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Shifting the Musical Beat to Influence Running Cadence

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ABSTRACT

The use of music in the fields of sport and rehabilitation has been explored in several ways. Mostly, these studies have dealt with the effect of different types or genres of music and the difference between using synchronous or asynchronous music. Within the studies on synchronous music there is some discrepancy as to what is considered to be synchronous. This varies from music with a tempo in the range of the tempo belonging to a certain task, to music that is exactly matched in tempo to the task's tempo. The use of tempo-matching music allows us to even do more fine-grained music alterations: shifting the beat to try to spontaneously manipulate a runner's cadence. Musical tempo has been shown to have an effect on running. Instead of changing running cadence by manipulating the musical tempo, we explored the possibility of manipulating cadence by changing the relative phase angle of the musical beat. Twenty-six recreational runners ran four minutes, nine times. The first minute of each 4-min sequence consisted of running without musical accompaniment. Running cadence was measured and the average cadence of the final 15 sec was used to select a musical track with matching tempo. In the following three minutes we tried to increase or decrease the runner's tempo up to 5%. Three different coupling strengths, meaning a small, medium or big timing difference between the beat and the footfall, were tested. The study revealed a significant main effect of the phase angle adjustment strategies on runners' cadence and velocity. Furthermore, a significant gender interaction effect was found for runners' cadence adaptation. Women spontaneously increased or decreased their running tempo with the +5% and -5% target tempo conditions respectively. Men, however, could be sped-up, but not slowed-down more than the decrease in cadence that was already observed when the musical beats were perfectly synchronized with the footfalls. In addition to effects on kinematics, the results showed higher enjoyment levels with music than with metronome, and a decrease in enjoyment with the -5% tempo conditions. Being able to influence runners' cadence, velocity, and enjoyment through phase-shifted music is an interesting finding in the light of preventing and treating common running-related injuries.

I. INTRODUCTION

The use of rhythmic auditory stimulation (RAS) has been given a lot of attention in light of influencing cadence in running and cycling and in gait rehabilitation programs for e.g. patients with Parkinson's disease. Metronome sequences as well as music (with clear beats) can be applied for RAS. The main influencers of gait with metronomes are the sound and the frequency of the clicks. For music, however, not only the sound and frequency of the beats are important. Other music-inherent qualities at micro-level (inter-beat period) and macro-level (over the course of several beat periods) can influence people's walking or running cadence, as well as their motivation (Buhmann, Desmet, Moens, Van Dyck, & Leman, 2016; Leman et al., 2013).

Within sports and gait rehabilitation the tempo (cadence) and strength (e.g. step size) of movement are important variables for improving performance or preventing injuries. According to a review study by van Gent et al. (2007) running may cause injuries, especially to the lower extremities, ranging from 20-79% of incidences for non-elite runners. The knee is the predominant site for this type of injuries that are typically caused by overstriding. Therefore, a popular strategy for preventing knee injuries is to reduce step size by increasing running cadence (Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011).

Music is pre-eminently adequate to guide or spontaneously influence a person's running cadence while being motivating as well. A study by Van Dyck et al. (2015) revealed the possibility to spontaneously affect running cadence by deviating the tempo of the music from runners' individual preferred cadence. Tempo manipulations within 2.5% of a runner's cadence were found to be effective. Larger deviations from runners' cadence were not or less effective. A music-to-movement alignment strategy that continuously manipulates the musical tempo only affects the time between subsequent beats. Such a strategy does not take into account the specific moments when the beats occur, or how these time instants relate to the instants of the footfalls. In other words, the relative phase angle between beat and step is disregarded. An alignment strategy that is able to consider relative phase angles might be better suited to keep the synchronization level high and to spontaneously manipulate runner's cadence. In this study several variations of such relative phase alignment strategies are tested and compared.

Our hypothesis is that when people run in synchrony with a musical beat and the music is then manipulated in such a way that the beat is placed prior to the moment of the footfall (i.e. positive relative phase angle), the runner will try to re-establish synchronization (a zero relative phase angle) by speeding up (cadence and speed). On the contrary, we hypothesize that manipulating the beat to come after the moment of the footfall will result in slowing down cadence and speed to re-establish running in synchrony with the music. In this study we tested this hypothesis by trying to manipulate runners' cadence towards +5% and -5% of their measured preferred cadence. This was explored at three interesting 'levels' of relative phase angle manipulation:

- **Subconscious** or **subliminal**: a subtle phase shift up to a maximum of +/-25° that is not perceivable by the participant.
- **Barely noticeable**: a maximum phase shift of +/-50° that is most likely not perceivable by the participant.
- **Conscious**: a maximum phase shift of +/-75° that is most likely to be noticed by the participant. A relative phase angle of this size could be perceived as annoying by some runners.

