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Effects of synchronous music on treadmill running among elite triathletes

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Abstract

Objectives: Music can provide ergogenic, psychological, and psychophysical benefits during physical activity, especially when movements are performed synchronously with music. The present study developed the train of research on synchronous music and extended it to elite athletes. *Design*: Repeated-measures laboratory experiment. *Method*: Elite triathletes ($n = 11$) ran in time to self-selected motivational music, a neutral equivalent and a no-music control during submaximal and exhaustive treadmill running. Measured variables were time-to-exhaustion, mood responses, feeling states, RPE, blood lactate concentration, oxygen consumption and running economy. *Results*: Time-to-exhaustion was 18.1% and 19.7% longer, respectively, when running in time to motivational and neutral music, compared to no music. Mood responses and feeling states were more positive with motivational music compared to either neutral music or no music. RPE was lowest for neutral music and highest for the no-music control. Blood lactate concentrations were lowest for motivational music. Oxygen consumption was lower with music by 1.0%–.7%. Both music conditions were associated with better running economy than the no-music control. *Conclusions:* Although neutral music did not produce the same level of psychological benefits as motivational music, it proved equally beneficial in terms of time-to-exhaustion and oxygen consumption. In functional terms, the motivational qualities of music may be less important than the prominence of its beat and the degree to which participants are able to synchronise their movements to its tempo. Music provided ergogenic, psychological and physiological benefits in a laboratory study and its judicious use during triathlon training should be considered.

Keywords: Ergogenic; Mood; Motivational music; Psychology; Rhythm; Synchronisation

1. Introduction

Music-related research in a sport context can be categorised according to the degree of synchronicity between movement patterns and music tempo. When used *synchronously*, rhythmic aspects of music provide a stimulus that regulates movement temporally. Contrastingly, when music is used *asynchronously*, it provides background stimulation without conscious synchronisation between movement patterns and musical tempo.[1] Music has been shown previously to provide ergogenic (i.e., increased work output), psychological (e.g., enhanced emotional responses), psychophysical (i.e., reduced perceived exertion) and psychophysiological (e.g., improved oxygen consumption) effects in sport and exercise contexts.[2–4]

The natural predisposition of humans to respond to the rhythmical qualities of music has long been acknowledged.[5] Karageorghis and colleagues referred to this phenomenon as *rhythm response* during development of the Brunel Music Rating Inventory, a measure used to rate the motivational qualities of music.[6,7] It has been postulated that a stable psychological pattern is instigated when listening to music that serves as a dynamic representation of the temporal structure of the rhythm,[8] which may lead, for example, to the synchronisation of musical tempo and a runner's stride.

Previous studies have tested effects of synchronous music, with ergogenic effects reported in treadmill walking,[9] cycle ergometry,[10] and 400-m running.[11] Synchronous use of music represents a form of auditory-motor synchronisation in which a runner and the music serve as oscillators; each gen-

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erating its own rhythm yet sharing a common frequency.[12] Based on an initial frequency mismatch, a runner can adjust stride rate to the tempo of the music using the supplementary motor area of the brain, which plays a central role in both the perception of musical rhythm and the rhythmic ordering of motor tasks.[13]

Karageorghis et al.[9] examined effects of synchronous music on endurance, RPE, in-task affect, and exercise-induced feeling states during inclined treadmill-walking at 75% of maximal heart rate reserve. Motivational synchronous music enhanced in-task affect throughout the exercise bout yet only lowered RPE in the very early stages of the task. This finding was consistent with theoretical predictions, as physiological feedback relating to fatigue tends to dominate attention at high exercise intensities.[14] The ergogenic effect of the motivational music produced a 15% increase in time-to-exhaustion over the no-music control and a 6% increase over neutral music. Motivational music is generally of higher tempo (>120 bpm), has catchy melodies, inspiring lyrics, an association with sporting endeavour, and a bright, uplifting harmonic structure.[1] By contrast, neutral music would be perceived to have few, if any, of these characteristics although it would not be rated as demotivational.

