Journal of Science and Medicine in Sport 27 (2024) 276–280

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

The effects of pre-task music on choice visual reaction time in elite taekwondo athletes

Francesca Greco [a], Federico Quinzi [b,*], Salvatore Chiodo [b], Claudia Cerulli [a], Eliana Tranchita [a], Maurizio Bertollo [c], Gian Pietro Emerenziani [b]

[a] Department of Movement, Human and Health Sciences, University of Rome "Foro Italico", Italy
[b] Department of Clinical and Experimental Medicine, University of Catanzaro "Magna Græcia", Italy
[c] Department of Medicine and Aging Sciences, Behavioral Imaging and Neural Dynamics Center, University "G. d'Annunzio" of Chieti-Pescara, Italy

ARTICLE INFO

Article history:
Received 25 July 2023
Received in revised form 1 December 2023
Accepted 8 January 2024
Available online 11 January 2024

Keywords:
Martial arts
Feeling scale
Felt arousal scale
Heart rate
Response time
Combat sport

ABSTRACT

Objectives: The effects of music on sport performance mainly involved endurance or resistance exercises overlooking possible effects on reaction time, which is deemed essential in martial arts for a proficient performance. Therefore, the aim of this study was to investigate the effects of the exposure to pre-task music on choice visual reaction time in elite taekwondo athletes.
Design: Repeated measure study design.
Methods: Reaction time and mean Heart Rate (HR_{mean}) were recorded in twenty young taekwondo athletes (17.5 ± 2.5 years old) while performing a roundhouse kick in response to different visual stimuli after three warmup conditions: listening to self-selected music (SM), research-selected music (RM) or no music (CC). Moreover, Feeling Scale (FS), Felt Arousal Scale (FAS) were recorded before (T_0) and after warmup (T_1) in each testing session.
Results: SM and RM elicited significantly faster reaction times compared to CC (−3.3 % and −5.2 %, respectively). No significant difference in reaction time was observed between SM and RM. The FS and FAS scores were significantly higher at T_1 compared to T_0 in the SM and RM conditions, whereas no difference between T_0 and T_1 was observed in the CC condition. No difference was observed for HR_{mean} between SM, RM and CC conditions.
Conclusions: Listening to SM and RM during the warmup improved choice visual reaction times in elite taekwondo athletes. These results suggest the use of music as a performance-enhancing strategy prior to combat competition or training in martial arts.

Practical implications

- Listening to self-selected and motivational music during the warmup improved choice visual reaction times in elite taekwondo athletes.
- A change from a pleasant low-activation state to pleasant high-activation state was observed only with music.
- Warmup music may be a performance-enhancing strategy prior to combat competition in martial arts.

1. Introduction

The effects of music have been extensively investigated especially in the context of performance enhancement (for comprehensive reviews see [1,2]) in endurance sports. Different music factors such as rhythmic response[3] (tempo > 120 beats per minute (bpm)), musicality, cultural impact, and emotional responses may influence sport performance[4] through several psychophysiological mechanisms of action. It has been shown that motivational music (fast tempo and strong rhythm) reduces the subjective perception of fatigue during exercise, possibly by reducing the processing of interoceptive signals or by reorienting the attentional focus toward task-irrelevant information.[5] Moreover, music stimuli improve mood states[4] and regulate the psychomotor arousal.[6–8] Interestingly, it has been shown that arousal state influences also reaction time,[9,10] thus an upregulation of the arousal state to an optimal level would increase the performance in reaction time task. It is worth noting that musical preference may also affect the link between a musical stimulus and the individual affective responses to it.[2,11] Specifically, familiarity with a song, due to its influence on feeling status, may strengthen the effects of rhythmic response on performance enhancement.[2,12] Therefore, using self-selected music may represent an effective and alternative strategy to improve exercise performance. However, it is unclear whether the main effect of music on performance is due to its intrinsic characteristics or by the evoked affective responses (i.e., arousal and feeling states).

