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ORIGINAL ARTICLE

Training using a commercial immersive virtual reality system on hand–eye coordination and reaction time in students: a randomized controlled trial

Sebastian Rutkowski[1] · Aleksandra Jakóbczyk[2] · Kacper Abrahamek[2] · Aleksandra Nowakowska[2] · Magdalena Nowak[2] · David Liska[3] · Ladislav Batalik[4,5] · Vera Colombo[6] · Marco Sacco[6]

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Abstract

The implementation of VR games opens up a wide range of opportunities for the development of dexterity, speed and precision of movements among various professional groups. The aim of this study was to investigate the effects of a commercial immersive VR music game on hand–eye coordination and reaction time speed in students. This study enrolled 32 individuals, randomly assigned to the experimental or control group. The intervention consisted of a 15-min training session of the immersive music game "Beat Saber", once a day for 5 consecutive days. The primary outcomes included reaction time measurements: the plate tapping test and the ruler-drop test (Ditrich's test), trial making test (TMT) A and TMT B to assess coordination and visual attention, likewise VR sickness assessment by Virtual Reality Sickness Questionnaire (VRSQ). The secondary outcome included an energy expenditure assessment (SenseWear Armband). The data analysis revealed a statistically significant improvement in hand–eye coordination in the experimental group, with no improvement in the control group. The results were similar in measurements of reaction time. Analysis of the VRSQ questionnaire results showed a statistically significant reduction in oculomotor domain symptoms and total score during successive training days. The immersive VR music game has the potential to improve reaction time and hand–eye coordination in students.

Keywords Virtual reality · Beat Saber · Hand–eye coordination · Reaction time · Immersion

1 Introduction

From a physiological point of view, a reaction means an intentional voluntary response to an external stimulus. Between the application of a stimulus and the adequate motor response, a certain time window exists called reaction time. Instead, it reflects the rapidity of the flow of neurophysiological, cognitive and informational processes that occur in response to an aroused sensory system (Balakrishnan et al. 2014). Reaction time is an essential component of daily functioning, and its speed depends on the condition of the sensory system, cognitive processing and motor skills. Reaction time determines a person's alertness and in the case of many specialties that require a high degree of precision should be faster, such as athletes, drivers, the military, likewise doctors, nursing and physiotherapists (Batra et al. 2014). A number of factors affecting reaction time have been described, including gender, age, physical fitness, health status, fatigue level, distraction, stimulants, personality type along with type of stimulus: auditory, visual,

✉ Sebastian Rutkowski
s.rutkowski@po.edu.pl

1 Department of Physical Education and Physiotherapy, Opole University of Technology, 45-758 Opole, Poland

2 Descartes' Error Student Research Association, Faculty of Physical Education and Physiotherapy, The Opole University of Technology, 45-758, Opole, Poland

3 Matej Bel University, Faculty of Sports Science and Health, 97410 Banská Bystrica, Slovakia

4 Department of Rehabilitation, University Hospital Brno, 62500 Brno, Czech Republic

5 Department of Physiotherapy and Rehabilitation, Faculty of Medicine, Masaryk University, 62500 Brno, Czech Republic

6 Institute of Intelligent Industrial Technologies and Systems for Advanced Manufacturing (STIIMA), National Research Council of Italy (CNR), 23900 Lecco, Italy

kinsesthetic. It has also been shown that reaction time affects cognitive processes (Ede et al. 2012).

Hand–eye coordination, or eye-hand coordination, refers to the ability to perform activities that require the simultaneous use of hands and eyes. However, correct hand–eye coordination involves the synergistic function of several sensorimotor systems, such as vestibular, visual, proprioception and arms control. This process relates to the activation of neurophysiological processing loops involving different neurotransmitter systems (B, S. K., S, S., Ramachandran, A. 2022). Physiotherapy training has been proven to benefit patients with impaired coordination by, for instance, improving central and peripheral vision, improving the grasp of details and recognition of changes, and switching between near and far vision (Sittikraipong et al. 2020). However, physiotherapists themselves should present a high level of hand–eye coordination to effectively help their patients. Several techniques, e.g. in soft tissue therapy or massage, require a high degree of precision in both receiving sensory input (to localize increased muscle or fascial tension) and driving specific movement, e.g. in the direction of the restriction. Thus, it seems reasonable to search for modern forms of training to improve hand–eye coordination in the community of physiotherapists.