Synchronous music may reduce the energy cost of exercise by promoting greater neuromuscular metabolic efficiency.[13] Regular movement patterns require less energy to replicate due to muscle relaxation and the absence of minor adjustments requiring anticipatory movements and corrections. Simpson and Karageorghis[11] tested the ergogenic effects of synchronous music during a 400-m track run using a race-like protocol. Motivational and neutral music elicited faster times than the no-music control, suggesting that motivational qualities are not pivotal during anaerobic endurance tasks; a logical finding given the aforementioned attentional theories.[14]

The present study was the first to examine effects of synchronous music with high-level athletes. A group of triathletes from the Queensland Academy of Sport (QAS) was tested during treadmill running, using a range of indices under conditions of self-selected motivational music, music of the same tempo that was neutral in motivation terms, and a no-music control. It was hypothesised that motivational music would yield the most positive outcomes, followed by neutral music and the no-music control.

2. Methods

Baseline testing was conducted to establish aerobic capacity, blood lactate threshold velocity (modified Dmax method, Adapt 1995)[15] and individual stride rates at different running velocities. The baseline test included 4–5 sub-maximal steps (e.g., 12, 13, 14 and 16 km h^{-1}) each of 4-min duration followed, after a 4-min break, by a rapid ramp to exhaustion commencing 3 km h^{-1} below the final sub-maximal velocity and increasing in velocity then grade every 30 s. Baseline testing also served to habituate participants to the test environment. A Payne wide-bodied treadmill (Stanton Engineering, Sydney, Australia) set at 0% grade was used for all testing.

Oxygen consumption was assessed continuously using an Applied Electro Chemistry Moxus metabolic cart (AEI Technologies, Pittsburgh, PA), with the average of the final minute of each stage reported. Gas analysers were calibrated immediately before each trial. An OptoJump light sheet timing system (Microgate, Bolzano, Italy) was fitted to the treadmill bed and used to confirm stride rates for each participant at each running velocity. Blood lactate analysis was performed with a hand-held, strip-based system (Lactate Pro, Arkray Inc., Japan) from samples collected from warm/hyperaemise earlobe after puncture with sterile lancet, according to methods recommended by the Australian Sports Commission.[16]

Participants were six male and five female elite triathletes, aged 19.5 ± 2.3 years (mean ± SD), with $\dot{V}O_2$ peak scores ranging from 58.6 to 72.6 mL kg^{-1} min^{-1}. Each participant completed three test trials (no music, neutral music, motivational music) in counterbalanced order at the same time of day, commencing with a 5-min warm-up at 10–12 km h^{-1}, followed by three 4-min periods of submaximal running at progressively faster velocities (e.g., 14, 16 and 18 km h^{-1}) with a 2-min break in between. Velocities for the three submaximal running periods equated to approximately 76%, 82% and 87% $\dot{V}O_2$ peak, for each participant. Finally, after a 5-min break, participants completed a run-to-exhaustion at approximately 110% of blood lactate threshold velocity (99% $\dot{V}O_2$ peak), adjusted to the nearest .5 km h^{-1}.

To compare running economy across conditions for the submaximal running stages, oxygen consumption was normalised for each participant using allometric scaling.[17,18] We followed the recommendation of Svedenhag and Sjodin[18] and based our running economy index on .75 power of mass (mL kg$^{\cdot 75}$ min^{-1} km^{-1} h^{-1}). Other measures were taken after each 4-min period of running and after the run-to-exhaustion, for RPE, in-task affect, and blood lactate concentration, which was also assessed prior to the test. Mood responses were assessed prior to and following each test. Time-to-exhaustion was recorded using a Prisma 200 hand-held stopwatch (Hanhart, Diessenhofen, Germany).

