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Effects of Auditory-Motor Synchronization on 400-m Sprint Performance: An Applied Study

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Abstract

There is a conspicuous dearth of empirical research regarding the ergogenic and psychological effects of synchronous music when applied in a sports training context. The main purpose of this longitudinal intervention study was to investigate the ergogenic and psychological effects of synchronous music applied over a 1-month period of speed endurance training. Twelve participants (6 women and 6 men; 21.1 ± 1.7 years) were randomly assigned to either an experimental group (sprint training coordinated with synchronous music) or a control group (conventional sprint training). Immediately after each training session and each time trial the Feeling Scale, CR-10 Rating of Perceived Exertion (RPE) Scale, and Physical Activity Enjoyment Scale (PACES) were administered to each participant. No significant interaction effect of Group × Time for RPE (p = .898) or PACES (p = .411) was identified during the training sessions. A significant Group × Time interaction was identified for Feeling Scale scores (p = .007). Nonetheless, following Bonferroni adjustment for pairwise comparisons, the between-group differences in Feeling Scale scores did not reach significance. No significant interaction effect of Group × Time or main effect of group was identified for sprint performance, although the latter effect was associated with a large effect size ($\eta_p^2 = 0.35$). Experimental group participants executed the 400-m time trials 5.07% faster than control group participants. This finding is noteworthy from an applied perspective given the potential ergogenic effects associated with auditory-motor synchronization.

Keywords: Affect, Entrainment, Music, Physical endurance, Rhythm, Running

1.0 Introduction

During sport- or exercise-related activity, music can be applied in either an asynchronous or synchronous mode.[1] When used asynchronously, music provides background stimulation without an individual consciously synchronizing their movement patterns with the rhythmical qualities of music.[2] In contrast, the synchronous application of music entails performing repetitive movements in time with its rhythmical elements, which exploits the innate human tendency to synchronize movement with auditory rhythms.[3] Synchronization of movement to musical rhythm is a form of *auditory-motor synchronization* in which the individual and the auditory stimuli are “oscillators”, generating their own rhythms.[4] When two non-identical oscillators, each with their own frequency (e.g., an individual’s running stride and a musical beat), are coupled, they may start to oscillate at a common frequency.[4] Central to this coupling is the concept of *entrainment*, a phenomenon in which two or more independent rhythmic processes synchronize with each other.[5]

Central pattern generators, intraspinal neuronal networks that coordinate and control human locomotion, are capable of producing oscillatory behaviour.[6] Acoustic cues can enhance gait by creating a stable coupling between footfalls and musical beat.[3] Temporal anticipation and adaptation contribute to the quality of auditory-motor synchronisation.[7] When listening to music, individuals generate temporal expectations based on structural regularities related to the musical beat.[8] These coordinate with efferent neural motor signals issued from motor regions of the brain (e.g., precentral and paracentral gyri). Afferent feedback-based error detection allows for the correction of asynchronies as well as tempo drift within a closed-loop system.[9,10] Aligning the temporal dynamics of movement to external patterns reduces movement variability, resulting in more efficient and stable locomotion,[11] which can enhance task performance.[12]

A burgeoning literature has emerged over the last two decades indicating that the application of synchronous music yields significant ergogenic (i.e., work-enhancing) effects in sport and exercise settings.[12,13] A landmark study by Anshel and Marisi,[14] which compared synchronous and asynchronous music, found that synchronous music elicited superior endurance in a cycle ergometer task when compared to either asynchronous music (Cohen's d = .4) or a no-music control condition (d = .6). Music was chosen somewhat arbitrarily from the "popular rock" category without due consideration of the music preferences and sociocultural background of participants, suggesting that the potential benefits of both synchronous and asynchronous music could have been even greater.[15] Subsequent studies have tested the ergogenic effects of synchronous music on treadmill walking,[13] cycle ergometry,[16] and circuit training.[17]

Simpson and Karageorghis[12] were among the few researchers who assessed the effects of synchronous music on anaerobic endurance performance. They reported that both motivational and *oudeterous* (i.e., motivationally neutral)[18] synchronous music elicited faster times for 400-m track running when compared with a no-music control. Along similar lines, two additional studies demonstrated a beneficial effect of synchronous music on task performance during high-intensity treadmill running.[3,19] Among a sample of elite triathletes, Terry et al.[19] reported that time to exhaustion was 18.1% and 19.7% longer, respectively, when running with motivational and oudeterous synchronous music compared to no music. At such high intensities (i.e., > ~75% $\dot{V}O_{2max}$), music is ineffectual in terms of ameliorating fatigue-related symptoms (e.g., breathlessness and limb discomfort) or lowering RPE, owing to the phenomenon of attentional switching;[20] ostensibly, there is a forced shift from dissociative to associative thoughts.[21] Nonetheless, when paired with music, recent work shows that exercise is recalled as a more pleasant and enjoyable experience.[22,23]