In recent years, there has been a significant increase in reports on the use of virtual reality (VR) as a treatment approach for a range of clinical conditions, such as pain management Ahmadpour et al. (2019), Czech et al. (2021), phobias, anxiety Cieślik et al. (2020), Rutkowski et al. (2021) and other disorders or health conditions Rutkowska et al. (2022), Czech et al. (2022). On the other hand, there is growing interest in the use of VR in the training of high-specification professions, among others, dentists (Buchanan 2004), and surgeons (Andersson et al. 2020) have been reported. Technological advances have made VR devices immersive, providing a sense of presence that translates into user motivations for active participation. Although the typical cost of a high-quality consumer HMD-VR kit remains high for individual consumers (€2000+), this technology line-up has seen notable uptake in research settings (Garrett et al. 2018). However, VR technology companies have released more accessible, less expensive and easy-to-use HMDs, such as the Oculus Quest (Facebook, Menlo Park, USA), which could have major applicability for health applications. In this area, VR applications are often designed as a first-person scenario focused on a specific motor task in the form of a direct movement task, or as an implicit goal without a particularized narrative to perform an activity. The next group of software includes motivational or relaxation, for instance, Virtual Meditative Walk, where users follow a guided meditation to reduce anxiety and chronic pain (Tao et al. 2021). Alternatively, commercially available HMD-VR games can be used as novel supportive interventions. Exercise-based games, such as Audioshield and Beat Saber, represent rhythm-based physical activity. Besides cardiovascular workouts, these games demand the involvement of psychomotor and even cognitive skills. Thus, it seems that offering such games to brain workers, such as students, might bring not only somatic as well as mental benefits. Therefore, the main objective of this study was to test the effect of using a commercial immersive VR game on hand–eye coordination and reaction time speed in students.

2 Materials and methods

2.1 Participants

This study enrolled 32 individuals (17 females, 15 males, age = 22 ± 1.8 years, body mass index = 22.23 ± 3.4), physiotherapy students of the Opole University of Technology in Opole. Participants were randomly assigned to two groups, with 16 subjects in the experimental group and 16 subjects in the control group. The randomization (ratio 1:1) sequence was generated at the start of the trial using a computerized block randomization generator (randomizer.org). The inclusion criteria included individuals aged 18 to 25 years and university students who were declared to be not active athletes nor to engage in systematic physical activity training. The exclusion criteria included diagnosed neurological diseases, fear of wearing goggles, diagnosed diseases or injuries of the musculoskeletal system and regular sports activities during the week. All participants signed a written informed consent prior to their participation in the study. The study adhered to the Declaration of Helsinki (World Medical and A 2013), ethical approval was obtained from the Bioethics Committee of the Opole Chamber of Physicians on the basis of Resolution No. 243 of 06 April 2017, and the study was registered in ClinicalTrials.gov (NCT05458804). The study was designed in accordance with the recommendations of the CONSORT statement (Fig. 1).

2.2 Intervention

The participants of the experimental group were submitted to a 15-min training session of the immersive music game "Beat Saber" (Beat Games, 2019), once a day for 5 consecutive days at the same time. The VR source consisted of an HTC Vive Pro headset (HTC Corporation, New Taipei, Taiwan) including goggles, controllers and motion sensors (Fig. 2). The aim of the game is to slice through approaching objects with lightsabers of different colours, separately for the right and left hand to the rhythm of the music being played or to evade large blocks by moving to either side or crouching (whole-body movement). A collection of Imagine Dragons songs was used for the study:

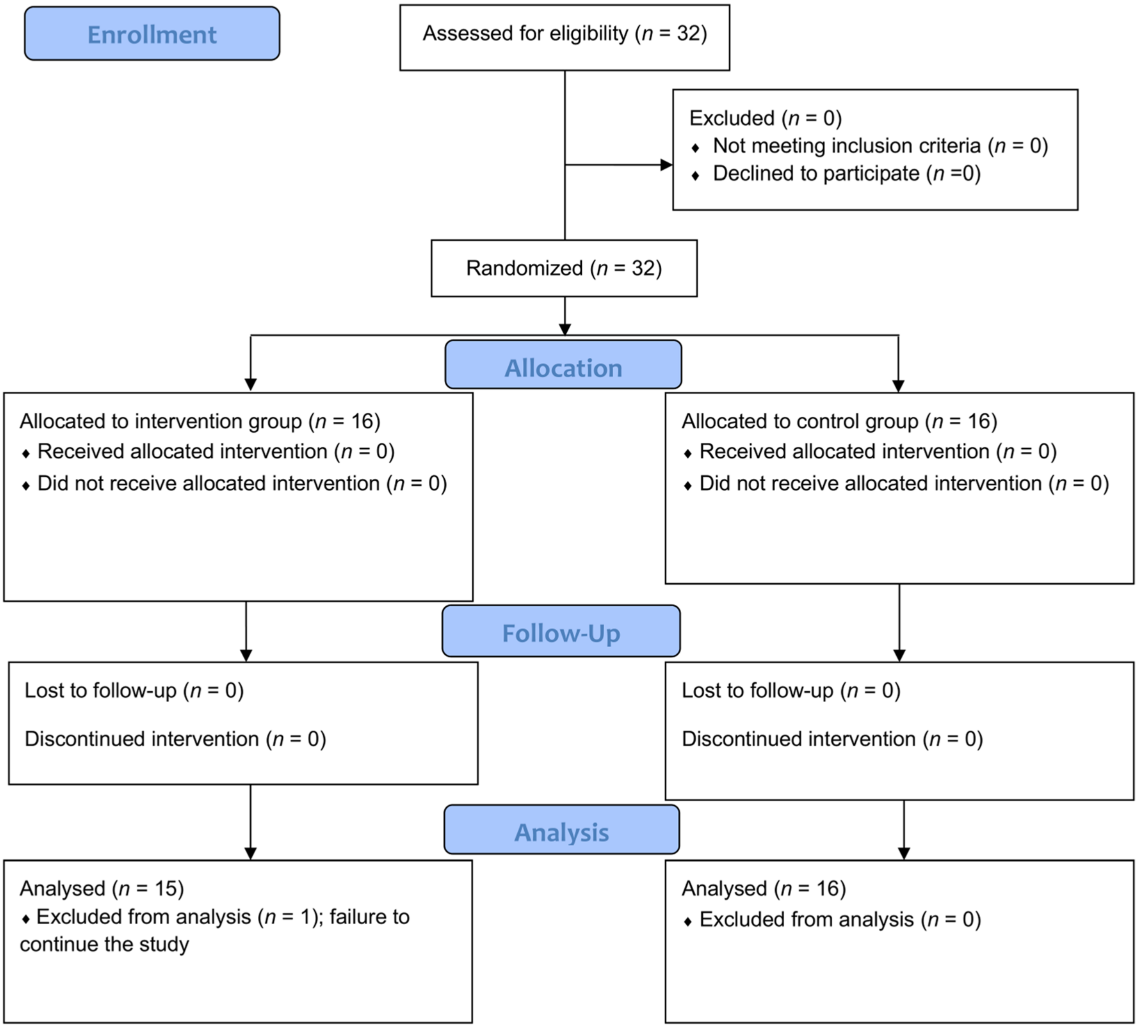

Fig. 1 Study flow

It's time, Believer, Thunder and Radioactive. A broader description of the research station was described in the pilot study (Rutkowski et al. 2021b). The control group participants did not undertake specific tasks after the initial assessment. The passive control group was selected to consider whether VR training would result in significant changes in reaction time and hand–eye coordination.

2.3 Measures

The experimental procedure involved assessments on both the first and last days of the study. Initial measurements were taken prior to the commencement of the first training session. Subsequently, the final measurements were taken precisely 30 min after the conclusion of the last training session for each participant.

2.3.1 Reaction time

To evaluate reaction time, the plate tapping test (PTT) and the ruler-drop test (Ditrich's test) were used.

The PTT test evaluates the speed of movement of the upper limb while touching two discs whose centres are 80 cm apart. The test is performed by the dominant hand, and the non-dominant hand is on the plate in the middle between the hitting discs. The result of the test is the time of 25 hits on each disc (Tsigilis et al. 2002).

The Ditrich's test is carried out using a 1.5-cm-diameter 50-cm-long rod with a marked scale (in cm increments). The participant is seated in a chair with the face towards the backrest, supporting the forearm in the middle of its length. The fingers are arranged by combining the thumb and index finger into a circle, while inside, the stick is placed. The testee's task is to react as quickly as possible

Fig. 2 Training station

and grab the stick released by the tester. The procedure is repeated 10 times for each hand; in accordance with the methodology, two extreme results are excluded (Sienkiewicz-Dianzenza and Maszczyk 2019).

2.3.2 Hand–eye coordination

The trial making test (TMT) A and TMT B were used to assess coordination and visual attention. The goal of the test in the first part (TMT A) is to link 25 circles in the sequence from the smallest to the largest and in the second part (TMT B) to connect numbers with letters of the alphabet according to the formula 1-A, 2-B, 3-C, etc., with a continuous line (Dobbs and Shergill 2013).

2.3.3 Virtual Reality Sickness Questionnaire (VRSQ)

THE VRSQ assesses motion sickness symptoms in a virtual reality environment. The newly derived VRSQ consisted of 9 items, which are included in two components, namely oculomotor and disorientation. Each question is graded in categories: none, slight, moderate, or severe. The following symptoms shall be evaluated: General discomfort, Fatigue, Headache, Eye strain, Difficulty focusing, Fullness of the Head, Blurred vision, Dizziness with eyes closed, and Vertigo (Kim et al. 2018).

2.3.4 Energy expenditure

Energy expenditure was assessed using the SenseWear Armband Pro 3 (BodyMedia, Inc., Pittsburgh, PA, USA). The device monitors such parameters as energy expenditure, expressed in kilocalories (kcal), the total number of steps, intensity, and duration of physical activity. The device was active each day during training. Several studies have demonstrated the accuracy, utility, validation, and test–retest reliability of the device for estimating energy expenditure during physical and daily activity Drenowatz and Eisenmann (2011), Brazeau et al. (2011).