* Corresponding author.
E-mail address: fquinzi@unicz.it (F. Quinzi)
@FraGre97.

https://doi.org/10.1016/j.jsams.2024.01.002
1440-2440/

Noteworthy, music is also classified according to the time of administration with respect to the task. Indeed, several studies have focused on the effects of listening to music during (in-task) and prior to (pre-task) a given task.[12–14] Pre-task music seems to be particularly suitable for elite athletes.[14] Indeed, as reported by Laukka,[14] athletes prefer listening to music in the pre-competition preparation and during the warmup phases. Moreover, pre-task music is eligible for a variety of sports in which music cannot be applied during the activity, such as team or combat sports.

In these latter, proficient performance relies also on fast reaction time (RT). Indeed, athletes must be able to perform powerful kicks or punches within an extremely brief time[15] often in response to an opponent's attack. Moreover, combat sport athletes continuously undergo to speeded (i.e., react as fast as possible) decision-making processes to choose the most effective technique to be performed at the right time in response to the opponent's action. The crucial role of RT has been also evidenced by cross-sectional studies that showed the importance of a fast RT in different combat sports in athletes.[16–18] In taekwondo, as in other combat sports, RT represents a cornerstone between being successful or not. Moreover, performing or not the correct technique according to the opponent's movement is a fundamental skill for proficient performance. This is confirmed by the increasing number of studies that focused on RT in taekwondo athletes. This body of evidence has focused on the effect of experience,[16] fatigue[19] and muscle activation[16,20] on RTs during the roundhouse kick. The roundhouse kick, either performed at waist or head level, is one of the most commonly performed kicking technique in Taekwondo combat competitions[17,21] as well as in other martial arts.[22,23] In this framework, the evaluation of the effectiveness of novel methods to shorten RT in combat sports may mark the difference between being a gold medalist or a runner-up. Since different music stimuli may influence affective responses (i.e., feeling status and arousal state) and RT differently, the aim of this study is to assess the effects of self-selected and research-selected music (motivational music) administered during the warmup on subsequent visual choice reaction time and affective responses in elite taekwondo athletes. We hypothesize that listening to research-selected music prior to a visual reaction time task would increase affective responses (i.e., feeling status and arousal state) and thus reduce RT.

2. Methods

Twenty young elite taekwondo (Olympic style) athletes volunteered to participate in this study (mean ± standard deviation (SD): age = 17.5 ± 2.5 years; height = 1.69 ± 0.10 m; body mass = 63.6 ± 12.1 kg). An a priori sample size estimation performed using G-Power 3.1 showed that eighteen participants were sufficient to achieve a statistical power of $\beta = 0.80$ (medium effect size of 0.25). Participants had an average experience in taekwondo of 9.9 ± 4.0 years, sixteen of them were black belt (nine were ranked second Dan, and seven were ranked first Dan black belt) while the remaining four were red belt. Sixteen athletes were competing at national level, while the remaining were competing at international and regional levels. Participants attended 5.0 ± 1.8 training sessions per week, each lasting approximately 2 h. None of the participants practiced any other sport. All participants reported to have a normal or corrected to normal visual acuity and were asked to refrain from assuming psychoactive substances for at least 12 h prior to the execution of the study. Exclusion criteria were any contraindication to the practice of sport, history of osteo-articular injuries in the last twelve months preceding the study, being color-blinded. After being informed of the goals, the risks, and the benefits of participating in the research, participants signed the written informed consent approved by the ethics committee of the Calabria region (Approval number: 122). All the procedures detailed in the following paragraphs comply with the Declaration of Helsinki on research on human participants.

In a repeated measure study design participants attended the laboratory in three separate occasions spaced approximately 3 days apart (experimental sessions). Participants were granted a familiarization session before the experimental procedure. During the familiarization session, anthropometric and body composition characteristics were assessed. Height was measured to the nearest 0.01 m by means of a stadiometer. Leg length was measured using a tape measure with participants in a standing position as the distance between the greater trochanter and the lateral malleolus. Athletes' mean leg length was 0.95 ± 0.05 m.