It is worth noting that music tracks should be carefully selected through a meticulous process in order to elicit positive psychological outcomes and ergogenic effects during sports training and competition.[24–26] In this context, a wide range of factors such as cultural background and psychosocial aspects need to be considered in the music-selection process.[18] However, it is also important to emphasize that music preference is highly idiosyncratic in nature.[27] During sport-related tasks, music preference can bear a meaningful influence on psychological and performance outcomes.[28] Accordingly, well-selected pieces are recommended in order to reawaken long-term memories, evoke positive emotions, render a given activity more enjoyable, and enhance physical performance.[1]

Although music has been used extensively in the sport and exercise domain as a means by which to assuage perceptions of fatigue and enhance participants' affective state,[29,30] the brain mechanisms that underlie such psychological effects have only recently been investigated.[23,31,32] There is compelling evidence that music has the potential to optimize the neural control of working muscles by reducing the frequency of neural outputs that originate in the central motor command.[23] This cortical pattern of response allows athletes/exercisers to execute movements through a more reflexive control of the musculature.[33] Consequently, processing of internal bodily signals is reduced, and individuals become less aware of their physical sensations during physical exercise.[34] These psychophysiological mechanisms can also engender more positive affective responses and enhance perceived enjoyment relative to normal conditions (i.e., no music).[33] This is mainly due to a reduction in the processing of interoceptive sensory signals which, by extension, causes the detrimental effects of fatigue-related sensations (e.g., limb discomfort) to be ameliorated.[32]

1.1 Rationale, Purpose, and Hypotheses

There is considerable scope for further investigation of the ergogenic and psychological effects of synchronous music when applied to a training regimen in a longitudinal, applied context rather than to a singular experimental trial, as was the case in all previous related work.[3,12,16] It has yet to be ascertained whether a training program coordinated with synchronous music can confer additional performance and/or psychological benefits over identical training conducted without music (i.e., conventionally). Accordingly, the purpose of this applied study was to examine the ergogenic, affective, and perceptual effects of synchronous music applied over a 1-month period of speed-endurance training. We hypothesized that the motivational music training group would exhibit significantly better performance (H_1) and psychological outcomes (i.e., affective valence and perceived enjoyment; H_2) than the no-music control group, which was subjected to the same training regimen. We did not predict differences between groups in the psychophysical variable of RPE, given that a ceiling effect was expected owing to the high-intensity nature of all training sessions (H_3). This variable was used to check whether participants ran at the required level of intensity in the prescribed training sessions.

2.0 Method

2.1 Power Analysis

Albeit the present study had a strong applied orientation, the required sample size was calculated using G*Power 3.1[35] for an F test (repeated-measures ANOVA, within-between interaction). The effects of music on running performance during 400-m time trials (i.e., the dependent variable of primary instance) were used as group parameters to estimate the effect size required to calculate sample size. Given the similarities with the present study, the Simpson and Karageorghis[12] study was used to estimate the effect for synchronous music on sprint performance (f = .56). The calculation indicated that 10 participants would be required to detect an effect of this magnitude (α = .05; 1-β = .80). One additional participant was added to each group to account for the possibility of experimental dropout.

2.2 Participants

Twelve volunteer participants (6 women and 6 men; 21.1 ± 1.7 years) from Brunel University London, UK were recruited. The ethnicities represented in the sample were White UK/Irish (*n* = 6) and mixed race (*n* = 6). Participants regularly engaged in weight-bearing athletic activities but were not high-level track athletes (i.e., of county standard or above). The decision to recruit recreational athletes was predicated on the assumption that highly-trained individuals would have well-established motor patterns for the completion of 400 m.[36] Therefore, recreational sportspeople were more likely to derive benefit from music than their elite counterparts. No financial inducements were provided to participants and the main benefit outlined in relation to their participation was that they would receive 5 weeks of structured, supervised training on a running track.