2.4 Statistical analysis

Data were analysed using STATISTICA 13 software (StatSoft, Cracow, Poland) and JASP 0.16.1 software (University of Amsterdam, Netherlands). The sample size was calculated based on the results of the pilot study; the medium effect size of 0.3 according to the changes in reaction time of immersive VR was assumed. The G*power 3.1.9 software was used to calculate the sample size. The calculation was based on the F test repeated measures, within-between interaction: the type I error rate was set at 5% (alpha-level 0.05), the effect size of the main outcomes was 0.3, and the type II error rate gave 90% power. It was determined that 32 participants should be enrolled. Differences between hand–eye coordination and reaction time variables were compared using the Mann–Whitney U test. The Friedman test was used to compare differences in the energy expenditure between training days. Continuous variables were presented as mean ± standard deviation (SD) or median with the lower (Q1) and upper (Q3) quartile, where appropriate, according to the Shapiro–Wilk test. The effect sizes were calculated with Cohen's d. An effect size ≥ 0.20 was considered small, while an effect size ≥ 0.50 was considered medium and an effect size ≥ 0.80 was considered large (Cohen 1988). The statistical significance of the results was accepted at $p < 0.05$.

3 Results

The analysed data were obtained from 31 participants. After randomization, one participant discontinued the experimental intervention (Fig. 1). The analysis of the initial analysed parameters showed no statistically significant differences between the study groups with regard to PTT ($p < 0.984$), TMT A ($p < 0.921$), TMT B ($p < 0.323$), Ditrich's test for right hand ($p < 0.188$). However, the differences in the Ditrich's test for the left hand were statistically significant ($p < 0.027$).

The analysis of hand–eye coordination within the experimental group showed significant improvement in TMT A

($p < 0.016$), and TMT B ($p < 0.007$). A significant decrease in the time to complete the task was observed, while in the control group statistically significant deterioration in TMT A ($p < 0.011$) was observed, likewise non-statistically significant changes in TMT B ($p < 0.066$)(Fig. 3. Intergroup analysis showed significant statistical differences between groups in TMT A ($p < 0.001$) with a large effect size ($d = -1.076$) and non-statistically significant in the TMT B ($p < 0.937$) with medium effect size ($d = -0.38$) when analysing post-training scores (Table 1).

The analysis of reaction time within the experimental group showed significant improvement in PTT ($p < 0.001$) and Ditrich's test for right hand ($p < 0.002$) and non-statistically significant changes for the left hand ($p < 0.164$). In the control group, the average time to perform PTT decreased statistically significantly ($p < 0.007$), while no statistically significant changes were observed in the Ditrich's test (left $p < 0.077$ vs. $p < 0.925$ for the right hand)(Fig. 4and Fig. 5). Intergroup analysis showed significant statistical differences between groups in PTT

Table 1 Results of the hand–eye coordination and reaction time

Variables	Experimental group ($n = 15$)			Control group ($n = 16$)			*P*	Effect size d
	Pre	Post	Δ Post–Pre	Pre	Post	Δ Post–Pre		
Hand–eye coordination								
TMT A [s]	15.4 (3.1)	14 (2.03)	−1.39	15.6 (3.89)	18.1 (4.2)	2.51	<0.001*	−1.076
	14.2 [13.3–16.9]	14.1 [12.3–15]	−1.11	14.9 [13.6–17]	17 [15.6–19.1]	0.31		
TMT B [s]	33.9 (9.61)	27 (7.45)	−6.99	30.7 (9.37)	27.5 (6.72)	−3.24	0.937	−0.38
	32.7 [25.4–40.3]	27.1 [24.4–29.7]	−2.16	27.3 [24.2–32]	25.8 [24.5–28.5]	−2.65		
Reaction time								
PTT [s]	12.3 (1.58)	10.4 (1.19)	−1.87	12.4 (0.8)	11.3 (1.38)	−1.09	0.046*	−0.629
	11.9 [11.2–13]	10 [9.4–11.1]	−0.40	12.3 [11–13.3]	11.3 [10–12.1]	−1.03		
Ditrich's right hand [cm]	20.3 (3.52)	17.2 (3.02)	−3.04	21.9 (3.74)	21.7 (3.66)	−0.20	0.001*	−0.777
	21.5 [19.3–22.9]	17 [14.8–19.4]	−0.50	22.3 [20.9–24.4]	21.8 [20–24.9]	−0.07		
Ditrich's left hand [cm]	20.4 (3.92)	18.8 (2.99)	−1.55	23 (2.41)	22.1 (2.6)	−0.88	0.003*	−0.211
	20.9 [17.7–23]	18.7 [16.7–20.1]	−0.93	23.3 [22.8–24.2]	23.1 [20.9–23.9]	0.19		

Values are expressed as mean (SD) and the median [lower–upper quartile]; *$p < 0.05$ between-group analysis (Mann–Whitney U test);