Music was played via a laptop computer using Virtual DJ software (Atomix Productions, Los Angeles, USA) with two SP-965 multi-media speakers (KTX, Sydney, Australia) placed at 45° angles in front of the triathletes. Volume was standardised at 75 dB (ear level) which is safe from an audiological perspective[19] but loud enough to be heard clearly above the treadmill noise. Prior to testing, a selection of musical tracks of appropriate tempi for various running velocities was presented to participants (see Appendix A). Given the rapid stride rates of participants (158.6–194.4 min^{-1}) music was selected to which athletes could synchronise their stride on the half beat rather than the full beat (i.e., two strides per beat). Therefore, the tempo of tracks available to participants fell in the range of 80–97 bpm.

Using the Brunel Music Rating Inventory-2 (BMRI-2),[7] participants rated tracks as motivational or neutral. Tracks

Table 1
Performance, RPE and physiological data for 11 elite triathletes under two music conditions and a no-music control. Data expressed as mean (standard deviation).

	Motivational	Neutral	No music	Effect size (d) vs no-music	
				Motivational	Neutral
Time-to-exhaustion (s)	509.00 (50.25)	516.00 (47.02)	431.45 (46.15)	.50	.54
RPE – 4 min	10.64 (1.50)	10.36 (1.03)	10.73 (1.42)	.11	.39
RPE – 10 min	12.00 (1.41)	11.64 (.67)	11.91 (1.51)	−.09	.19
RPE – 16 min	13.09 (1.45)	13.00 (.87)	13.36 (1.21)	.19	.29
RPE – exhaustion	17.91 (1.64)	17.82 (1.54)	17.73 (2.20)	−.10	−.06
Lactate – pre-test (mmol l^{-1})	1.03 (.35)	1.02 (.36)	1.03 (.40)	−.01	.05
Lactate – 4 min (mmol l^{-1})	1.48 (.41)	1.47 (.48)	1.46 (.42)	−.06	−.02
Lactate – 10 min (mmol l^{-1})	1.49 (.35)	1.66 (.48)	1.63 (.41)	.37	−.13
Lactate – 16 min (mmol l^{-1})	1.99 (.44)	2.19 (.62)	2.01 (.37)	.07	−.34
Lactate – exhaustion (mmol l^{-1})	6.47 (1.69)	6.16 (2.83)	5.94 (2.14)	−.15	−.06
$\dot{V}O_2$ – 4 min[a] (mL kg^{-1} min^{-1})	46.36 (3.17)	46.24 (2.82)	46.85 (4.00)	.16	.28
$\dot{V}O_2$ – 10 min[a] (mL kg^{-1} min^{-1})	49.88 (2.97)	49.20 (3.12)	50.13 (4.15)	.07	.38
$\dot{V}O_2$ – 16 min[a] (mL kg^{-1} min^{-1})	53.80 (3.09)	52.86 (3.39)	54.33 (4.49)	.13	.51
$\dot{V}O_2$ – exhaustion[a] (mL kg^{-1} min^{-1})	63.72 (4.62)	63.04 (5.43)	64.16 (5.32)	.09	.21
Running economy[a] (mL $kg^{\cdot 75}$ min^{-1} km^{-1} h^{-1})	10.12 (.99)	9.19 (1.68)	10.63 (1.92)	.29	.64

[a] Based on data from 10 participants.

rated ≥36 on the BMRI-2 (possible range 6–42) were used as motivational music. Tracks rated from 18–30 were used as neutral music. Tracks rated from 31–35 were not used because it was unclear whether they were motivational or neutral. Tracks rated <18 were considered to be potentially demotivational and were not used. The tempo of selected tracks was adjusted where necessary (±≤4 bpm) to ensure an exact match to the stride of the participant.