2.3 Apparatus and Measures

Three handheld stopwatches were used to time 400-m trials on an outdoor all-weather track. The Physical Activity Enjoyment Scale (PACES)[37] was administered to participants immediately after each 400-m time trial and training session to assess activity enjoyment levels. At the end of each time trial and training repetition, the single-item Feeling Scale[38] and Borg's CR10 Rating of Perceived Exertion (RPE) Scale[39] were administered to assess participants' affective states and perceptual responses (i.e., session-RPE method),[40] respectively. Participants in the experimental group had their music liking assessed by use of a single item after each training session: "Based on how you feel right now, rate how much you liked the music" with responses provided on a 10-point scale anchored by 1 (*I did not like it at all*) and 10 (*I liked it very much*).[41]

2.4 Procedures

Prior to commencing the training program, participants were administered a habituation and familiarization trial. They were led through a standardized warm-up routine (see Table 1) by a member of the research team and had the Feeling Scale, RPE scale, and PACES explained to them. They were then instructed to run 400 m (one lap of an outdoor athletics track) at maximal effort (i.e., “run one lap of the track as fast as you can”). Immediately thereafter, they were administered the Feeling Scale, RPE scale, and PACES. Participants were fully familiarized with these scales and it should be noted that almost all had encountered the RPE scale either in classes or through volunteering for other studies at the university.

Table 1

Each participant completed a 400-m time trial in the session that immediately followed habituation and familiarization (i.e., on a separate day). To minimize the technical demands of the all-out running effort, the participant was instructed in how to use a standing start. Following “Set” and “Go” commands that were delivered verbally by an experimenter, the participant commenced a solo, maximal effort that was timed by two timekeepers. To minimize inter-individual variability in timing, the timekeepers were well practiced in starting their stopwatch upon the participant’s first foot contact over the start line and stopping it immediately after the participant’s entire torso had crossed the finish line. The mean time from the two timekeepers was calculated and recorded to ensure consistency in timing.

Each participant was filmed during their initial 400-m time trial to ascertain their stride rate per min (i.e., strides over 400 m ∕ trial time [s] × 60). Using a high-resolution digital camera (Samsung Galaxy S8), filming was conducted by a member of the research team who stood atop the timekeepers’ mobile stairs, which were suitably positioned in the center of the track's infield. Following completion of the time trials, three female and three male participants were randomly assigned to one of two training groups (No-Music Control Group [i.e., conventional track training], *n* = 6; Synchronous Music Group, *n* = 6;). The research team selected the music tracks for each participant in the Synchronous Music Group with beats per min (bpm) to match target stride rate (stride cycle [two foot contacts with the ground] per beat). One musical beat (i.e., a crotchet beat) was used for each stride cycle to reduce the amount of information processing required for auditory-motor synchronization to take place.[1]

A preliminary track list was created, consisting of highly recognizable tracks that had placed in the top 100 of the UK billboard charts during the 4 years preceding data collection. This approach was taken to maximize the probability of participants being familiar with the tracks.[15,42] The tracks were characterized by a consistent beat (i.e., without *accelerandos* or *rallentandos*) and an easily extractable meter, in order to facilitate auditory-motor synchronization during high-paced running. The main beat of each track had to be initiated with the first 30 *s* of the recording (i.e., following any nonrhythmical introduction). To enable progression in stride rate through the training program, the playlist had a broad tempo range of 70–111 bpm (see Table 2). The music was delivered via a smartphone mp3 player (Samsung Galaxy S8). Due to hygiene concerns, participants were instructed to use their own headphones, but music intensity was standardized insofar as the music was loud (i.e., volume level 10) but the experimenter's voice remained clearly audible.[15]

Table 2

Participants' training was scheduled over a period of 1 calendar month and took place at a frequency of 2 days per week at the outdoor athletics track of Brunel University London, UK. The synchronous music group and control group trained at separate times so that they did not come into contact or even catch sight of one another. For instances in which a participant was unable to attend one of the training sessions, an additional session was made available each week to accommodate her/him. The training sessions were of ~45-min duration for each group, comprising a 5-min briefing period (essentially to allow for tardiness), a 10-min warm-up, a 25-min speed endurance-based session, and a standardized 5-min cool-down (see Table 2). The content of training sessions was identical for the synchronous music and control groups with the exception that the synchronous music group were instructed to coordinate their strides with a musical beat that was pre-set by the research team to match participants' estimated stride rate for the required distance. Estimations of stride rate were made using the digital video footage and adjustments were made to music tempi on a session-by-session basis if any mismatch was perceived (i.e., the tempo was increased slightly to account for participants' improving speed endurance).