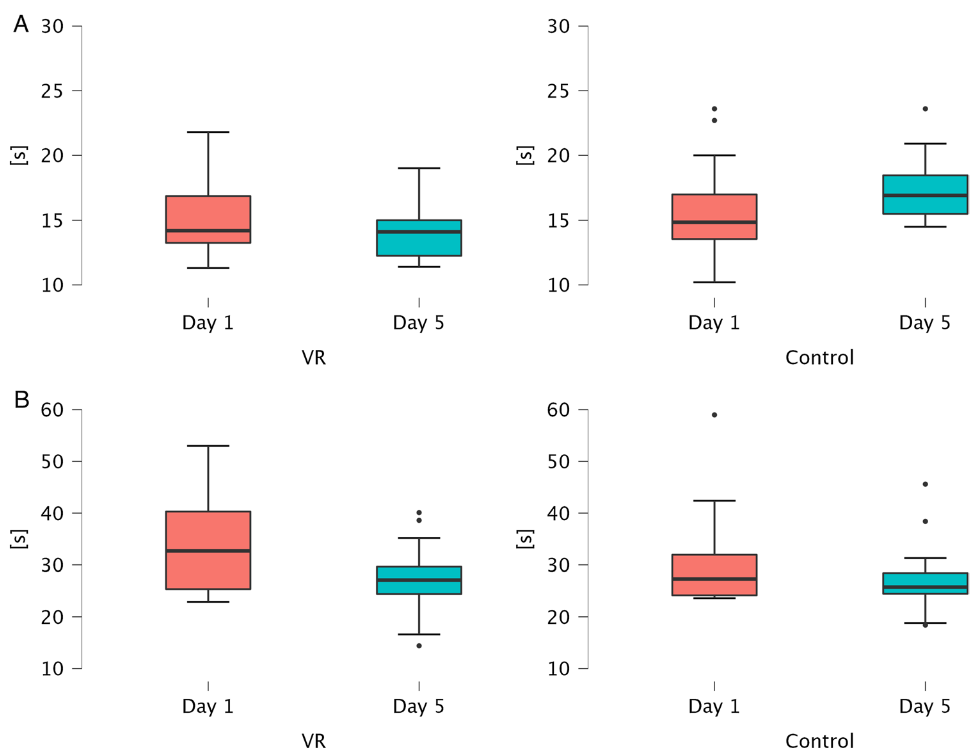

Fig. 3 Results of TMT tests

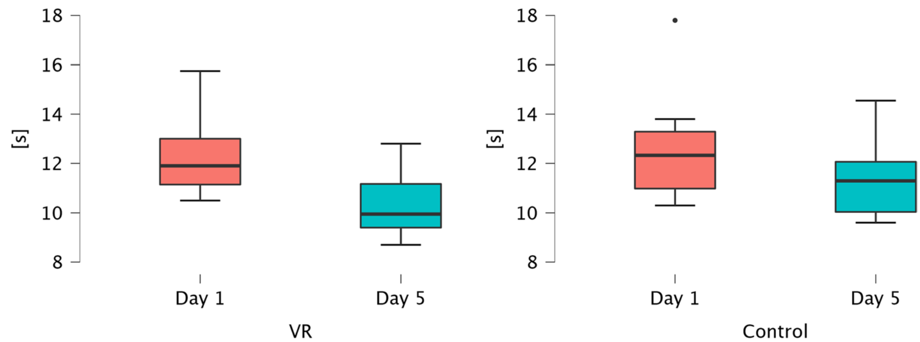

Fig. 4 Results of PTT tests

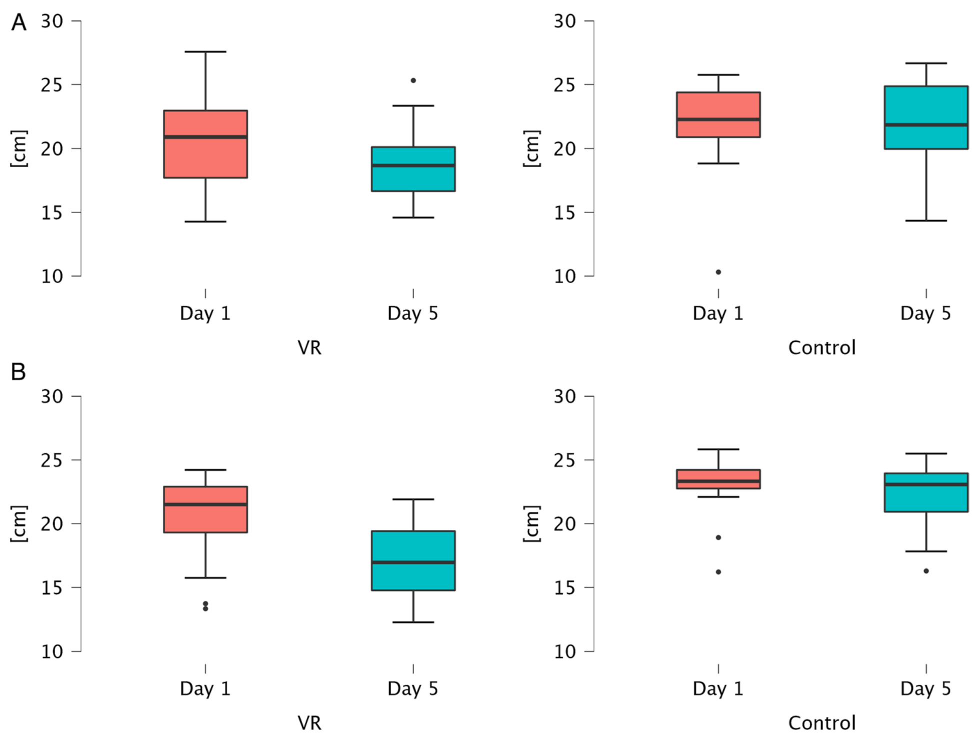

Fig. 5 Results of Ditrich's test

($p < 0.046$) with large effect size ($d = -0.629$), likewise in both Ditrich's test; left hand ($p < 0.003$) with small effect size ($d = -0.211$), right hand ($p < 0.001$) with large effect size ($d = -0.777$) (Table 1).