II. METHODS

A. Participants

In total, 26 healthy, adult participants (12 males) took part in the study. All participants were recreational runners (M_{age} = 22.81 years; SD_{age} = 3.25 years) and indicated to be capable of running 30 minutes continuously. The study was approved by the Ethics Committee of the Faculty of Arts and Philosophy of Ghent University and was in accordance with the statements of the Declaration of Helsinki.

B. Experimental Design

1) *Stimuli.* The natural running cadence for recreational runners lies somewhere between 130 and 200 steps per minute (SPM). We therefore selected musical tracks within this tempo range in four different genres: pop, rock, dance, and classics. This gave participants the opportunity to run with music they would normally choose to listen to. Using the Essentia Beat Tracker (Bogdanov et al., 2013) all beat instants were extracted and hence the number of beats per minute (BPM). After that, BeatRoot (Dixon, 2007), a beat-tracker with a graphical user interface, was applied to double-check the beats of each track and alter beats not picked up correctly by the software if needed. Using MatLab the stability of the track's tempo was checked. Every track with a standard deviation from the mean BPM of more than two was excluded. We also excluded tracks that were shorter than 3 min 30 s, as each tested condition had to last at least three minutes, and an increase in original tempo could shorten the duration of a track. In total 112 tracks were selected: pop (26), rock (31), dance (33) and classics (22). Furthermore, we made sure the tracks were uniformly spread over the database in terms of BPM, so every BPM category was adequately represented. This was achieved by dividing the tempo range in sub ranges, each representing at least five tracks.

2) *Apparatus.* In order to have a mobile data collection system, participants were equipped with a backpack holding a 7" tablet (Panasonic FZ-M1) running Windows 8.1. They were also equipped with two (fourth generation) iPods, one on each ankle, and a Wi-Fi router (TP-Link M5360) that ensured a reliable communication between all crucial components. Using the Sensor Monitor Pro application on the iPods, data from accelerometers and gyroscopes was streamed wirelessly to the tablet at a sampling rate of 100 Hz, enabling the detection of footfall instants. Speed measurements were performed using a sonar system (MaxBotix LV-MaxSonar-EZ: MB1010) mounted on the backpack and connected to the tablet through a Teensy 3.1 micro-controller. It detected regularly placed marker rods around the running track of 1.90 m high. The time it took to cover each 10-m interval was used to compute the absolute speed of the runner. The analogue signal was sampled at 30 Hz and digitized using the Teensy. The software on the tablet computed the running tempo from the detected footfall instants, which was used as a basis for defining the tempo of the selected music. The relative phase of the moment of the musical beat compared to the moment of the footfall was adapted based on the selected alignment strategy (see Table 1). Finally, the manipulated music was sent back to the participant using Sennheiser HD60 headphones connected to the tablet.

Table 1. Descriptions of all the tested audio-to-movement strategies: low (L), medium (M), or high (H) phase angle adjustments (PAA) to manipulate runners' preferred cadence (f_{pref}) or not (Metronome and Music control).

Strategy	Type of auditory adaptation
+5%_LPAA	Low relative phase angle adjustment of music (approx. 25°) until +5% of f_{pref} is reached.
+5%_MPAA	Medium relative phase angle adjustment of music (approx. 50°) until +5% of f_{pref} is reached.
+5%_HPAA	High relative phase angle adjustment of music (approx. 70°) until +5% of f_{pref} is reached.
-5%_LPAA	Low relative phase angle adjustment of music (approx. -25°) until -5% of f_{pref} is reached.
-5%_MPAA	Medium relative phase angle adjustment of music (approx. -50°) until -5% of f_{pref} is reached.
-5%_HPAA	High relative phase angle adjustment of music (approx. -70°) until -5% of f_{pref} is reached.
Music control	Relative phase angle adjustment at 0°: musical beats continuously match steps at runner's f_{pref}.
Metronome	Isochronous metronome sequence where the tempo matches the initially measured f_{pref}.