When completing sprint repetitions, the synchronous music group self-initiated their effort immediately after the introductory section of the track that they were assigned (i.e., when the beat could be felt prominently in order to facilitate auditory-motor synchronization). Experimental participants were issued with explicit instructions to synchronize their stride rate with music tempo. Tracks were purposefully selected with short introductions to reduce the time required for the main beat to initiate. In between repetitions, participants in the synchronous music group were instructed to recover in silence. To gauge progress, after 2 weeks, participants underwent a second 400-m time trial without music. At the end of one month (i.e., at the beginning of Week 5), participants underwent a third and final 400-m time trial without musical accompaniment.

Immediately after each repetition and each time trial, the Feeling Scale and CR-10 RPE Scale were administered to each participant to assess her/his immediate psychological/psychophysical responses. After each time trial and each training session, the participant completed the PACES. This was administered at the end of the session but before the warm-down and the final Feeling Scale/RPE measures were administered prior to PACES. The synchronous music group (experimental group) completed the music-liking item after each training session. There was no music played during the three 400-m time trials, which took place at the beginning, middle, and end of the 1-month period of the study.

2.5 Data Analysis

Following data screening and the relevant diagnostic tests, a mixed-model, 2 (Group) × 2 (Time) ANCOVA was computed to ascertain the effects of the synchronous sprint training on 400-m time trial performance. The covariate used was time trial performance (s) from Time Trial 1. ANOVA with the same configuration was used for separate analyses of Feeling Scale, RPE, and PACES as they were not theoretically linked.[43] The decision to compute separate ANOVAs to compare affective and perceptual responses was predicated on the fact that affective valence, perceived exertion, and perceived enjoyment are independent constructs that are not adopted within an ecumenical theory.[43] Where the assumption of sphericity was violated, Greenhouse-Geisser adjustments were made to the relevant *F* tests. Bonferroni adjustments were applied to pairwise comparisons used to locate significant differences between groups and across time-points. The effects of synchronous music on psychological and psychophysical responses during the training sessions were analyzed by use of mixed-model 2 (Group) × 6 (Session) ANOVA. In this case, psychological/psychophysical measures were analyzed as a time series and averaged within training sessions to enable the research team to ascertain the overall effects of the synchronous music intervention. Effect sizes are reported as partial eta squared (η_p^2) values. As detailed by Cohen,[44] an effect size value lower or equal to .01 is considered "small", within the range .06–.14 is considered "medium", and > .14 is considered "large". Alpha was set at $p < .05$ and all statistical procedures were conducted using IBM SPSS 22.0.

3.0 Results

No univariate outliers were identified in the dataset ($z > -3.29$ and < 3.29). Participants considered the pieces of music to be moderately pleasant ($M = 6.42$, $SE = .75$). There was no significant higher-order interaction effect of Group × Time for RPE ($p = .898$, $\eta_p^2 = .03$; Table 3) or PACES ($p = .411$, $\eta_p^2 = .09$; Table 3) during the training sessions. A significant Group × Time interaction was identified for the Feeling Scale ($p = .007$, $\eta_p^2 = .27$; Table 3), that was associated with a large effect size. Nonetheless, following Bonferroni adjustment, the between-group differences in Feeling Scale scores were not sufficient for statistical significance to emerge (Session 1, $p = .323$; Session 2, $p = .939$; Session 3, $p = .926$; Session 4, $p = .261$; Session 5, $p = .139$; Session 6, $p = .074$).

Table 3

There was no significant higher-order interaction effect for task performance in the ANCOVA (Group × Time; $p = .891$, $\eta_p^2 = .00$; Fig. 1 and Table 4). Similarly, there were no significant Group × Time interaction effects for RPE ($p = .183$, $\eta_p^2 = .15$; Table 2), Feeling Scale ($p = .625$, $\eta_p^2 = .04$; Table 2), and PACES ($p = .101$, $\eta_p^2 = .20$; Table 2) immediately after time trial performances. However, the latter was associated with a large effect size.

Table 4

Figure 1

A significant main effect of Time was identified for Feeling Scale scores ($p < .001$, $\eta_p^2 = .39$; Table 1), with pairwise comparisons showing that there were marginal differences between Session 3 and Session 4 ($p = .048$) as well as Session 3 and Session 5 ($p = .035$). There was a significant main effect of Time for RPE ($p = .003$, $\eta_p^2 = .29$; Table 1), with pairwise comparisons indicating a difference between Session 1 and Session 6 ($p = .004$). However, there was no significant main effect of Group for RPE ($p = .535$, $\eta_p^2 = .04$). No significant effect of Group was identified for Feeling Scale scores ($p = .507$, $\eta_p^2 = .04$). There was no significant main effect of Time for PACES (p = .193, η_p^2 = .13) or Group (p = .807, η_p^2 = .00).

