Assessing Physical Activity Levels While Playing Virtual Reality Exergames: A Pilot Study

Mário Teixeira[1], Hildegardo Noronha[1,2], Pedro Campos[1,2,3] and Cíntia França[2,4]

[1]*Department of Informatics Engineering and Interactive Media Design, University of Madeira, Funchal, Portugal*
[2]*LARSyS, Interactive Technologies Institute, Funchal, Portugal*
[3]*WoWSystems Informática Lda, Funchal, Portugal*
[4]*Department of Physical Education and Sports, University of Madeira, Funchal, Portugal*

Keywords: Heart Rate, Intensity, Exercise, Adults.

Abstract: Due to the exponential growth in technology, exergames emerged as innovative tools that might be used to promote PA enjoyably. This study describes the development of a virtual reality (VR) exergame and the preliminary implementation results. The system was developed through the Unity3D platform and the HCT Vive, consisting of two mini games: a dance game and a snow skiing game. Five healthy adults (25.2 ± 3.9 years) performed one VR exergame session and were monitored for PA intensity and heart rate (HR). After the session, participants were asked to report their perceived exertion and to fill in a system usability questionnaire. During the session, participants spent more time in sedentary activity (≈ 37.5%), followed by light activity (≈ 35.1%), and moderate-to-vigorous activity (≈ 27.4%). An average of 27.2 steps/min and HR of 123.5 bpm were registered while playing. Perceived exertion scores were higher in the dance mini game than in the snow skiing mini game. Regarding usability, participants considered the system easy to use and would like to use it more often. This study summarizes preliminary and promising results on the ability of VR exergames to promote light and moderate PA.

1 INTRODUCTION

Worldwide, physical inactivity and increased sedentary behavior have become public concerns (WHO, 2020). According to the literature, physical activity (PA) is any bodily movement produced by skeletal muscles that promotes energy expenditure (Caspersen et al., 1985). Although the well-established benefits of PA on physical fitness components (i.e., body composition, muscular strength, balance, flexibility, etc.) (Cox et al., 2020; Wickramarachchi et al., 2023), and overall well-being (Trajković et al., 2023), an alarming rise in sedentary lifestyles have been observed in the past years.

The exponential growth in technology usage has been associated with increased screen time and decreased PA levels (Lee et al., 2012). However, innovative approaches based on technology have been emerging to foster PA, particularly through exergames (videogames that demand PA to be played) (Boulos & Yang, 2013). In previous literature, the positive contribution of exergames interventions to prevent childhood obesity (Gao & Chen, 2014; Pope et al., 2016), and to enhance strength and balance among older adults (Alhagbani & Williams, 2021) have been reported. Among the solutions used, commercial devices, such as Nintendo Wii, PlayStation, and Xbox 360, have been widely implemented in exergames interventions (Agmon et al., 2011; Trost et al., 2014). Indeed, these solutions are presented as affordable and can be used in home-approach.

The technological landscape has evolved in the last few years, allowing new possibilities for human interaction and experience. In deploying new exergames, virtual reality (VR) arises as a more interactive platform that can increase adherence and the probability of achieving general health benefits. VR is considered appealing since it takes users to different worlds and gives them a high level of presence and interaction. Based on previous literature on the topic, positive outcomes have been described on the cognitive and physical performance of different populations through VR exergames (Costa et al., 2019), although emphasis has been given to younger and older populations. Therefore, this paper aims to describe the development of an exergame

Teixeira, M., Noronha, H., Campos, P. and França, C.
Assessing Physical Activity Levels While Playing Virtual Reality Exergames: A Pilot Study.
DOI: 10.5220/0013061300003828

In *Proceedings of the 12th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2024)*, pages 95-101
ISBN: 978-989-758-719-1; ISSN: 2184-3201

design to promote PA among healthy adults and the results of a first-stage testing phase (pilot study) regarding PA intensity level and system usability.

2 METHODS

2.1 Game Development

For the development of the VR session, the authors' developed two minigames, each centered around dance and snow skiing themes. The review of previous studies supports the theme selection focused on exergames, which have commonly used dance (Comeras-Chueca et al., 2020; Maddison et al., 2011) and sports games (Agmon et al., 2011; Meldrum et al., 2012) to implement PA programs among different populations. Additionally, previous highlights of its efficacy supported the choice to include a snow skiing game, especially among individuals who prefer gaming over traditional exercise (Ko et al., 2020). Both mini games were designed to simulate real-world physical activities, providing a fun and immersive way to engage, particularly the aerobic capacity.