RPE was assessed verbally using the original Borg scale[20] with incremental descriptors of perception of effort ranging from 6 "no exertion at all" to 20 "maximal exertion". Satisfactory intra-test (r = .93) and re-test (r = .83–.94) reliability for the scale has been established.[20] In-task affect was assessed using the Feeling Scale, which was designed specifically for exercise contexts.[21] It is an 11-point, single-item scale ranging from +5 (*very good*) to −5 (*very bad*) with a midpoint of 0 (neutral); validity was supported in three studies.[21] Mood responses were assessed using the Brunel Mood Scale (BRUMS), a 24-item inventory assessing anger, confusion, depression, fatigue, tension and vigour. Satisfactory psychometric characteristics were demonstrated in two validation studies.[22,23]

To help standardise dietary intake, which was monitored over the 24 h preceding each test, each participant was provided with 3× $20 food vouchers. To reduce attrition, those who completed all tests were eligible to win one of three $100 raffle prizes. The elite population under study inevitably limited the availability of participants, which reduced statistical power and the probability of finding significantly different outcomes among the three conditions. Effect sizes (Cohen's d) were therefore used in preference to p values to quantify differences among conditions, a strategy endorsed by several research methodologists and statisticians.[24,25] Cohen's d represents the difference between group means divided by the pooled standard deviation. An effect size of .2 is considered small, .5 is considered moderate, and .8 is considered large.[26]

All procedures used in the study met the ethical standards of the Australian Psychological Society and were formally approved by the University of Southern Queensland Human Ethics Committee (ethics approval #H09REA095). Participants provided written informed consent prior to testing. The QAS provided laboratory facilities, access to participants, plus scholarship and research costs.

3. Results

Table 1 includes descriptive statistics and between-condition effect sizes for time-to-exhaustion, RPE and physiological indices (blood lactate concentration, oxygen consumption, running economy) at the various time points. During the three periods of submaximal running, the same amount of work was completed by the triathletes for each condition. Notably, during the time-to-exhaustion trial, participants endured for more than a minute longer while running in time to motivational music when compared to the no-music condition (mean ± SD, 78 ± 47 s), representing an 18.1% improvement in performance. Neutral music was also superior at prolonging endurance performance when contrasted with the no-music control (85 ± 47 s), a 19.7% improvement.

Music did not benefit every participant, with some enduring longer in the no-music condition than either music condition. Among eight participants who ran for longer with music, their mean improvement was greater (149 ± 32 s for motivational music and 157 ± 34 s for neutral music) compared to the mean decline in performance among three participants who reached exhaustion faster when running to music (108 ± 91 s for motivational music and 106 ± 74 s for neutral music). Of the three participants whose time-to-exhaustion was *slower* with music, two were identified as statistical outliers, one each for the motivational and neutral music conditions. Removal of one outlier from each con-

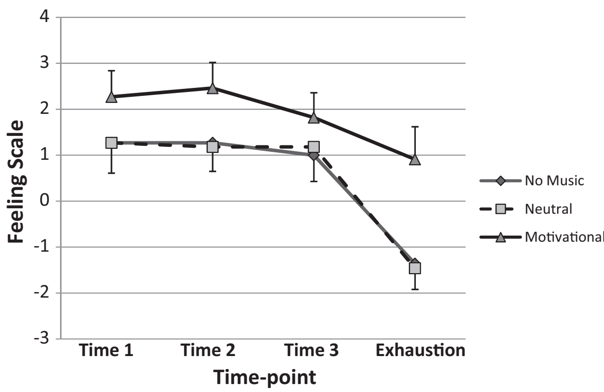

Fig. 1. Feeling Scale scores of triathletes under two music conditions and a no-music control condition.

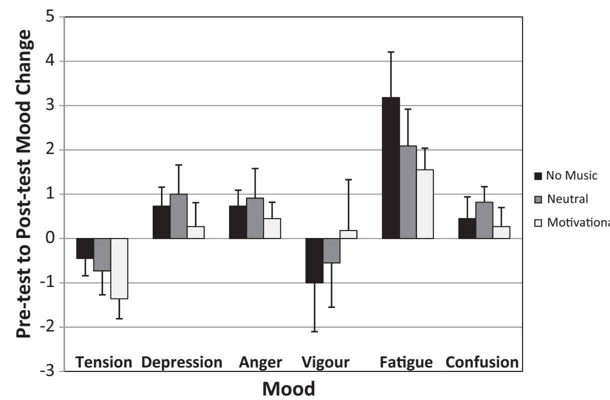

Fig. 2. Mood changes of triathletes from pre- to post-testing under two music conditions and a no-music control condition.

dition saw mean improvement in time-to-exhaustion rise to 115 s (±33 s) and 119 s (±37 s) for motivational and neutral music, respectively, while the mean decline for the two remaining participants who endured longer without music fell to a negligible level.

