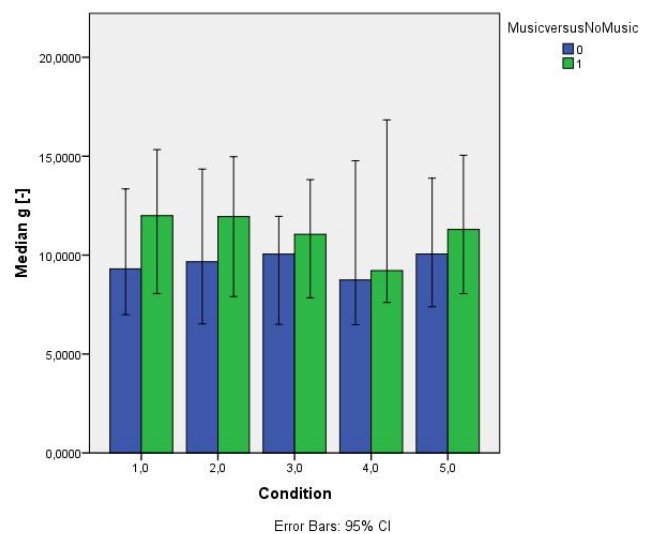
Figure 3. Median g-force with and without music across conditions.

When looking at pairwise comparisons, the no music condition (4) reveals to be the only condition without significant difference. For the other conditions, a mid to high effect size was found, of which the highest for the adaptive sync condition.

In general, an average increase in g-force of about 13% over conditions was observed after the start of the music compared to the initial g-force level.

The SPM-values were analyzed in the same way. In this case, no significant effect across conditions was found ($p > 0.05$).

B. Questionnaires

Participants were asked to rate the pleasantness and motivational effect of the different synchronization strategies on a 7-point Likert scale. No overall significant difference was found across conditions (Friedman test).

When comparing independent groups, differences were observed between participants with music education and participants without music education. First a summary of the pleasantness ratings:

1. *Adaptive Sync*: Mann-Whitney test showed a significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 4), $z = -2.60$; $p < 0.01$.
2. *Initial Sync*: Mann-Whitney test showed no significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 5), $z = -1.62$; $p > 0.05$.
3. *SPM-30%*: Mann-Whitney test showed no significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 4), $z = -1.62$; $p > 0.05$.
4. *SPM+30%*: Mann-Whitney test showed a significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 4), $z = -2.24$; $p = 0.03$.

Hereafter a summary of the rating about motivational effect among the two groups:

1. *Adaptive Sync*: Mann-Whitney test showed a significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 3), $z = -2.11$; $p = 0.04$.
2. *Initial Sync*: Mann-Whitney test showed no significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 5), $z = -1.14$; $p > 0.05$.
3. *SPM-30%*: Mann-Whitney test showed no significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 4), $z = -0.97$; $p > 0.05$.
4. *SPM+30%*: Mann-Whitney test showed no significant difference between the scores of people with music education (*Mdn* = 5) and people without music education (*Mdn* = 4), $z = -0.67$; $p > 0.05$.

No significant differences were found across gender and across training level of participants.

IV. DISCUSSION

The purpose of this study was to investigate the effect of synchronized running to music on runners' foot strike impact. The results of these tests will be used in later experiments to design novel impact reduction strategies through acoustic feedback. The hypothesis was that, using the D-Jogger technology, synchronization of the tempo and phase of the music with running behavior would increase the motivational effect of the music (Bood, 2013; Terry, 2012), and would in turn lead to a higher impact level due to accentuation of movements (Leman, 2013). However, the latter hypothesis was rejected, as no significant effect on foot strike impact level could be ascribed to different synchronization strategies.

However, a non-negligible average difference of the impact could be observed between the part without music (first 30 seconds) and the part with music (2 minutes after start of music), for all conditions with music (average 13% increase). This difference is minimal for the no music control condition (< 5%) and can be ascribed to fatigue. This should be taken into account when designing new experiments on impact reduction using sonification. Further analysis will be dedicated to consider variations of impact in time due to fatigue.

The increase in foot strike impact with music could also be ascribed to the specific music choice. In the present case, a song with clear and regular beats was used for all conditions and this could have led to accentuation of movements due to the activating character of the music (Leman, 2013). Further research will be devoted to investigate the effect of specific musical features on runner's foot strike impact.

The musical background of the participants did not have a direct influence on the g-force levels but implied differences in terms of pleasantness and motivational effects in the questionnaires. In particular, people with music education rated the adaptive sync strategy (D-Jogger) as more pleasant and motivational (Moens, 2014). Commercial software (e.g., Spotify running) is often based on tempo synchronization without phase alignment (initial sync condition). Most runners are unfamiliar with adaptive phase synchronization and this could feel unnatural for some runners when introduced to this strategy. Tempo changes and stretching seems to be perceived as more natural and appealing by people with musical background.

In order to make the experiment as ecological as possible participants were not constrained to keep the same speed for all conditions. Speed variations were allowed among conditions for all participants. ANCOVA analysis using the variations of speed as covariate confirmed non-significant differences across conditions. However, it could be argued that the mechanism of foot landing might vary for different speed regimes and the effect of music synchronization could be different at different speeds.

Some technical problems occurred during the experiment mainly due to the attachment of the accelerometers on the skin of the participants. Loose attachment of the sensors, due to sweat or poor pre-stretching caused irregular oscillations of the sensors for some participants. Those participants were excluded from further analysis. Furthermore, a wireless system could have improved ergonomics and consequently the pleasantness of the system.

This study showed that running to music may increase foot strike impact level irrespective of any further synchronization with the music. This should be kept in mind for further research on impact reduction through acoustic feedbacks.

V. CONCLUSION

An experiment was performed to check the influence of different music synchronization strategies on runner's foot strike impact. From the analysis, it seems that synchronization does not lead to variations in impact level. However, music onset seems to cause an average impact level increase up to 13% compared to running without music, irrespective of the synchronization strategy.

No significant difference in pleasantness and motivational effect were observed across the different synchronization strategies, although phase alignment of the footfalls with musical beats seems to be preferred by people with musical background.

ACKNOWLEDGMENT

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