There was no significant main effect of Time for task performance (p = .875, η_p^2 = .00). There was also no main effect of Group for task performance (p = .212, η_p^2 = .35). However, the latter was associated with a large effect size (Table 4 and Figure 1).

There was no significant main effect of Time for Feeling Scale scores (p = .914, η_p^2 = .01) and no main effect of Group for Feeling Scale scores (p = .560, η_p^2 = .03). There was a significant main effect of Time for RPE (p = .001, η_p^2 = .53; Table 1), with pairwise comparisons showing that there were differences between Time Trial 1 and Time Trial 3 (p = .004) and Time Trial 2 and Time Trial 3 (p = .020). There was, however, no significant main effect of Group for RPE (p = .550, η_p^2 = .03). There was no significant main effect of Time for PACES (p = .218, η_p^2 = .14) and no main effect of Group for PACES (p = .817, η_p^2 = .00).

4.0 Discussion

The principal aim of this applied study was to examine the ergogenic and psychological effects of synchronous music applied to track-based, speed endurance training over a 1-month period. H_1 was not accepted as the experimental (synchronous music) group did not exhibit significantly better sprint performance when compared to the no-music control group. Nonetheless, it is notable that experimental group participants executed the second and third time trials 4.34% and 5.80% faster than control group participants, respectively (Table 4; η_p^2 = .35). Accordingly, it appears that a synchronous music-based training program did have a *meaningful* influence on speed endurance performance, albeit not one that was statistically significant.

It is also the case that H_2 is not supported by the present findings given that, although a significant (p = .007) Group × Time interaction emerged for Feeling Scale scores in the training sessions, follow-up pairwise comparisons indicated that no significant between-group differences were evident across sessions (see Table 3). Similarly, H_2 was also not supported in the case of PACES scores given the nonsignificant Group × Time interaction (see Table 3). In the time trials, none of which were conducted with music, again a Group × Time interaction did not emerge for either of the psychological variables (see Table 4). This finding suggests that any psychological benefits derived from auditory-motor synchronization in training sessions bore no influence on subsequent time trials (i.e., participants did not report enhanced affect as a consequence of superior regulation of running pace).

With reference to the psychophysical variable (RPE), H_3 was accepted, as there were no significant Group × Time interactions either in the training sessions or in the time trials (see Table 4). RPE scores were recorded to check that participants were working maximally, as intended, and from a theoretical standpoint, music is not expected to moderate RPE at exercise intensities that exceed the ventilatory threshold.[13,20] On the basis of the large effect sizes observed for performance *and* RPE, it can be deduced that experimental group participants were, generally, working harder during the training program and perceiving lower levels of exertion.

The main interest in the present study entailed the originality of setting a speed-endurance training program coordinated with music in apposition to a conventional speed-endurance program. Albeit that neither a significant Group × Time interaction nor main effect of group emerged for time trial performance (see Table 4), the latter effect was associated with a large effect size ($\eta_p^2 = .35$). The strong effect is noteworthy from a coach's perspective given the potential ergogenic effects observed when coordinating such a training program with the rhythmical qualities of music. Specifically, it seems that participants either made greater gains in speed endurance through the synchronous music-based training programme[12,19] or acquired better pace judgement[3] that they were able to capitalize upon during execution of their second and third time trials (see Figure 1).

When we examine the overall ergogenic effect associated with the application of synchronous music in training over the second and third time trials, it appears to confer a 5.07% performance benefit. In terms of time over 400 m, this equates with a 3.71-s benefit, which is five times larger than the benefit reported by Simpson and Karageorghis[12] (.68 s), who applied synchronous music *during* 400-m time trials. It is worth emphasizing that although the present participants were active in weight-bearing sports, they were not high-level track athletes and so their potential to derive performance benefits was greater than highly-trained individuals, who would have well-established motor patterns for the completion of 400 m.[36] Nonetheless, even a running-based study with elite athletes (Australian triathletes) demonstrated significant performance benefits when music was applied in the synchronous mode.[19]

The music-based training program employed in the present study was not sufficiently potent to influence the psychological variables of affective valence and enjoyment (see Table 3 and Table 4). This finding needs to be considered in light of the possibility that experimental participants might have worked at marginally higher intensities in the presence of music when compared to control participants. In other words, music-based training programs have the potential to lower the level of experienced pleasure given that participants are likely to work at higher intensities in response to upward adjustments in music tempo over time.[3,16] However, no statistically significant between-group differences were identified either for the Feeling Scale or PACES. It is known that music can exert a direct influence on emotion[45] and this can serve to moderate the potentially deleterious influence of fatigue-related signals on a participant's affective state (i.e., a type of compensatory response).[5] This phenomenon is supported in previous work, which demonstrated that even during high-intensity cycle ergometry, exercise can be perceived as more pleasant when performed in the presence of music.[21,26]