In the dance mini game (Figure 1), users engage in a dynamic and rhythmic environment where their body movements synchronize with virtual dance moves. Players engaged with four music tracks, chosen based on popularity and high danceability. In this game, players score points by hitting color-coded virtual obstacles that appear at foot level, timed to the beat of the music. Green is used for the left foot and blue for the right foot. The player must hit the corresponding obstacle with the correct foot to earn points. The scoring system is designed with three tiers of accuracy: Hit, Good, and Perfect, which are determined by how closely the player's foot aligns with the center of the obstacle. This game tests the player's rhythm and coordination and provides an aerobic workout, requiring continuous foot movement and engagement with the music's tempo.

Figure 1: Dance mini game scenario.

The snow skiing mini game (Figure 2) aims to transport users to a thrilling virtual snowscape, encouraging them to simulate the physical motions of skiing and avoid specific obstacles on the way. This game allows players to virtually ski down a mountain, with each run focusing on navigating a series of challenges while descending the slope. The player controls the direction of their descent by turning their head left or right, corresponding to their virtual skis' movement. The course is filled with various obstacles that players must avoid by either ducking or jumping, mirroring these actions in real life to navigate the course successfully.

The game incorporates a life system where players start with four lives. Colliding with an obstacle results in losing a life; if all lives are lost, the game ends prematurely. Additionally, a countdown timer starts at two minutes, adding a layer of urgency, with the game concluding if the timer reaches zero. However, players can extend their time by passing through checkpoints marked by two flags; passing directly between them rewards the player with an additional minute on the clock. This combination of physical movement and time management challenges the player's reflexes and agility and ensures that the game maintains a high level of aerobic activity.

Figure 2: Snow skiing mini game scenario.

2.1.1 Software and Hardware

Regarding technology, both VR mini games were developed using the HTC Vive hardware, integrated with Unity, with a notable difference between them: the dance game incorporated HTC Vive Feet Trackers, while the ski game did not require their use.

For the VR dance mini game, the SteamVR plugin was used to streamline the integration of the foot trackers, which were essential for tracking foot movements. Additionally, the game employed a tool called BeatMapper to create custom beat maps for the music. This tool allowed the development team to precisely map the obstacles to the rhythm of the music, generating a file with the timing and positioning of the notes. The game script then reads this file to spawn obstacles at the correct times, ensuring an accurate rhythm-based gameplay experience.

In the VR snow skiing mini game, the "OpenXR plugin" was used instead of SteamVR, as it was simpler to work with and did not require the complexity of integrating the feet trackers. From a development perspective, the ski game involved more intricate mechanics, particularly the implementation of the jumping action. To detect a jump, three conditions were checked: whether the player was on the ground, whether there was acceleration along the "Y-axis" detected by the Vive sensors, and whether the player's current height was greater than the initial height within a defined margin of error. A Unity collider was dynamically adjusted in size for ducking based on the player's height from the ground. The collider's height would increase or decrease accordingly, ensuring it never exceeded the initial measured height. A force is applied to the "Rigidbody" component to ensure the player continuously moves downhill, simulating the effect of gravity and momentum during the descent.

2.2 Pilot-Study

2.2.1 Participants

Participants in this pilot study were five adults (two females) aged 25.2 ± 3.9 years (height: 166.2 ± 9.5 cm and body mass: 69.0 ± 4.8 kg). All individuals were healthy and did not present any constraints for PA participation. The procedures implemented in this study were approved by the Ethics Committee of the University of Madeira (Nº94/CEUMA/2023, 5th December), and all participants previously signed informed consent.

2.2.2 Instruments

The ActiGraph wGT3X-BT Activity Monitor (ActiGraph, 2023) assessed PA intensity level while playing the VR exergame session. The device was positioned on the right hip following previous research recommendations (Karaca et al., 2022), before the experiment commencement. The accelerometer was programmed before each data collection moment and started when the VR exergame session began. The accelerometer was initialized with a 30 Hz sampling frequency and raw data from GT3x files were converted to 10 s epoch data files before analysis. Time spent in sedentary behavior, light PA, moderate PA, vigorous PA, very vigorous PA, and moderate-to-vigorous PA was calculated using the ActiLife software, version 6 (ActiGraph, Pensacola, FL, USA), using the cutoff points suggested by the previous literature (Freedson et al., 1998). The number of steps per minute and total metabolic equivalent of task (MET) were also used for analysis.