Body mass and composition were assessed using a hand-to-foot bioelectrical impedance instrument in upright position (InBodyR20, Seoul, Korea). Specifically, participants' muscle mass (28.0 ± 5.8 kg), fat mass (13.2 ± 3.7 kg), percentage of fat mass (20.4 ± 8.4 %) and basal metabolic rate (1457.9 ± 207.4 kcal) were estimated. During each experimental session, participants performed a choice visual reaction task (CRT) composed by thirty stimuli after three different warmup conditions (self-selected music, research-selected music or to a control condition). The CRT was performed using the FitLight system (FitLight Trainer, Milan, Italy). This system allows the presentation of visual stimuli of different colors. Through a dedicated device, the light activation of the unit is programmed to be deactivated by direct foot contact allowing to measure RT as the time elapsed between the presentation of a stimulus (light turns on) and the response (contact with the Body Opponent Bag Dummy).

For the present study, participants were randomly shown three visual stimuli (red, green, blue) that lighted on a single unit. The unit was firmly attached to a Body Opponent Bag Dummy (Fig. 1). Participants performed the roundhouse kick at different height according to the color stimuli: green color - roundhouse kick to the head; blue color - roundhouse kick to the abdomen; and red light - no action. Participants' ear and umbilicus were identified as references for head and abdomen roundhouse kicks, respectively.

Visual stimuli were presented in random order and lasted for 1.80 s. A fixed interstimulus interval of 2 s was adopted. For each color, ten stimuli were presented. Participants were asked to kick as fast as possible, when needed. Kicking distance was freely chosen by the athletes, recorded by the experimenter, and kept constant across experimental sessions (mean kicking distance: 0.54 ± 0.14 m). Average RTs were computed collapsing the RT of head and abdomen roundhouse kicks. A schematic representation of the setup of the CRT test is depicted in Fig. 1.

Before performing the CRT, participants performed a 10-minute self-administered warmup. During the warmup, participants listened to different types of music through the same headphones (Beats studio3 Wireless; Apple Inc., Culver City, CA, USA). Participants were randomly exposed to self-selected music (SM), research-selected music (RM) or to a control condition during which they wore the headphones, but no music was administered (CC). The participants were asked to individually select SM by identifying five songs that they believed to improve their performance. RM consisted of five songs that were identified a priori by the experimenters and kept constant across participants. The

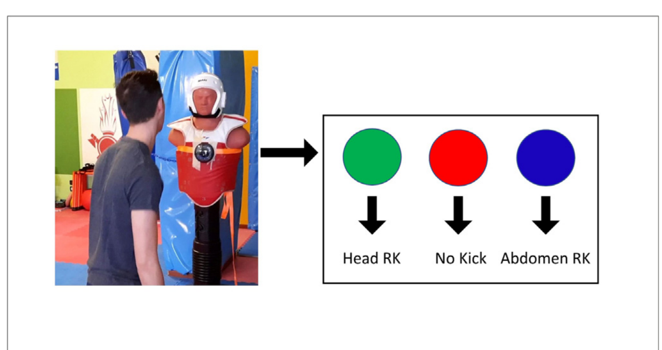

Fig. 1. Schematic representations of the CRT test. Stimuli were interspersed by 2 s. Abbreviations: CRT = Choice Reaction Task; RK = Roundhouse kick.

rhythmic response of RM matched the requirements to be classified as motivational music (tempo > 120 bpm).[4]

Moreover, to account for the cultural appropriateness and for familiarity, songs were selected from the Italian top 10 chart. Both SM and RM music were played at an intensity level of 75db. To investigate the effect of music on affective responses, immediately before (T_0) and after the warmup (T_1) the Feeling Scale (FS)[24] and the Felt Arousal Scale (FAS)[25] were administered. Participants' heart rate (HR) was continuously recorded with a wearable HR monitor (RS 400, Polar Electro™, Kempele, Finland) and the average HR was computed from the beginning of the warmup to the end of the CRT. For all participants and for all conditions the delay between the administration of the three experimental conditions (SM, RM and CC) and the beginning of the CRT was <1 min, as measured by a stopwatch.

All the statistical procedures were performed using the SPSS Software 20 (SPSS Inc., Chicago, IL, USA). All variables were tested for normal distribution using the Shapiro–Wilk test and the assumption of homoscedasticity was verified via the Mauchly's sphericity test. Since RTs and HR_{mean} showed a normal distribution a repeated measure analysis of variance (RM-ANOVA) with condition (SM, RM, CC) as repeated factor was conducted to detect the effects of music on RTs and HR_{mean}. When significant differences were detected, a paired *t*-test was performed. Since the affective responses (Feeling Scale and the Felt Arousal Scale) showed a skewed distribution, they were analyzed using the Friedman ANOVA. Whenever significant, the Wilcoxon test for matched pairs as post hoc analysis was carried out. Bonferroni–Holm correction was applied to all pairwise comparisons. For all statistical tests, significance level was set to $\alpha < 0.05$.