Analysis of the median score of the VRSQ questionnaire results showed statistically significant differences between day 1 and 4 and day 1 and 5 within the oculomotor domain training and the total score.

Analysis of the results of energy expenditure showed that, during 5 days of training, the total average energy expenditure was 329 kcal, approximately 66 kcal per training session. No statistically significant difference between training days ($p = 0.304$) were noted (Fig. 4). The average body mass index of the participants falls within the normal weight category (< 25 kg/m2).

4 Discussion

This paper aimed to examine the effect of VR music game training on reaction time and hand–eye coordination, likewise to assess the sickness in VR and evaluate the energy expenditure of such training.

Regarding the analysed results in terms of reaction time, a statistically significant change was noted in both groups in terms of reduction of PTT time, although noteworthy is the fact that the effect size was large. Thus, it can be assumed that the change in the control group was due to the effect of learning to perform the test. A large effect size was also noted for changes in the Ditrich's test for the right hand, which leads to the conclusion that VR training significantly improves reaction time. In regard to hand–eye coordination, opposite trends were noted in the performance of the TMT A test; the experimental group decreased the time, and the control group increased it, which affected the large effect size in this test. TMT B showed a reduction in test execution time, but the delta in the experimental group was doubled. Summarizing the results of this study, it is worth highlighting the significant reduction of symptoms during the following days of training in terms of symptoms of oculomotor issues, which affected the total score of the Virtual Reality Sickness Questionnaire. This can provide valuable insight into the perception of symptoms during an immersive music exergame; however, the analysed group was small. Our results align with previous studies in the literature that evaluated the sickness symptoms associated with the use of the Beat Saber game (Sousa et al. 2022). Szpak et al. (Szpak et al. 2020) found that healthy adults well tolerate both short (10 min) and long (50 min) experiences and that the immediate aftereffects are usually short-lived. With respect to the type of symptoms, we observed more effects in the oculomotor domain and less in the disorientation one, in accordance with a previous study following a similar design (Dong et al. 2022). Moreover, such symptoms mainly occurred in the first days of exposure, while participants experienced almost no symptoms in the last sessions. As reported in a recently published work, such a reduction may be caused by several factors: behavioural and sensory adaptation, habituation, as well as task improvement (Palmisano and ConsTable 2022). In their study, Palmisano et al. showed that two sessions of 15 min of a rollercoaster game are enough to reduce side effects related to sickness drastically. Our results, although employing a VR experience different for task and way of interaction, confirm that symptoms decrease after two sessions of playing (Fig. 6).

With regard to reaction time, the results are in line with the results from the pilot study (Rutkowski et al. 2021b). There were statistically significant improvements in reaction time in the PTT test; however, different results in Ditrich's test were observed: in the pilot study, the statistically significant results resulted for the left hand and in the randomized study for the right hand. Yet it seems that the dissimilarity of these results lies in the different study groups. Musicians,