It is noteworthy that the within-subject variance in applied studies, such as the present one, is likely to be greater than that found in acute experimental manipulations, such as that used by Simpson and Karageorghis[12] (see Table 4 and Figure 1). Essentially, there is far less experimental control over what participants do and how they perform in applied research. However, it is also important to emphasize that applied studies hold greater ecological validity (i.e., application to real-life situations) when compared with laboratory-based approaches.[13,16] Accordingly, studies of this nature are extremely relevant for both coaches and exercise professionals, as they are more representative of real-life scenarios than their laboratory-based counterparts.[16,19] The ergogenic and psychological effects of music identified in laboratory settings are not easily replicated on the track due to situational demands and unforeseen circumstances (e.g., a coach's verbal instructions or fluctuating wind speed/direction).

Secondly, it is important to highlight that the effect size used in the power calculation for the present study was predicated on an acute, within-subjects crossover design.[12] It therefore appears reasonable to surmise that a sample size of 12 participants might not have been sufficient to test the effects of synchronous music applied over a 1-month period of speed endurance training. Nonetheless, this was the first experiment to have explored the long-term effects of synchronous music on psychological responses and performance outcomes. It was a logical initial decision to extract the effect size from an experimental study that was similar to the present study in terms of its purpose and design.

Thirdly, participants only considered the pieces of music to be *moderately* pleasant (M = 6.42, SE = .75). It is therefore conceivable that a music program scoring higher for pleasantness (i.e., > 8.00) would elicit greater psychological benefits than the music program employed in the present study. Findings from past studies indicate that when participants select their own music, psychological benefits are magnified;[22,28] however this also impacts heavily on internal validity given the possibilities for experimenter and expectancy effects.[15,36] Moreover, there is the possibility that granting participants autonomy in music selection serves to bolster their intrinsic motivation, which will have positive behavioral and affective consequences.[1] Studies that have allowed participants to self-select music can be criticized on several grounds, and it cannot be deduced that the music *per se* is eliciting any reported effects.[1,36]

5.0 Conclusions and Recommendations

The present findings indicate that the music-based training program enhanced running performance by ~5% on average when compared to control participants. However, no significant differences were identified in terms of performance, psychophysical, and psychological outcomes. Coaches and conditioning experts are encouraged to explore the benefits of music-fueled training programs on sprint-related performance. The methodological approaches employed to identify participants' stride rate and select appropriate music tracks could be replicated or suitably adapted from those described herein. It would be advantageous to train athletes or exercisers in beat perception in order to maximize the ergogenic effects and psychological benefits that they might derive from auditory-motor synchronization.

Hutchinson et al.[28] suggested that music-related interventions hold potential to elicit more positive affective memories and increase adherence when compared to training or exercise without music. Therefore, the need remains to examine whether music-based training programs can impact upon adherence and compliance behaviors.[9] Furthermore, there is now a need to assess the efficacy of synchronous music applications on more extensive training programs (e.g., 1 year), using a broad range of training/exercise modes (e.g., indoor cycling, rowing, and swimming) and metabolic demands (e.g., ultramarathons, middle-distance running, and resistance training).

6.0 References

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Table 1. Warm-up exercises and training program.

Warm-up Exercises	Time Trial Schedule and Training Program
Pulse-Raiser	**Week 1, Session 1:**
400-m jog at a self-paced speed	400-m habituation time trial
Stretching (~10 s for each exercise)	**Week 1, Session 2:**
Stretching of each major muscle group	Initial 400-m time trial (TT1)
Hands to toes drill (× 5)	**Week 2, Session 1:**
Lunge twists (× 10 each side)	3 × 300 m with 7-min recovery
Open/close books (× 5 each side)	**Week 2, Session 2:**
Sideway leg swings (× 5 each leg)	6 × 200 m with 3.5-min walking recovery
Forwards/backwards leg swings (× 5 each leg)	**Week 3, Session 1:**
Dynamic inchworm stretches (× 5)	Second 400-m time trial (TT2)
Basic Drills	**Week 3, Session 2:**
Skips forwards/backwards (× 20 m each)	2 × Split 400-m (200 m, 1-min rest, 200 m)
Sideways skips (2 × 20 m)	with 8-min recovery
Skips for height (× 20 m)	**Week 4, Session 1:**
Skips for length (× 20 m)	4 × 300-m with 6-min recovery
Dynamic Drills	**Week 4, Session 2:**
A-Skips (× 20 m)	7 × 200-m with 3-min walking recovery
A-Switch (× 20 m)	**Week 5, Session 1:**
Straight-leg run (× 20 m)	2 × Split 400-m (200 m, 45-second rest, 200 m)
Gluteal kicks (× 20 m)	with 8-min recovery
Running Preparation	**Week 5, Session 2:**
Sprint stride (2 × 40 m)	Final 400-m time trial (TT3)