Small-to-moderate variations in RPE were evident among the three conditions. Perceived exertion was lower for neutral music compared to the no-music control after each of the three submaximal phases (d = .39, .19, .29, respectively). Motivational music was associated with a small reduction in perceived exertion compared to no music, after the third submaximal period (d = .19). Blood lactate concentrations remained almost identical across the three conditions at the first two time-points. Motivational music was associated with lower blood lactate concentrations after the second period of submaximal running compared to the no-music control (d = .37), and lower blood lactate concentrations after both the second and third periods of submaximal running compared to neutral music (d = .57, .42, respectively).

Compared to the no-music condition, oxygen consumption during the first period of submaximal running was lower when running in time to either neutral music (1.3% less) or motivational music (1.0% less). During the second period of submaximal running, oxygen consumption was 1.9% lower for neutral music compared to no music. During the third submaximal running phase, oxygen consumption was lower for neutral music (2.7%) and motivational music (1%) compared to no music. In terms of running economy over the three submaximal phases, motivational music was associated with a small-to-moderate benefit over no music (d = .29), and neutral music was associated with a moderate-to-large benefit compared to the no-music control (d = .64).

Fig. 1 shows Feeling Scale scores for the three conditions over the course of the running test. Feelings remained more positive throughout with motivational music compared to either neutral music or no music. No differences were evident between neutral music and no music. Feeling states became less positive as the test progressed, particularly after the run-to-exhaustion. Compared to the no-music control, the benefit of motivational music was moderate at time points 1 (d = .49), 2 (d = .60), and 3 (d = .45), and very large immediately after the run-to-exhaustion (d = 1.08). Compared to neutral music, the benefit of motivational music was moderate at time point 1 (d = .49), large at time 2 (d = .78) and very large after the run-to-exhaustion (d = 1.23). Notably, feelings remained positive (i.e., above neutral) throughout the test even after the run-to-exhaustion with motivational music but became negative for the other two conditions after the run-to-exhaustion.

Fig. 2 illustrates how mood responses changed from pre-test to post-test. Generally, participants reported increases in depressed mood, anger, fatigue and confusion, and decreases in tension and vigour from pre-test to post-test. Compared to the no-music and neutral music conditions, motivational music was associated with greater reductions in tension (d = .50, .38, respectively). In addition, motivational music curtailed increases in depressed mood, anger and confusion when contrasted with the other two conditions, although these effects were small. Notably, vigour scores fell in both the no-music and neutral music conditions but rose slightly with motivational music (d = .34; no music v motivational music). Compared to running without music, increases in fatigue after the run-to-exhaustion were reduced when running with neutral music (d = .31) or motivational music (d = .43), even though more work was completed under the two music conditions.

4. Discussion

Results demonstrated potential benefits to elite athletes of running in time to music across a range of indices, partially supporting the research hypothesis. Motivational music produced the most positive results overall, but for some indices neutral music was equally or more effective. Music increased time-to-exhaustion by well over a minute. This scale of improvement is undoubtedly meaningful in absolute terms and also replicates recent findings.[9] Results were generally consistent with those reported among other athletic populations engaged in similar exercise modalities, although for some indices beneficial effects were larger than those reported previously.[2,10] Synchronous music may potentially provide benefits in other submaximal and performance-to-exhaustion activities, including swimming, cycling and rowing. Although neutral music did not, on the whole, produce the same level of psychological benefits as motivational music, it proved equally beneficial in terms of performance-to-exhaustion and oxygen consumption. In functional terms, therefore, the perceived motivational qualities of music may be less important than, for example, the prominence of its beat and the degree to which participants are able to synchronise their movements to its tempo.[3,11]