3. Results

The SM had an average tempo of 118.7 ± 22.9 bpm. All songs were written in major keys. The most represented keys were “B” (13 % of the songs) and “C#/D♭” (11.7 %). The RM music had an average tempo of 129.0 ± 4.6 bpm and all songs administered to the participants were written in major keys. The most represented keys for the RM were “C#/D♭” (75 %) and “D” (25 %).

The average RTs, collapsed across conditions, was 821 ms. The shortest RTs were observed in the RM condition (650 ms), while the longest in CC (1006 ms). The RM-ANOVA showed a significant main effect of condition for the RT ($F_{2,38} = 5.039$; $p = 0.011$; $\beta = 0.785$). Post hoc analysis showed that RT was significantly lower in SM (−3.3 %) and RM (−5.2 %) condition compared to CC ($p = 0.006$ and $p = 0.020$, respectively). No difference was observed between SM and RM ($p = 0.62$) on RTs. The RTs across conditions (SM, RM and CC) are reported in Fig. 2 panel A. No significant effect of condition was observed for HR_{mean} ($F_{2,38} = 0.667$; $p = 0.519$; $\beta = 0.154$) as reported in Fig. 2 panel B.

The Friedman ANOVA showed significant differences across time of measurement (T_0 vs T_1) for FS. Post hoc analysis showed that FS was significantly higher at T_1 compared to T_0 in SM and RM conditions (SM T_0: 3.0 ± 2.0; SM T_1: 4.0 ± 1.8; $p = 0.018$; RM T_0: 3.0 ± 2.0; RM T_1: 4.0 ± 1.0; $p = 0.045$). No difference was observed between T_1 and T_0 in CC (CC T_0: 3.5 ± 2.0; CC T_1: 3.7 ± 1.7; $p = 0.18$). FAS was significantly larger at T_1 than at T_0 in the SM and RM conditions (SM T_0: 3.0 ± 2.5; SM T_1: 5.0 ± 1.0; $p = 0.009$ and RM T_0: 4.0 ± 1.7; RM T_1: 5.0 ± 1.0; $p = 0.0018$). No difference between T_1 and T_0 was observed in CC (CC T_0: 3.8 ± 1.7; CC T_1: 4.1 ± 1.0; $p = 0.070$). Fig. 3 shows the changes over time in the Felt Arousal Scale (FAS) score as a function of changes over time in the Feeling Scale (FS).

4. Discussion

This study investigated the influence of music on RTs and affective responses in elite taekwondo athletes. Results showed that pre-task music enhances RT and affective responses in young taekwondo athletes. Specifically, we showed that listening to research- and self-selected music during the warmup reduced the RTs in response to visual stimuli to perform a roundhouse kick compared to a no-music condition. Since in taekwondo competitions, to perform or not (i.e., inhibition) the correct technique according to the opponent's movements is fundamental, we used three different color stimuli to possibly mimic the decision-making process adopted during the competition. Regarding affective responses, our results showed that arousal