3) *Procedure.* All experiments took place in the Flanders Sports Arena of Ghent, Belgium. After a 4-minute warm-up to get to know the running track participants were equipped, and asked to run on the 200 m running track for four minutes continuously, and this for eight consecutive times. They had to select at least two of the four genres where the software could select music from. Each 4-minute condition started with one minute running in silence, after which a metronome sequence or a musical track was started. The first run was the isochronous metronome condition in which the music tempo was matched to the runner's preferred cadence. In each of the following seven 4-minute runs, a different music alignment strategy was tested (Table 1) and it was ensured that all orders could occur only once. Participants were instructed to run at their own preferred tempo (f_{pref}). No information was distributed concerning the real purpose of the experiment, and all participants ran in solo conditions. After each run, the participants were instructed to fill out a questionnaire, and recover before starting the next condition. The first part of the questionnaire related to the perceived amount of exertion (RPE) indicated on the Borg Scale (Borg, 1998). The second part related to the motivational aspects of the musical tracks they heard while running (Brunel Music Rating Inventory-2 (BMRI-2) by Karageorghis, Priest, Terry, Chatzisarantis, & Lane, 2006). Participants were also asked if they knew the track they had just heard. The third part of the questionnaire related to the physical enjoyment. This was indicated on the 8-item version of the Physical Activity Enjoyment Scale (PACES) (Kendzierski & DeCarlo, 1991; Mullen et al., 2011), a single factor scale to assess the level of enjoyment during physical activity in adults across exercise modalities. Afterwards, the participants filled out the last part of the questionnaire on personal background, music education and sports training.

C. Cadence and Speed Measurements

We examined the effect of the different alignment strategies on kinematic parameters such as cadence and speed. Average cadence and speed values during music playback (2:30-3:30) are compared to those in the preceding silence (0:45-1:00). The resulting dependent variables are reflected as percentages, where zero indicates no difference, while a negative or positive value indicates a respective decrease or increase in cadence or speed compared to the initial silent part of the condition.

D. Data Analysis

All six phase angle adjustment (PAA) strategies were compared to the music control. A 2x7 mixed-design ANOVA test with gender (male, female) as between-subjects variable and alignment strategy as within-subjects variable was performed for change in cadence and speed. For motivational scores (PACES) Wilcoxon signed-rank tests were performed comparing all PAA strategies with the music control, average -5% and +5% with the music control, and all music conditions with the metronome condition.

III. RESULTS

A. Cadence

A 2x7 mixed-design ANOVA test with gender (male, female) as between-subjects variable and alignment strategy as within-subjects variable revealed a significant main effect of the strategy on the change in cadence from silence to music, $F(6, 72) = 13.23$, $p < .001$. Contrasts revealed that for all speeding up conditions - (+5%_LPAA) $F(1, 12) = 12.99$, $p = .004$, $r = .72$, (+5%_MPAA) $F(1, 12) = 8.76$, $p = .012$, $r = .65$, (+5%_HPAA) $F(1, 12) = 8.57$, $p = .013$, $r = .65$ - cadence changes were significantly higher ($M = 0.53\%$, $SE = 0.52$, $M = 0.52\%$, $SE = 0.33$, and $M = 0.54\%$, $SE = 0.47$ respectively), than the music control ($M = -0.80\%$, $SE = 0.52$). Also, -5%_LPAA results in significantly lower tempo ($M = -1.86\%$, $SE = 0.27$) than the music control, $F(1, 12) = 11.47$, $p = .005$, $r = .70$.

There was no significant main effect of gender, indicating that on average there were no significant differences in change in cadence between male ($M = -0.96\%$, $SE = 0.41$) and female participants ($M = -0.16\%$, $SE = 0.40$), $F(1, 12) = 1.94$, $p = .19$, $r = .37$.

Nevertheless, a significant gender interaction effect was observed, $F(6, 72) = 3.19$, $p = .008$, indicating that for men and women changes in cadence varied between strategies. Contrasts were performed, revealing interaction effects between gender and all -5% conditions: gender x -5%_LPAA x music control, $F(1, 12) = 15.14$, $p = .002$, $r = .75$, gender x -5%_MPAA x music control, $F(1, 12) = 8.73$, $p = .012$, $r = .65$, and gender x -5%_HPAA x music control, $F(1, 12) = 5.11$, $p = .043$, $r = .55$. Figure 1 shows the cadence change for the different strategies and genders. Compared to the music control, both males and females increase cadence in the +5% conditions, but only females slow down their cadence in the -5% conditions. For men, the -5% conditions have no effect compared to the music control.