Note: A split 400 m entails the participant running 200 m all-out, taking a prescribed recovery period during (i.e., 45 or 60 *s*), then running the second 200 m all-out. A-Skips are a commonly used dynamic warm-up exercise (also known as "high-knee skips") in which the participant skips while driving the alternate knee up to abdomen level. Concurrently, the elbow of the arm opposing the rising knee is driven back (see https://m.youtube.com/watch?v=YFGw5pTcUl4). A-Switch is a similar drill to A-Skips but in this instance the participant does not skip in between alternating phases of driving the knee up and the elbow of the opposing arm back (see https://m.youtube.com/watch?v=8hF3J-wVDVg).

Table 2. Details of music selections used in experimental conditions.

Artist	Track	bpm	Start of Main Beat
Rita Ora, Tinie Tempah	R.I.P.	72	00:02
Trey Songz	Bottoms Up	74	00:16
Rag‘n’Bone Man	Human	75	00:00
Shawn Mendes	Stitches	75	00:32
Kendrick Lamar	Humble	75	00:07
Justin Timberlake	Mirrors	77	00:25
The Chainsmokers feat. Daya	Don’t Let Me Down	80	00:12
Miley Cyrus	We Can’t Stop	80	00:24
DJ Khaled feat. Justin Bieber, Quavo, Chance The Rapper & Lil Wayne	I’m The One	81	00:00
Niall Horan	Slow Hands	86	00:00
Little Mix feat. Stormzy	Power	86	00:11
James Arthur	Emergency	87	00:00
Macklemore & Ryan Lewis	Make The Money	88	00:32
Luis Fonsi & Daddy Yankee feat. Justin Bieber	Despacito (remix)	89	00:09
Selena Gomez	Good For You	89	00:33
Jason Derulo	Ridin’ Solo	90	00:11
21 Pilots	Heathens	90	00:27
Sia	Cheap Thrills	90	00:05
Gym Class Heroes feat. Adam Levine	Stereo Hearts	90	00:24
Rihanna feat. Drake	Work	92	00:10
B.o.B, Haley Williams	Airplanes	93	00:10
Flo Rida	My House	94	00:10
Chain Smokers feat. Halsey	Closer	95	00:10
Drake	Find Your Love	96	00:00
Ed Sheeran	Shape Of You	96	00:05
Lady Gaga feat. R Kelly	Do What U Want	97	00:00
Jason Derulo feat. Nicki Minaj & Ty Dolla $ign	Swalla	98	00:02
French Montana feat. Swae Lee	Unforgettable	98	00:10
Major Lazer & DJ Snake feat. MØ	Lean On	98	00:29
Maroon 5	This Summer	99	00:20
Justin Beiber	Sorry	100	00:10
Jason Derulo feat. 2 Chainz	Talk Dirty	100	00:12
Rihanna feat. Drake	What’s My Name?	100	00:10
Kygo & Selena Gomez	It Ain’t Me	100	00:29
Shakira	Hips Don’t Lie	100	00:10
Calvin Harris feat. Pharrell Williams, Katy Perry & Big Sean	Feels	101	00:12
J Balvin & Willy William	Mi Gente	103	00:09
Usher, Lil Jon, Ludacris	Yeah!	105	00:01
Deamn	Give Me Your Love	105	00:28
Camila Cabello, Young Thug	Havana	105	00:00
Martin Garrix, Troye Sivan	There For You	106	00:09
Drake	Come Thru	106	00:00
Rita Ora	Anywhere	107	00:00
Bruno Mars	24K Magic	107	00:26
The Black Eyed Peas	Let’s Get It Started	108	00:28
John Newman	Come and Get It	109	00:09
Sia	The Fight	109	00:19
Galantis	Rich Boy	110	00:09
Charlie Puth	How Long	110	00:00
Jason Derulo	Get Ugly	111	00:03

Table 3. Descriptive statistics for dependent variables under each condition and for each training session.