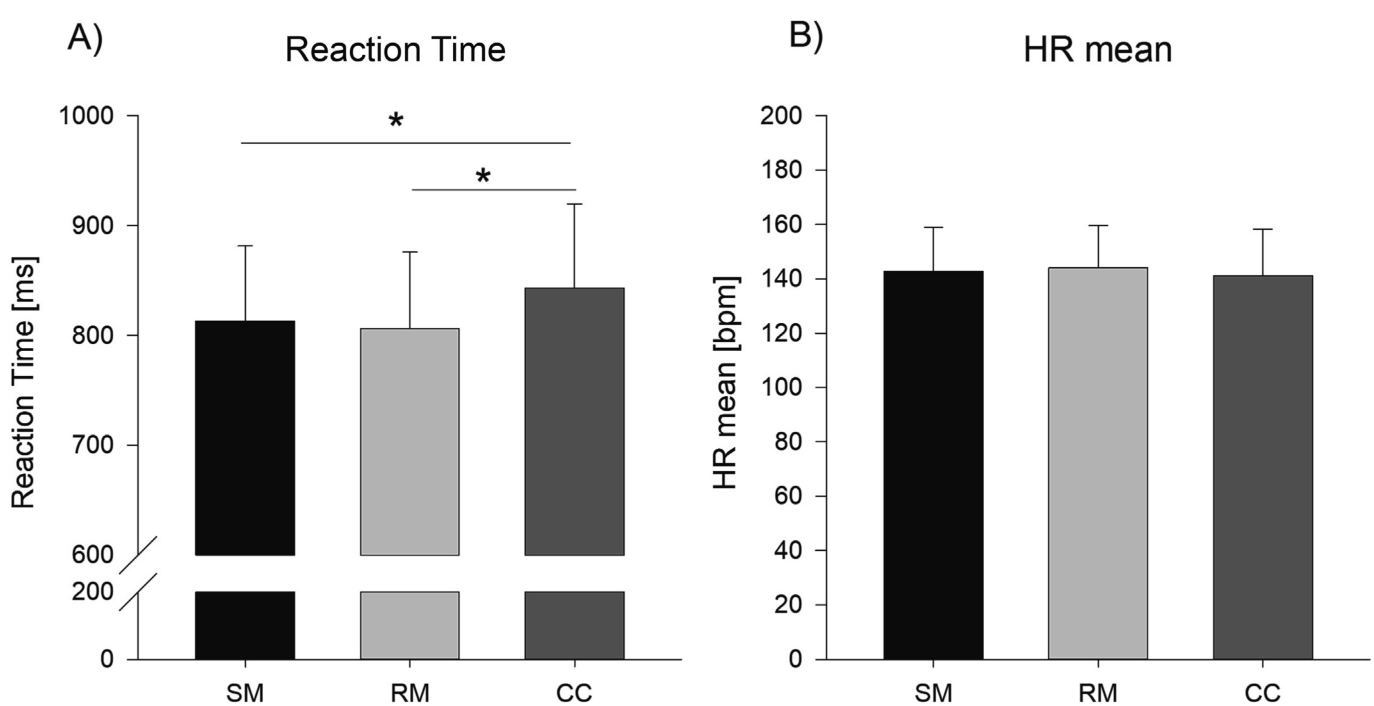

Fig. 2. A) Reaction time, and B) Heart Rate mean (HR_{mean}) reported for the three experimental conditions (self-selected music: SM; research-selected music: RM; and no music: CC). Data are reported as mean and standard deviation. *$p < 0.05$.

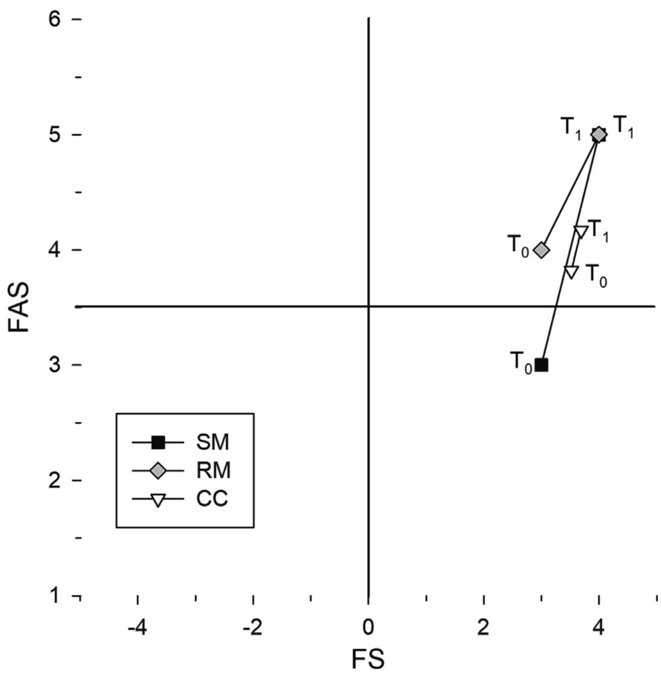

Fig. 3. Changes over time (T_0 and T_1) in the Felt Arousal Scale (FAS) as a function of the changes over time in the Feeling Scale (FS) observed during the three experimental conditions: self-selected music (SM), research-selected music (RM) and control condition (CC). Data are presented as median.