B. Speed

All PAA strategies were compared with the music control. A significant main effect of the strategy on the change in speed was observed, $F(6, 72) = 2.36$, $p = .039$. Contrasts revealed that for +5%_LPAA, $F(1, 12) = 10.30$, $p = .008$, $r = .68$, the speed change was significantly higher ($M = 3.97\%$, $SE = 1.41$) than for the music control ($M = -1.08$, $SE = 1.45$).

There was no significant main effect of gender, $F(1, 12) = 2.44$, $p = .144$, $r = .41$, and also no interaction effect between strategy and gender, $F(6, 72) < 1$, $p = .43$.

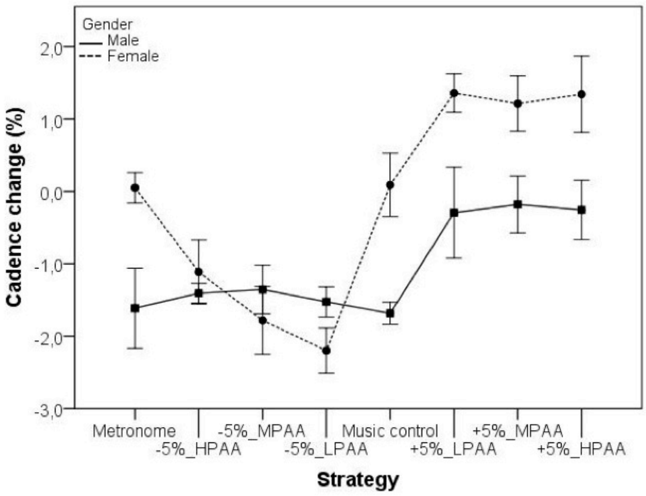

Figure 1. Mean cadence change (% of music vs. silence) and SEs for men and women per audio-to-movement alignment strategy.

C. Enjoyment

Wilcoxon signed-rank tests (comparing all PAA strategies with the music control) were performed on the scores of the PACES test. No effect on ratings of physical enjoyment was observed. We were also interested to see if enjoyment ratings would differ when people were spontaneously sped-up or slowed-down. Therefore, we compared average PACES ratings for the three +5% and the three -5% conditions with the music control. After Bonferroni corrections (significance level at 0.025) Wilcoxon signed-rank test showed no difference, $T = 145$, $p = .63$, $r = -.07$, in ratings for the +5% conditions ($Mdn = 64.66$) and the music control ($Mdn = 67.13$). Nevertheless, the -5% conditions were rated significantly lower ($Mdn = 58.83$) than the music control, $T = 52$, $p = .009$, $r = -.39$.

In addition, compared to the metronome condition all music conditions were rated significantly more motivating (significance level at 0.007 after Bonferroni corrections). See Table 2 for the results of the Wilcoxon signed-rank tests.

IV. DISCUSSION

This study showed the possibility to spontaneously increase or decrease a runner's cadence with music-to-movement alignment strategies that manipulate the relative phase between the moments of the musical beats and the footfalls. In addition a strategy x gender interaction effect was observed, indicating that although the speeding-up strategies were effective for men and women, only women responded with decreased cadence to the slowing-down strategies.

Finally, no motivational differences were revealed between the different music-alignment strategies, although on average the slowing down strategies were enjoyed less than the music control strategy. Additionally, all of the music strategies were enjoyed more than the metronome condition.

Table 2. Significant differences in enjoyment ratings (PACES): Wilcoxon signed-rank tests comparing metronome with music conditions, and -5% conditions with the music control.

Comparisons (*Mdn*)			*T*	*p*	*r*
Metronome (37.06)	x	+5%_LPAA (72.63)	2	< .001	-.61
		+5%_MPAA (69.38)	2	< .001	-.61
		+5%_HPAA (65.63)	22	< .001	-.53
		-5%_LPAA (60.75)	18	.002	-.50
		-5%_MPAA (66.88)	3	< .001	-.60
		-5%_HPAA (57.56)	9	< .001	-.58
		Music control (67.13)	0	< .001	-.62
-5% (58.83)	x	Music control (67.13)	52	.009	-.39

A. Phase shifting effects on cadence and speed

For speeding-up all three phase angle adjustment levels resulted in higher cadence than the control condition. The largest effect size however, was observed for the strategy that manipulated the phase angle the least. This was also the only strategy that significantly increased speed. In addition, for slowing down only the strategy that induced the smallest relative phase angles proved to be effective in decreasing runner's cadence. It seems that manipulating the phase angle between the beat and the footfall on a subconscious level was most effective. On average a 25° positive or negative relative phase was continuously induced by the strategy to drive runners to a 5% higher or lower cadence than their initial preferred cadence. For a running cadence of 160 SPM this comes down to shifting the beat 26ms before or after the predicted moment of the footfall.