During the VR exergame session, heart rate (HR) was monitored using the Polar H10 sensor (Polar Electro, Kempele, Finland) (Polar, 2023), which has been described as a valid instrument in previous literature (Schaffarczyk et al., 2022). Participants used the device in the chest using the manufacturer's strap. This positioning ensures optimal contact with the skin, allowing the sensor's electrodes to collect real-time HR data. This instrument has been widely used in several sports' activity settings. The mean HR scores of each session were used for analysis.

To examine the usability of the VR exergame session, the European version of the System Usability Scale (SUS) was used (Martins et al., 2015). The instrument is composed of 10 statements scored on a 5-point Likert scale (1 – strongly disagree, 5 – strongly agree) and allows the evaluation of the system's usability. Each participant filled out the questionnaire after the VR exergame session.

Finally, the rate of perceived exertion (RPE) scale was used to measure the level of PA intensity based on the participants' perception. RPE was collected at two moments, immediately after each mini-game completion, using the OMNI picture system (Robertson, 2004), elucidating different levels of effort (0 – extremely easy, 10 – extremely hard).

2.2.3 Study Design

Data collection was conducted in a research center facility equipped with a VR station. The experiment comprised three phases:

(1) First, participants were asked to fill out a form to collect information about their demographics (age, gender, nationality, height, and body mass), followed by a brief explanation of how the system works and informed consent signing.

(2) Second, the HCT Vive and PA monitoring sensors were placed on participants' bodies, and the VR exergame session was implemented.

(3) Third, participants reported their RPE and responded to the SUS questionnaire right after the VR game session.

Each mini game had a duration of approximately 20 min, and nearly 2 min were ensured for the transition between the first (dance) and the second game (snow skiing). The playing sequence of the two mini games was the same for all participants: first the dance game followed by the snow skiing game. In total, each participant played the VR games for nearly 40 min.

3 RESULTS

Table 1 summarizes the data collected through accelerometry concerning PA intensity level. During the VR game session, participants spent more time in sedentary behavior (37.5 ± 6.6 %), followed by light (35.1 ± 13.5 %), and moderate-to-vigorous (27.4 ± 17.6 %) activity. Overall, the VR game session elicited a mean value of 909.6 ± 358.5 steps, with an average of 27.1 ± 7.7 steps per minute and 123.5 ± 29.7 bpm. These data corresponded to a mean value of 2.2 ± 0.9 METs.

Table 1: Descriptive statistics for PA intensity.

Variables	M ± SD
Sedentary behavior (min)	12.1 ± 3.0
Light PA (min)	11.1 ± 4.0
Moderate PA (min)	8.2 ± 5.5
Vigorous PA (min)	0.8 ± 0.8
Very vigorous PA (min)	0.3 ± 0.5
Moderate-to-vigorous PA (min)	9.3 ± 6.7
Sedentary behavior (%)	37.5 ± 6.6
Light activity (%)	35.1 ± 13.5
Moderate PA (%)	24.1 ± 14.3
Vigorous PA (%)	2.4 ± 2.4
Very vigorous PA (%)	0.8 ± 1.4
Moderate-to-vigorous PA (%)	27.4 ± 17.6
Total steps counts (n)	909.6 ± 358.5
Steps per min (n)	27.1 ± 7.7
METs	2.2 ± 0.9
Heart rate (bpm)	123.5 ± 29.7
M ± SD (mean ± standard deviation), PA (physical activity), MET (metabolic equivalent of task)	

Figure 3 displays the results of the RPE for each mini game. Participants perceived exertion scores were higher in the dance mini game than in the ski mini game, probably due to whole-body rhythmic movements elicited and synchronized with the virtual dance moves.

Figure 4 presents the SUS questionnaire responses by each participant. The results indicate that participants would like to use this system more frequently, and only one participant reported that the system was not easy to use. Overall, participants indicated that they would not need technical support or much time to learn about the system to play the games. Participants also agreed that most people could learn how to use the system quickly.