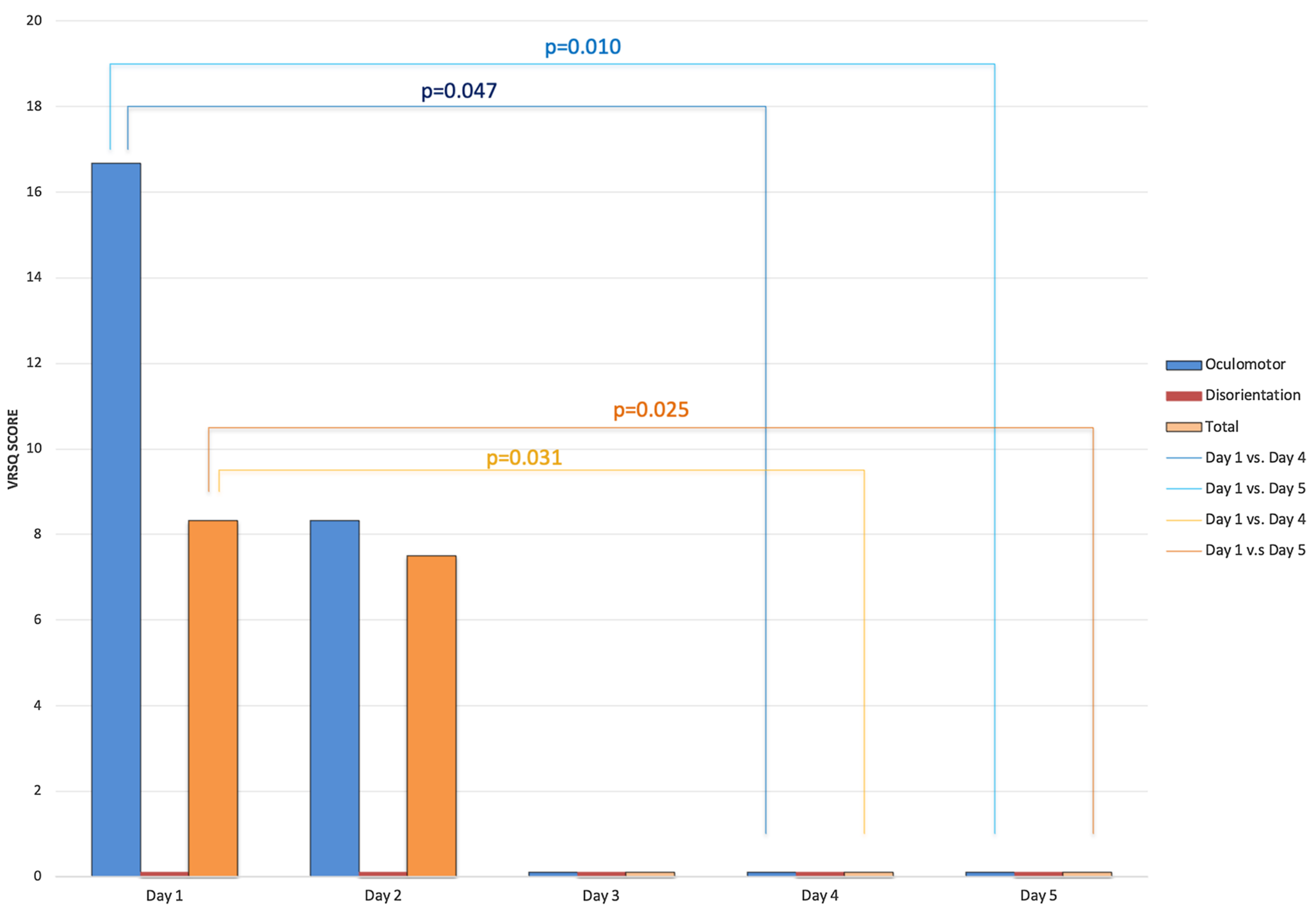

Fig. 6 Results of Virtual Reality Sickness Questionnaire

by the nature of the manual activities involved in playing instruments, use both hands, while the students were entirely right-handed. Regarding hand–eye coordination, the results of this study are consistent with those of the pilot study, in the intervention group participants significantly reduced the time to perform TMT A and B tests after a 5-days of VR music game intervention. Previous literature revealed that action video game players showed faster response times (Chandra et al. 2016), improved attention (Bisoglio et al. 2014), faster processing speeds (McDermott et al. 2014), improved multitasking abilities (Bavelier et al. 2012), and visuo-motor reaction time and balance performances (Glueck and Han 2020), however, does not yield effects in a single training session (Ferreira et al. 2022). A similar study by Keller et al. enrolled 32 individuals, randomly assigned to two groups, an experimental group and a control group, and conducted a 15-min training session of the immersive music game "Ump Saber" on a daily basis for 5 consecutive days. The results of the study showed that there were no significant differences in the physiological measures between the experimental and control group. However, the reaction time increased for the experimental group, while it decreased for the control group, and these pre–post-changes between groups were statistically different. The study also found that the VR group became slower in the match to sample reaction time metric, but only the control group reaction time significantly increased. There were also mild trends of decreasing Amotivation for the VR group over time, although the overall differences between VR and No-VR condition in this subscale were mild (Fig. 7).

The literature shows few studies evaluating the energy expenditure while playing Beat Saber. One of those found that the game is able to elicit moderate to vigorous physical activity in sedentary healthy young students and that such intensity is maintained for around 40% of the time spent playing (Sousa et al. 2022). The results of our study reveal similar levels of energy expenditure. The average energy

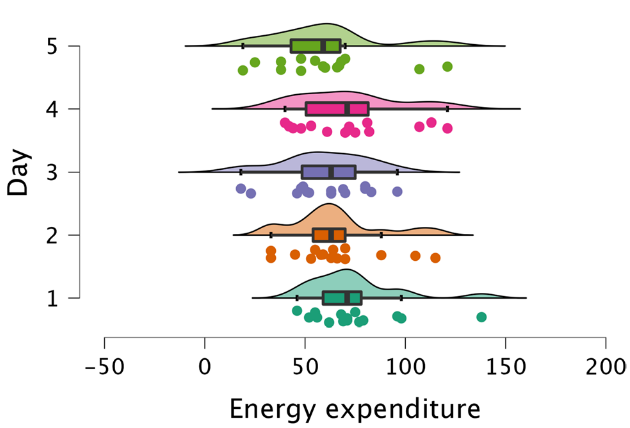

Fig. 7 Results of energy expenditure

expenditure during a single session was about 66 kcal, or about 4.45 MET. Moreover, we confirmed similar results among music school students, where the average energy expenditure during the session was 64 kcal/session (Rutkowski et al. 2021b). Given students' interest in technology, possible VR-based intervention approaches should be explored for their potential to promote physiological health and psychological well-being.