Although no changes in RPE were unveiled between the different PAA levels, we did observe higher levels of synchronization (resultant vector length) with the LPAA strategies (M = 0.92, SE = 0.01), than with the HPAA strategies (M = 0.87, SE = 0.01), $F(1, 21) = 9.23$, $p = .006$, $r = .55$. Being more in phase with the LPAA strategies means that the cadence-guiding capacity was more constant over the course of a 4-minute run. The HPAA strategies contained more out-of-phase, so no-cadence-guiding moments. The fact that small, subliminal changes in relative phase are most effective in manipulating cadence could be explained by the higher stability in cadence guiding.

B. Gender interaction effects

The hypothesized effects of the phase manipulation strategies proved to be true for the women in this study. For men, however, the effects were slightly different: although the speeding-up strategies were able to increase running cadence, the slowing-down strategies had no effect compared to the music control condition. We can conclude from the music control condition that women tend to keep their cadence more or less stable throughout a 4-minute run: 0.09% cadence increase compared to the beginning of the run where no music was played. Nevertheless, on average the men tend to slow down -1.69% in the control condition. A possible explanation could be that male runners typically start somewhat faster and slow down their cadence over the course of time. Their tempo already being decreased makes it harder for the slowing-down strategies to have an additional effect. The speeding-up strategies resulted in higher running cadence compared to the control condition, but cadence was only increased up to the cadence level runners had at the start of the 4-minute run. In other words, for male runners the speeding-up conditions resulted in maintaining cadence (-0.29%) throughout the run.

According to Karageorghis, Terry, & Lane (1999) men pay less attention to the rhythmical characteristics of music than women do. This could explain that beat-shifting techniques as tested in this study are less effective for cadence manipulation in males than in females.

C. Enjoyment

Enjoyment ratings with the PACES scales proved to be higher for all seven of the music conditions compared to the metronome condition. This is in line with a study on cycling that showed more positive affective valence for music conditions (synchronous and asynchronous) compared to a metronome condition (Lim, Karageorghis, Romer, & Bishop, 2014).

When we compare all the music PAA conditions with the music control condition, enjoyment ratings are not significantly different. However, a difference was observed when the average ratings for the speeding-up conditions were compared with the average ratings for the slowing-down conditions. Compared to the music control no additional enjoyment of the speed-up strategies was observed, but for the slowing-down strategies a decrease in enjoyment level was observed. A study by Wellenkotter, Kernozek, Meardon, & Suchomel (2014) revealed that a 5% decrease in cadence is accompanied by increased contact time with the ground per foot strike and increased peak force and peak pressure on the heel. This increases the risk for running-related injuries, which might in turn decrease running comfort or enjoyment, as shown in our results.

V. CONCLUSION

With this study we were able to show that shifting musical beats influences runners' cadence, speed, and enjoyment. Playing the music in such a way that the beat comes slightly earlier than the footfall results in increased running cadence and speed. If the beats are played just after the footfalls, running cadence is decreased. We also demonstrated that this method is less effective for men: we only achieved a speed-up in tempo, but the slowing-down strategies had no additional slowing-down effect compared to the non-manipulated music condition.

Music being more motivating than a metronome is almost stating the obvious. Our results confirm this. It is, however, worth noting, since the use of a metronome is still common practice in running training (to achieve higher cadence) and gait rehabilitation. In addition to other studies, our results underline a benefit of music over a metronome.

Although the size of the relative phase angle adjustments had no effect on enjoyment, a significant decrease in enjoyment was observed when runners were slowed-down. This is in line with a higher impact caused by a decrease in cadence. Hence, trying to decrease cadence should be done with care if at all necessary.

Music-to-movement alignment techniques such as demonstrated can help preventing running-related injuries, and improve gait or running performance. In view of general health the use of motivating music contributes to improved adherence to training programs.

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