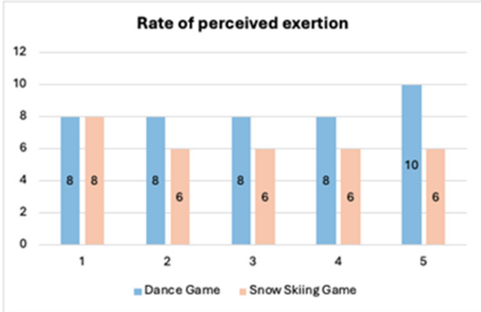

Figure 3: Rate of perceived exertion reported in each mini game.

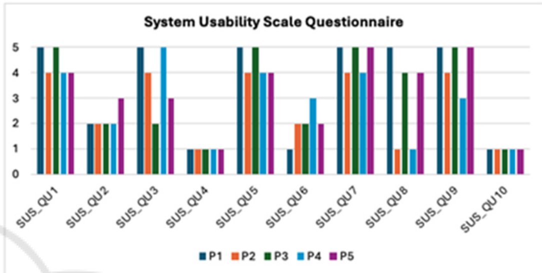

Figure 4: System Usability Scale questionnaire responses by each participant.

4 DISCUSSION

This study presents the preliminary results of a pilot study conducted in the first testing stage of a new VR exergame system designed to promote PA. Concerning PA intensity, most of the VR game session was spent in sedentary activity (≈ 37.5%), followed by light activity (≈ 35.1%), and moderate-to-vigorous activity (≈ 27.4%). Additionally, combining the data of average steps per minute (≈ 21.1) and average HR (≈ 123.5 bpm), the VR exergame session elicited ≈ 2.2 METs.

Intensity is an indicator of the metabolic demand of activity, and the MET is a standard unit used to express exercise intensity, influenced by several factors such as sex, age, and body composition (Katch et al., 2011). Regarding METs, the results of this pilot study were within the range of 1.6 to 2.9, which is indicative of light PA intensity (Strath et al., 2013). Curiously, from the participants' perception, the intensity was higher than the objective measures collected. Light PA has been associated with RPE values ranging from 4 to 5 (Strath et al., 2013), which is lower than the RPE scores reported in this pilot study (ranging from 6 to 10). Although previous research has reported RPE is a useful tool for most individuals, scores might be over or underestimated based on sex or sports experience (Skatrud-Mickelson et al., 2011).

On the other hand, HR variability is also associated with changes in PA intensity and is a frequently used metric for exercise prescription (Karvonen & Vuorimaa, 1988). In several sports contexts, professionals use average HR values to characterize a specific activity. In this study, participants' average HR was within the data reported in previous studies. For instance, in a study conducted with 24 adults aged 27.8 ± 3.3 years, the authors reported an average HR of 122.8 ± 15.9 bpm while playing a VR exergame involving standing, jumping, and arm swinging movements (Park et al., 2020). In another study involving 129 individuals aged between 18 and 26 years, an average HR of 109.2 ± 45.0 bpm was registered while playing Just Game 3 (Lin, 2015). Although HR may present a significant variability based on an individual's specific characteristics, including their maximal HR, the results of the current pilot study suggest a moderate intensity level elicited by the VR exergame session (based on the estimation of 195 bpm as maximum HR for this population). Though METs data indicate a predominance of light intensity PA, HR insinuates greater intensity, which might justify the results of RPE.

In the meantime, participants accumulated ≈ 17.5 min of moderate and moderate-to-vigorous PA. According to the American Heart Association, among adults, substantial health benefits are related to 150 min per week of moderate PA or 75 min per week of vigorous PA (Strath et al., 2013). Unequivocally, these recommendations would not be achieved exclusively using VR exergame sessions. However, this system might emerge as a complementary tool to traditional PA, offering a different and engaging way of being active while providing part of the necessary amount of PA intensity weekly recommended.

Finally, the assessment of the usability of the system is an important phase of system/product development (Martins et al., 2015). Besides assessing PA levels while exergaming, this pilot study also included the evaluation of the system from the participants' perspective. Overall, most participants considered the system easy to use and learn, which validates its development process.