	Feeling Scale ($M \pm SE$)		RPE ($M \pm SE$)		PACES ($M \pm SE$)	
	CO	MU	CO	MU	CO	MU
Session 1	1.66 ± 0.72	2.55 ± 0.45	5.94 ± 0.86	5.77 ± 0.60	85.50 ± 10.62	93.33 ± 6.06
Session 2	2.05 ± 0.77	1.97 ± 0.73	7.36 ± 0.37	6.47 ± 0.31	92.33 ± 6.81	92.66 ± 4.47
Session 3	2.25 ± 0.38	2.33 ± 0.78	6.91 ± 0.43	7.00 ± 0.60	81.16 ± 7.70	93.50 ± 6.42
Session 4	1.45 ± 0.46	0.21 ± 0.93	7.16 ± 0.29	6.87 ± 0.49	82.33 ± 9.09	81.66 ± 5.05
Session 5	1.64 ± 0.39	0.24 ± 0.78	7.16 ± 0.55	6.69 ± 0.48	97.33 ± 6.84	90.66 ± 4.96
Session 6	1.91 ± 0.54	0.41 ± 0.52	8.08 ± 0.94	7.50 ± 0.54	88.83 ± 5.90	87.00 ± 6.51

Note: RPE = Rating of Perceived Exertion; PACES = Physical Activity Enjoyment Scale; CO = Control condition; MU = Music Condition; *M* = Mean; *SE* = Standard error.

Table 4. Descriptive statistics for dependent variables under each condition and for each time trial.

	Performance ($M \pm SE$)		Feeling Scale ($M \pm SE$)		RPE ($M \pm SE$)		PACES ($M \pm SE$)	
	CO	MU	CO	MU	CO	MU	CO	MU
Time Trial 1	77.08 ± 4.64	74.51 ± 6.18	2.17 ± 0.70	2.00 ± 0.44	5.67 ± 0.98	7.50 ± 1.02	88.00 ± 4.35	95.83 ± 5.50
Time Trial 2	76.75 ± 4.29	73.49 ± 4.93	1.83 ± 0.87	1.67 ± 1.20	8.00 ± 0.57	8.77 ± 0.47	90.66 ± 9.06	98.16 ± 5.60
Time Trial 3	73.73 ± 4.32	69.57 ± 4.95	2.67 ± 0.76	1.17 ± 1.42	10.33 ± 0.42	9.50 ± 0.62	105.50 ± 4.66	94.83 ± 5.60

Note: RPE = Rating of Perceived Exertion; PACES = Physical Activity Enjoyment Scale; CO = Control condition; MU = Music condition; *M* = Mean; *SE* = Standard error.

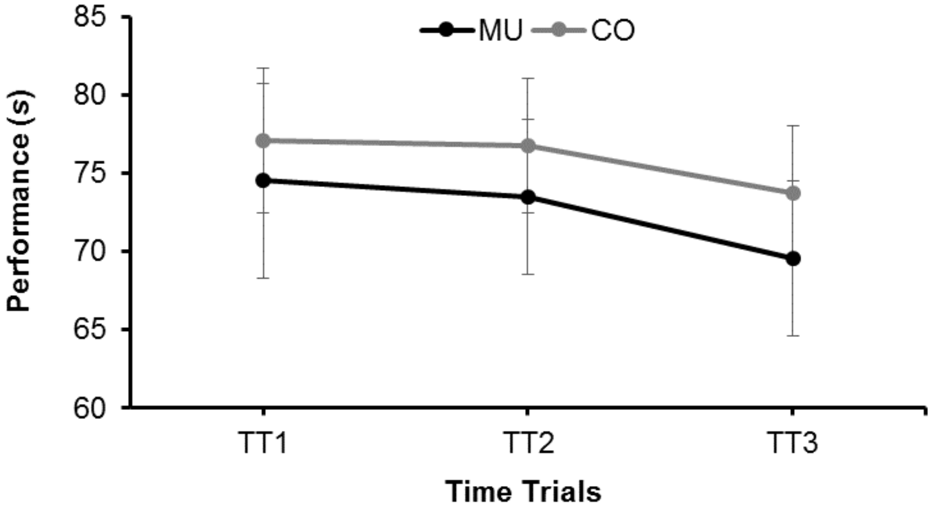

Figure 1. Mean 400-m times by group across three time trials.
Note: s = Seconds. MU = Music condition; CO = Control condition. TT1 = Initial 400-m time trial; TT2 = Second 400-m time trial; TT3 = Final 400-m time trial. Error bars denote standard error.