While several studies have demonstrated that both physical activity and virtual reality positively influence cognitive functions, there is still little research demonstrating the potential of the Beat Saber game. Flores-Gallegos et al. found that 15 sessions of Beat Saber can improve motor balance, motor coordination, and visual attention in children with reading learning disability. In addition, children showed a positive qualitative effect on their reading ability and self-perception (Flores-Gallegos et al. 2022). Several studies from multiple disciplines have examined the relationship between physical activity and well-being, finding that physical activity influences emotional processes, with almost immediate anti-anxiety and anti-depressant effects Basso and Suzuki (2017), Powers et al. (2015), inducing higher positive emotions than traditional exercise (Li et al. 2018). According to meta-analyses, exergame interventions have physiological and hemodynamic effects comparable to traditional exercise-based programs (Peng et al. 2011, Blasco-Peris et al. 2022). In addition, higher patient satisfaction with VR interventions has been reported (García-Bravo et al. 2020). Nevertheless, to achieve significant health effects, exercise intensity needs to be at least at a moderate level, i.e. 3.0–6.0 METs (Mendes et al. 2018). Thus, the essential aspect of monitoring exercise intensity is preferably through heart rate or rating of perceived exertion (Scherr et al. 2013).

In the medical field, VR has been used to improve non-dominant hand performance and laparoscopic skills in medical students (Harrington et al. 2018), as well as for rehabilitation of stroke patients and individuals with vestibular and balance deficits (Rutkowski et al. 2020). Studies have also found positive impacts of VR on reaction times and hand–eye coordination in children with cerebral palsy (Shin et al. 2015) and developmental coordination disorders (Straker et al. 2011). Recently, it has been found that interplay during exergame intervention with a partner or family increased motivation and facilitated adherence, especially in older participants. In addition, challenges that involved the presence of a teammate and/or counterplay with others were more motivating (Davis et al. 2021). These promising outcomes open the possibility of further development and implementation of VR, particularly in older populations of healthy individuals or those with chronic disease. Healthy ageing is associated with cognitive as well as sensorimotor decline. During VR, participants must perform physical activity while cognitively responding to a challenging environment. However, little is known about the impact of exergame training interventions on a wide range of motor, sensory, and cognitive skills, and further research is needed.

In the light of recent advancements in the field of virtual reality (VR) and its applications across various domains, it is imperative to address the limitations and challenges associated with VR experiences. One such limitation is cybersickness, a phenomenon that not only affects user experience but also has implications for cognitive and motor skills (Kourtesis et al. 2023). Our study employed the Virtual Reality Sickness Questionnaire (VRSQ) as a measure of VR experience, which has been validated against other established tools like the Simulator Sickness Questionnaire (SSQ). The study by Kourtesis et al. substantiates the psychometric properties of VRSQ and highlights its utility in capturing a temporary decline in performance due to cybersickness. This is particularly relevant to our study as it aligns with our focus on hand–eye coordination and reaction time speed, variables that are susceptible to the effects of cybersickness. Furthermore, the study by Kourtesis et al. introduces pupil size as a significant predictor of cybersickness intensity, offering an additional avenue for future research.

Our study was associated with a couple of limitations. The limitations of the study include the small sample size of 32 participants, all of whom were physiotherapy students of the same university, which may limit the generalizability of the findings to other populations. Additionally, the study only used a 15-min training session for 5 consecutive days which may not be sufficient to observe long-term effects. Also, the study used only one immersive music game, "Beat Saber" which may limit the generalizability of the findings to other types of VR games. Furthermore, the study did not examine the neural mechanisms underlying the observed effects and did not assess the long-term effects of the intervention on reaction time and hand–eye coordination.

Future research directions in this field should aim to replicate the current study with larger sample sizes to further establish the validity of the findings. Additionally, it is important to investigate the long-term effects of “Beat Saber” VR training on reaction time and hand–eye coordination. The utilization of alternative VR games or interventions to improve reaction time and hand–eye coordination in similar populations should also be examined. Furthermore, exploring the effects of VR training on cognitive and motor skills in different populations, such as older adults or children, is warranted. Lastly, it would also be beneficial to investigate the impact of varying durations and frequencies of VR training on reaction time and hand–eye coordination, as well as to compare the efficacy of VR training with traditional physical therapy interventions for improving reaction time and hand–eye coordination.

5 Conclusion

One-week training in immersive VR music game has the potential to improve reaction time and hand–eye coordination in students. The average energy expenditure of this type of training was approximately 4.5 MET (66 kcal); thus, it can be considered a moderate intensity physical activity. Analysis of VR sickness showed oculomotor symptoms on the first day of training, which decreased significantly in subsequent training.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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