The current study presents several limitations that must be recognized. First, this is a pilot study with few participants, and although the results are promising, more testing sessions are still needed to validate the system thoroughly. Second, the VR exergame session development did not consider recommended guidelines for structuring PA sessions (i.e., warm-up, main phase, cool-down). Indeed, including this structure would allow us to replicate a traditional PA class in a virtual environment. Third, details concerning individuals' previous PA experience were not collected, which would allow a more in-depth analysis of the results. Finally, data collection was cross-sectional, while a longitudinal approach would be far more informative. Even though, the results presented are valuable, particularly by emphasizing the ability of this VR exergame session to provide light to moderate PA. Therefore, exergames might be complementary to traditional PA settings, providing users with a different and engaging experience while developing health-related benefits.

5 CONCLUSIONS

In the VR game session (dance plus snow skiing mini games) designed for this study, participants spent nearly 37.5%, in sedentary activity, 35.1% in light activity, and 27.4% in moderate-to-vigorous activity. The average of steps per minute was 21.1 and average HR around 123.5 bpm, eliciting approximately 2.2 METs. The results regarding PA intensity suggests predominance of light intensity activity, however, HR values suggest greater exercise intensity which is aligned with participants' RPE (ranging from 6 to 10). According to the participants' perception, the dance mini game was more physically demanding than the snow skiing mini game, probably due to the need of using continuously whole-body movements. The results of the SUS questionnaire indicate an overall good usability of the VR system. This study emphasizes the ability of promoting light to moderate PA through a VR game session. Exergames might be implemented as a complementary and diversifying tool to traditional PA programs.

ACKNOWLEDGEMENTS

This research was funded by the Portuguese Recovery and Resilience Program (PRR), IAPMEI/ANI/FCT under the Agenda C645022399-00000057 (eGamesLab).

REFERENCES

ActiGraph. (2023). *ActiGraph wGT3X-BT*. Retrieved 2023/11/10 from https://theactigraph.com/actigraph-wgt3x-bt

Agmon, M., Perry, C. K., Phelan, E., Demiris, G., & Nguyen, H. Q. (2011). A pilot study of Wii Fit exergames to improve balance in older adults. *Journal of geriatric physical therapy*, *34*(4), 161-167.

Alhagbani, A., & Williams, A. (2021). Home-based exergames for older adults balance and falls risk: A systematic review. *Physical & Occupational Therapy In Geriatrics*, *39*(3), 241-257.

Boulos, M. N. K., & Yang, S. P. (2013). Exergames for health and fitness: the roles of GPS and geosocial apps. *International journal of health geographics*, *12*(1), 1-7.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health reports*, *100*(2), 126.

Comeras-Chueca, C., Villalba-Heredia, L., Perez-Llera, M., Lozano-Berges, G., Marin-Puyalto, J., Vicente-Rodriguez, G., Matute-Llorente, A., Casajus, J. A., & Gonzalez-Aguero, A. (2020). Assessment of Active Video Games' Energy Expenditure in Children with Overweight and Obesity and Differences by Gender. *International Journal of Environmental Research and Public Health*, *17*(18), Article 6714. https://doi.org/10.3390/ijerph17186714

Costa, M. T. S., Vieira, L. P., de Oliveira Barbosa, E., Oliveira, L. M., Maillot, P., Vaghetti, C. A. O., Carta, M. G., Machado, S., Gatica-Rojas, V., & Monteiro-Junior, R. S. (2019). Virtual reality-based exercise with exergames as medicine in different contexts: A short review. *Clinical practice and epidemiology in mental health: CP & EMH*, *15*, 15.

Cox, A., Fairclough, S. J., Kosteli, M. C., & Noonan, R. J. (2020). Efficacy of School-Based Interventions for Improving Muscular Fitness Outcomes in Adolescent Boys: A Systematic Review and Meta-analysis. *Sports Med*, *50*(3), 543-560. https://doi.org/10.1007/s40279-019-01215-5

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the computer science and applications, inc. accelerometer. *Medicine and Science in Sports and Exercise*, *30*(5), 777-781.

Gao, Z., & Chen, S. (2014). Are field-based exergames useful in preventing childhood obesity? A systematic review. *Obesity Reviews*, *15*(8), 676-691.

Karaca, A., Demirci, N., Yılmaz, V., Hazır Aytar, S., Can, S., & Ünver, E. (2022). Validation of the ActiGraph wGT3X-BT accelerometer for step counts at five different body locations in laboratory settings. *Measurement in Physical Education and Exercise Science*, *26*(1), 63-72.