and feeling status were positively influenced both by SM and RM. Contrary to our initial hypothesis, no difference on RTs and affective responses was observed between research-selected music (RM) and self-selected music (SM). This result could be partly explained by the intrinsic characteristics of the self-selected music which had similar rhythmic characteristics of RM. Indeed, it was shown that, music rhythm should be higher than 120 bpm[4] to be effective for performance enhancement. In our study, the average tempo of the self-selected music was 118 bpm while of the RM was 129 bpm. Although the rhythmic response of music has turned out to be the most relevant feature to increase the performance,[1] self-selected music administered in our study may represent a custom-tailored alternative being more specific in terms of the cultural impact and association. These considerations could account for the similar effects of SM and RM on RTs. It was shown that the effects of music may be less evident on athletes' performance possibly due to their high attentional focus on the task.[2,26] Despite this, we found positive effects of both RM and RM on RTs. Noteworthy, based on our results we could speculate that elite athletes are able to self-select the appropriate music to enhance their performance. However, further studies involving athletes practicing different sports are needed to verify this hypothesis.

The RTs observed in our study agree with those reported in previous studies.[19,20] Indeed, it has been shown that in adult elite taekwondo athletes the time elapsed from stimulus onset to target strike for a roundhouse kick is approximately 0.750 s.[19,20] Notably, our results showed that the shortest RT (650 ms) was observed after being exposed to RM. The slightly higher average RTs in our study (821 ms) compared to previous literature may partly be explained by the nature of the CRT that poses higher load on the decision-making process compared to a simple reaction task (i.e., one stimulus requires one reaction) that was used to investigate RT in previous literature. Furthermore, in the present CRT, to mimic the specific requirements of the combat competitions we added a condition (red light) in which participants had to refrain from responding (performing the kick), in analogy to what happens in response to a fake attack of the opponent during a combat competition. Therefore, the decision to perform a kick aiming to the head or to the abdomen or not to perform a kick poses a heavy burden on the decision-making process, and especially sensory-motor integration and stimulus–response mapping processes, possibly slowing down the emission of the response. Another possible explanation for the slightly longer RTs observed in our study is the age of our participants. Previous studies focused on adult elite athletes, whereas our participants were adolescents. This difference may imply an incomplete maturation of the prefrontal cortex[27] which, together with other cortical structures, may be accounted for the slower RTs.[28]

It is worth noting that the RT enhancement was associated with an increase in feeling status and arousal state after the warmup in the SM and RM conditions. Therefore, participants felt better and more "worked up" after listening to both pre-task music types, irrespectively of their preferences. This could be due to the similar rhythmic characteristics of both research-selected and self-selected music. If interpreted according to Russell's circumplex model,[29] it could be concluded that athletes, after being exposed all experimental conditions (Fig. 3, T_1), showed a pleasant high-activation state. A change from a pleasant low-activation state to pleasant high-activation state was observed only for SM music.

It has been shown that exercise alone, especially if performed at medium intensities, has the potential to enhance arousal leading to an optimal state[30] and consequent performance enhancement. In our study, participants had an average HR of approximately 70 % of their maximal estimated HR which can be considered a medium exercise intensity. However, since our results showed that warmup without music did not influence feeling status and arousal state, we may affirm that, music has a performance enhancing effect on RT in visual choice reaction task.

Some limitations of this study need to be acknowledged. Although the effects of music may vary according to experience and weekly training volume, we succeeded in observing the effects of music on both affective responses and RT, despite the heterogeneity in these variables in our athletes. In the present study, we were not able to determine whether the cognitive (pre-movement time) or motor component (movement time) was more influenced by music. This would allow a deeper understanding on the effects of music on speeded reaction task. Future studies should disentangle this dichotomy investigating muscular and brain activity after the exposure to motivational music as well as establish whether the familiarity or the rhythmic characteristics of music account for the improvement of RT and psychological variables.