Motivational music was clearly associated with more positive mood responses and feeling states compared to neutral music and no music. This echoes previous findings incorporating a similar task.[9] The heterogeneity of music selections makes it impossible to discern which musical (e.g., tempo, lyrics) or extra-musical qualities (e.g., associations) were responsible for the more positive affective responses. For identical workloads, perceived exertion was shown to be lowest for neutral music and highest for the no-music control. The magnitude of RPE differences was generally small, which is unsurprising given that RPE was assessed at moderate-to-high work intensities.[14] Overall, it appears that triathletes perceived similar levels of exertion in each condition but enjoyed the experience more when running to music; a finding that underlines the importance of *how* rather than *what* one feels during exercise.[21]

Neutral music was associated with lowest oxygen consumption, whereas motivational music was associated with lowest blood lactate concentrations. Given that the physiological testing protocol has an error range of approximately $\pm 3\%$, the meaningfulness of reductions in oxygen consumption of 1.0–2.7% is uncertain. Nevertheless, the trend towards beneficial effects was consistent, indicating that music may have potential to improve physiological efficiency by a small but important margin. Viewed in tandem with the superior economy associated with music, effects of synchronous music on physiological functioning may have practical value at the highest levels of competition due to the homogenous physiological characteristics of elite athletes.

Previous research has typically not identified physiological benefits of music in exercise settings[27,28] perhaps because physiological responses to music are very small relative to responses to exercise itself. There are precedents for the current findings, however, where observed physiological benefits were explained in terms of muscle relaxation and movement efficiency.[4] Few studies have investigated the impact of music on physiological indices among elite performers and, hence, further work with larger samples appears timely and warranted. Individual differences in responses to music found in the present investigation suggest that not all elite athletes will experience benefits from synchronous music.

The varied results obtained for motivational and neutral music were a feature of our study. It is possible that some tracks were rated as neutral because they were less familiar to participants rather than being less motivational *per se*. During the treadmill running tests, the novel stimuli of the neutral music may have occupied a greater proportion of participants' attentional capacity than the more familiar motivational music (i.e., a greater distraction effect), which might explain the lower RPEs associated with neutral music.

The laboratory setting of the present study enhanced internal validity but was a threat to ecological validity. Given the relative lack of visual stimulation in a laboratory compared to outdoors, the observed ergogenic and affective benefits might represent music relieving the tedium of a repetitive task rather than distraction from signals of exertion. Hence, replication during outdoor running would be advantageous. Another potential limitation is that preferred attentional style, which was not assessed, may affect responses to music. Elite endurance athletes tend to be associators rather than dissociators[29] and hence may stand to benefit less from external cues such as music. Finally, given the widespread use of music by athletes, it is possible that demand characteristics[30] may help to explain the observed psychological benefits of music, although they do not explain time-to-exhaustion improvements and physiological benefits nor do they explain fully why motivational music was associated with more positive mood responses and feeling states than neutral music.

5. Conclusion

Results of the present study are encouraging because they serve to highlight the potential importance of music in aiding the running experience and performance of elite athletes, a population that was previously understudied in this context. Music provided ergogenic, psychological and physiological benefits during intense aerobic work and these benefits are probably interlinked (e.g., more positive mood and lower RPE leads to greater endurance). There is considerable scope for the further investigation of ergogenic and psychological effects of music in other endurance sports (e.g., swimming, cycling and rowing) and in repetitive training activities (e.g., circuit training/resistance training). Researchers should consider the neurophysiological mechanisms by which music produces such effects.

Practical implications

- Use of synchronous music during triathlon training should be considered.
- Elite athletes should be encouraged to select their own motivational music.
- Ensure that music tempo corresponds with the desired movement tempo.
- Running gait analysis may assist choice of music with optimal tempo for different running cadences.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2011.06.003.

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