Karvonen, J., & Vuorimaa, T. (1988). Heart rate and exercise intensity during sports activities: practical application. *Sports Medicine*, *5*, 303-311.

Katch, V., McArdle, W., & Katch, F. (2011). Energy expenditure during rest and physical activity. *McArdle WD, Katch FI, Katch VL. Essentials of Exercise Physiology. 4th ed. Baltimore, MD: Lippincott Williams & Wilkins*, 237-262.

Ko, J., Jang, S.-W., Lee, H. T., Yun, H.-K., & Kim, Y. S. (2020). Effects of virtual reality and non–virtual reality exercises on the exercise capacity and concentration of users in a ski exergame: Comparative study. *JMIR serious games*, *8*(4), e16693.

Lee, I.-M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The Lancet*, *380*(9838), 219-229.

Lin, J.-H. (2015). “Just Dance”: the effects of exergame feedback and controller use on physical activity and psychological outcomes. *Games for health journal*, *4*(3), 183-189.

Maddison, R., Foley, L., Ni Mhurchu, C., Jiang, Y. N., Jull, A., Prapavessis, H., Hohepa, M., & Rodgers, A. (2011). Effects of active video games on body composition: a randomized controlled trial. *American Journal of Clinical Nutrition*, *94*(1), 156-163. https://doi.org/10.3945/ajcn.110.009142

Martins, A. I., Rosa, A. F., Queirós, A., Silva, A., & Rocha, N. P. (2015). European Portuguese validation of the system usability scale (SUS). *Procedia computer science*, *67*, 293-300.

Meldrum, D., Glennon, A., Herdman, S., Murray, D., & McConn-Walsh, R. (2012). Virtual reality rehabilitation of balance: assessment of the usability of the Nintendo Wii® Fit Plus. *Disability and rehabilitation: assistive technology*, *7*(3), 205-210.

Park, S.-B., Kim, M., Lee, E., Lee, D., Son, S. J., Hong, J., & Yang, W.-H. (2020). Energy system contributions and physical activity in specific age groups during exergames. *International Journal of Environmental Research and Public Health*, *17*(13), 4905.

Polar. (2023). *Polar H10*. Retrieved 2023/11/10 from https://www.polar.com/pt/sensors/h10-heart-rate-sensor?srsltid=AfmBOooszSlUm_t6Lk6IRpZf2255HVxmRH5UKFrtDECs1qvBhbhASBze

Pope, Z., Chen, S., Pasco, D., & Gao, Z. (2016). Effects of Body Mass Index on Children's Physical Activity Levels in School-Based "dance Dance Revolution" [Article]. *Games for Health Journal*, *5*(3), 183-188. https://doi.org/10.1089/g4h.2015.0098

Robertson, R. J. (2004). *Perceived exertion for practitioners: rating effort with the OMNI picture system*. Human Kinetics.

Schaffarczyk, M., Rogers, B., Reer, R., & Gronwald, T. (2022). Validity of the polar H10 sensor for heart rate variability analysis during resting state and incremental exercise in recreational men and women. *Sensors*, *22*(17), 6536.

Skatrud-Mickelson, M., Benson, J., Hannon, J. C., & Askew, E. W. (2011). A comparison of subjective and objective measures of physical exertion. *Journal of Sports Sciences*, *29*(15), 1635-1644.

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., Richardson, C. R.,

Smith, D. T., & Swartz, A. M. (2013). Guide to the assessment of physical activity: clinical and research applications: a scientific statement from the American Heart Association. *Circulation*, *128*(20), 2259-2279.
Trajković, N., Mitić, P. M., Barić, R., & Bogataj, Š. (2023). Effects of physical activity on psychological well-being. In (Vol. 14, pp. 1121976): Frontiers Media SA.
Trost, S. G., Sundal, D., Foster, G. D., Lent, M. R., & Vojta, D. (2014). Effects of a Pediatric Weight Management Program With and Without Active Video Games A Randomized Trial. *Jama Pediatrics*, *168*(5), 407-413. https://doi.org/10.1001/jamapediatrics.2013.3436
WHO. (2020). WHO guidelines on physical activity and sedentary behaviour.
Wickramarachchi, B., Torabi, M. R., & Perera, B. (2023). Effects of physical activity on physical fitness and functional ability in older adults. *Gerontology and Geriatric Medicine*, *9*, 23337214231158476.