5. Conclusion

In the present study, we showed that listening to SM and RM pre-task music enhances reaction times and affective states in elite taekwondo athletes. Moreover, we showed that athletes, if allowed to freely choose their music, are able to select the appropriate music to enhance their performance. However, future studies should verify this ability in athletes practicing different sports. Based on our results, martial art masters and physical trainers should consider suggesting their athletes to listen both SM and RM immediately prior to training and/or combat competitions with the aim to enhance their performance.

Funding information

This work is supported by a grant from the Italian Ministry of Education and University [2017FJSM9S]. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Confirmation of ethical compliance

We declare that the study design was approved by the Local Ethical Committee of the Calabria region (Approval number: 122) and was carried out according to the Declaration of Helsinki.

CRediT authorship contribution statement

Francesca Greco: Investigation, Data curation, Methodology, Formal analysis, Writing – review & editing. **Federico Quinzi:** Investigation, Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Salvatore Chiodo:** Conceptualization, Supervision, Methodology. **Claudia Cerulli:** Data curation, Visualization. **Eliana Tranchita:** Data curation, Visualization. **Maurizio Bertollo:** Methodology, Writing – review & editing, Supervision. **Gian Pietro Emerenziani:** Conceptualization, Supervision, Methodology, Formal analysis, Writing – review & editing, Project administration, Funding acquisition.

Declaration of interest statement

None.

Acknowledgments

We thank the athletes and their sports associations for taking part in this study. Moreover, the support of the Italian Taekwondo Federation and of its president Angelo Cito for participants' recruitment is gratefully acknowledged.

References

1. Karageorghis CI, Priest D. Music in the exercise domain: a review and synthesis (part I). *Int Rev Sport Exerc Psychol* 2012;5(1):44-66. doi:10.1080/1750984X.2011.631026.
2. Terry PC, Karageorghis CI, Curran ML et al. Effects of music in exercise and sport: a meta-analytic review. *Psychol Bull* 2020;146(2):91-117. doi:10.1037/bul0000216.
3. Ouergui I, Jebabli A, Messaoudi H et al. The effects of tempo and loudness variations during warm-up with music on perceived exertion, physical enjoyment and specific performances in male and female taekwondo athletes. *PLoS One* 2023;18(4):e0284720. doi:10.1371/journal.pone.0284720.
4. Karageorghis CI, Terry PC, Lane AM. Development and initial validation of an instrument to assess the motivational qualities of music in exercise and sport: the Brunel Music Rating Inventory. *J Sports Sci* 1999;17(9):713-724. doi:10.1080/026404199365579.
5. Bigliassi M, Karageorghis CI, Bishop DT et al. Cerebral effects of music during isometric exercise: an fMRI study. *Int J Psychophysiol* 2018;133(March):131-139. doi:10.1016/j.ijpsycho.2018.07.475.
6. Bigliassi M. Use the brain: complementary methods to analyse the effects of motivational music. *Front Hum Neurosci* 2015;9(September):9-11. doi:10.3389/fnhum.2015.00508.
7. Bishop DT, Wright MJ, Karageorghis CI et al. Tempo and intensity of pre-task music modulate neural activity during reactive task performance. *Psychol Music* 2013;42(5):714-727. doi:10.1177/0305735613490595.
8. Bishop DT, Karageorghis CI, Kinrade NP. Effects of musically-induced emotions on choice reaction time performance. *Sport Psychol* 2009;23:59-76.
9. Pavelka R, Třebický V, Třebická Fialová J et al. Acute fatigue affects reaction times and reaction consistency in Mixed Martial Arts fighters. *PLoS One* 2020;15(1):e0227675. doi:10.1371/journal.pone.0227675.
10. Huang J, Hensch T, Ulke C et al. Evoked potentials and behavioral performance during different states of brain arousal. *BMC Neurosci* 2017;18(1):1-11. doi:10.1186/s12868-017-0340-9.
11. Ouergui I, Jebabli E, Delleli S et al. Listening to preferred and loud music enhances taekwondo physical performances in adolescent athletes. *Percept Mot Skills* 2023;130(4):1644-1662. doi:10.1177/00315125231178067.
12. Greco F, Rotundo L, Grazioli E et al. Effects of self-selected versus motivational music on lower limb muscle strength and affective state in middle-aged adults. *PeerJ* 2022;10:e13795. doi:10.7717/peerj.13795.
13. Khemila S, Abedelmalek S, Romdhani M et al. Listening to motivational music during warming-up attenuates the negative effects of partial sleep deprivation on cognitive and short-term maximal performance: effect of time of day. *Chronobiol Int* 2021;38(7):1052-1063. doi:10.1080/07420528.2021.1904971.
14. Laukka P, Quick L. Emotional and motivational uses of music in sports and exercise: a questionnaire study among athletes. *Psychol Music* 2013;41(2):198-215. doi:10.1177/0305735611422507.
15. Kazemi M, Casella C, Perri G. 2004 Olympic tae kwon do athlete profile. *J Can Chiropr Assoc* 2009;53(2):144-152.
16. Ervilha UF, Fernandes FDM, Carvalho C et al. Reaction time and muscle activation patterns in elite and novice athletes performing a taekwondo kick. *Sports Biomech* 2020;19(5):665-677. doi:10.1080/14763141.2018.1515244.
17. Falco C, Alvarez O, Castillo I et al. Influence of the distance in a roundhouse kick's execution time and impact force in taekwondo. *J Biomech* 2009;42(3):242-248. doi:10.1016/j.jbiomech.2008.10.041.
18. Bianco V, Di Russo F, Perri RL et al. Different proactive and reactive action control in fencers' and boxers' brain. *Neuroscience* 2017;343:260-268. doi:10.1016/j.neuroscience.2016.12.006.
19. Sant' Ana J, Franchini E, Silva V. Effect of fatigue on reaction time, response time, performance time, and kick impact in taekwondo roundhouse kick. *Sports Biomech* 2017;3141:1-9. doi:10.1080/14763141.2016.1217347.
20. Moreira PVS, Fagundes M, Gonçalves M. Neuromuscular performance of Bandal Chagui: comparison of subelite and elite taekwondo athletes. *J Electromyogr Kinesiol* 2016;30:55-65. doi:10.1016/j.jelekin.2016.06.001.
21. Ferreira J, Wilson VD, Herrera-valenzuela T et al. Time-motion analysis and physiological responses to taekwondo combat in juvenile and adult athletes: a systematic review. *Strength Cond J* 2020;42(2):103-121. doi:10.1519/SSC.0000000000000517.
22. Quinzi F, Camomilla V, Felici F et al. Agonist and antagonist muscle activation in elite athletes: influence of age. *Eur J Appl Physiol* 2015;115:47-56. doi:10.1007/s00421-014-2990-y.
23. Koropanovski N, Dopsaj M, Jovanovic S. Characteristic of pointing actions of top male competitors in karate at world and European level. *Braz J Biomotricity* 2008;2:241-251.
24. Hardy CJ, Rejeski WJ. Not what, but how one feels: the measurement of affect during exercise. *J Sport Exerc Psychol* 1989;11:304-317.
25. Svebak S, Murgatroyd S. Metamotivational dominance: a multimethod validation of reversal theory constructs. *J Pers Soc Psychol* 1985;48(1):107-116.
26. Dyrlund AK, Wininger SR. The effects of music preference and exercise intensity on psychological variables. *J Music Ther* 2008;45(2):114-134.
27. Diamond A. Normal development of prefrontal cortex from birth to young adulthood: cognitive functions, anatomy and biochemistry, In: Stuss DT, Knight RT, eds. *Principles of Frontal Lobe Function*, New York, Oford University Press, 2002. p. 466-503. doi:10.1093/acprof.
28. Quinzi F, Perri RL, Berchicci M et al. Weak proactive cognitive/motor brain control accounts for poor children's behavioral performance in speeded discrimination tasks. *Biol Psychol* 2018;138:211-222. doi:10.1016/j.biopsycho.2018.08.014.
29. Russell JA. A circumplex model of affect. *J Pers Soc Psychol* 1980;39(6):1161-1178. doi:10.1037/h0077714.
30. Kamijo K, Nishihira Y, Hatta A et al. Changes in arousal level by differential exercise intensity. *Clin Neurophysiol* 2004;115(12):2693-2698. doi:10.1016/j.clinph.2004.06.016.