The Enjoyability of Physical Exercise: Exergames and Virtual Reality as New Ways to Boost Psychological and Psychosocial Health in Astronauts. A Prospective and Perspective View

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***Abstract*—On Earth, physical activity plays a tremendous role to preserve and improve the physical, psychological, and social well-being of people. The enjoyability, the appreciation, and the variability of the exercises are fundamental factors for the production of lifestyle benefits. Currently, exercise countermeasures for astronauts during long-duration missions focus more on the physiological side, frequently overlooking the relevant psychosocial one. Exergames are a form of physical activity that have taken hold in the last decades on Earth and has been widely accepted as a more enjoyable and engaging rehabilitation, reconditioning, and training tool compared to the previous conventional ones. After a review of the current needs of astronauts and of the positive effects of exergames on people on Earth, we suggest that exergaming should be implemented in space missions to improve physical, psychological, and social well-being of astronauts. We also propose practical methods on how exergames can be effectively implemented.**

***Index Terms*—Engagement, social-relationships, sport, team-spirit, well-being.**

***Impact Statement*—Exergaming can be a novel key support for astronauts' physiological, psychological, and social well-being during long-duration space missions.**

I. Introduction

PHYSICAL exercise is an essential and well-established tool to support and improve health and well-being of the people, and for the same reason it has been applied by space agencies to counteract and mitigate the physiological impairments caused by the long permanence of astronauts in the microgravity environment [1]. The exercise protocols followed by the astronauts are developed based on the scientific evidence of their effectiveness and on the existing availability of exercise hardware and equipment designed for space application. The design phase of exercise devices to be used in space is significantly slower and more complex compared with that for ground-application because factors like volume, mass, power, transportation, cost, load capacity, transmission of forces, and vibration isolation must be carefully considered and align with the characteristics of the spacecraft and its operational environment. The current training schedule on the International Space Station (ISS) consists of 1.5 net hours of exercise daily, and is a combination of strength, endurance, and cardiovascular protocols executed on different devices (Advanced Resistive Exercise Device, or ARED, treadmill, cyclo ergometer) [1]. Crew members alternate loads between 60–85% of maximal oxygen consumption (VO_2) for cardiovascular protocols, and 60–85% of the 1 Repetition Maximum (RM) for the resistance ones, respectively [1], [2]. It must be acknowledged and highlighted that exercise countermeasure programs developed in the last decades for astronauts aboard the ISS have been at least partly effective in avoiding or limiting muscular deconditioning, bone density loss, cardiovascular deficiencies, and hormonal disequilibrium, allowing astronauts to partly maintain their health and performance [1], [2], [3], [4], [5].

However, these exercises are always performed on an individual basis and consist of only the same physical load parameters, with a huge rate of repetitiveness from a qualitative point of view. Therefore, several sport-related positive psychological and psychosocial outcomes are not being addressed, targeted, and considered.

A. Astronauts Needs and Psychosocial Characteristics of Exercise

Sport and physical activity can significantly contribute to the psychological and social well-being of a person improving

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aspects like self-confidence, self-efficacy, fun, satisfaction, pleasure, enjoyment, stability, sense of meaning, social belonging, peer-support, team-spirit, motivation, sense of community, social harmony, and can help to reduce anxiety and depression [6], [7], especially when performed with other persons (i.e.,: team, couple, group activities) [8], [9]. Such aspects may be extremely useful and supportive for astronauts, given the variety of psychological and social challenges they face during their long-duration missions in a challenging confined environment [10], [11], [12], [13]. Accordingly, NASA currently reports that psychological and social risks for long-duration human space flights require monitoring and mitigation, with further counter and preventive measures to be taken [14]. In addition, boredom and monotony have been linked to psychological states of under-arousal and indicated as important mediators of mental fatigue [15].

Moreover, on Earth, the enjoyability of physical exercise and fun are of paramount importance to maintain the adherence to exercise protocols, to enhance the participation in sport, and to improve the outcomes of physical exercises [16], [17]. This is true also for astronauts after their return from a mission [18]. Social interaction and peer-related aspects like communication, experiencing novel activities (to daily routines) have been associated with the emergence of positive emotions during sport and exercise [19]. It also has been shown that performing novel and varied activities is a basic psychological need, and can promote intrinsic motivation, physical activity adherence, and other physical and psychological parameters [20].

Astronauts themselves believe that practicing enjoyable and varied exercise protocols is paramount to reduce boredom and improve their psychological status for space missions longer than 30 days, which is value under which a mission can be considered as short-duration and does not place the same psychosocial challenges of the long-duration ones [21]. Specifically, these considerations have been released by three astronauts referring to the design and implementation of exercise countermeasure protocols for the forthcoming lunar orbital missions [21]. One astronaut reported that "*Exercise in space needs to be an activity that the crew will enjoy, contributing to both physical and mental well-being*" [21]. Such a need has long been acknowledged, pursued, and followed by several space agencies [22]. Astronauts also report that they try to engage in some parallel activity while exercising, like watching movies or imagine themselves to be participating in some sort of activities on Earth such as marathons [23]. Therefore, considering the above-mentioned challenges and constraints in updating and developing new exercise devices for space applications and the well-identified astronauts' psychological and social needs for the future long-term missions, the aim of this paper is to present and discuss a promising exercise approach that makes the exercise protocol more enjoyable and foster more of the psychological and psychosocial aspects of physical activity. We present the characteristics of exergaming, which is a training and rehabilitation tool which has been effectively used on Earth and may represent a new promising approach to improve the exercise countermeasure protocols during long-term missions. The third section of the paper (III) will focus on how exergaming platforms and activities can be effectively and practically implemented in current and future space missions.

Fig. 1. A cycling exergaming platform, holodia holofit ©. Image taken from holodia holofit's official website.

Fig. 2. A rowing exergaming platform, holodia holofit ©. Image taken from holodia holofit's official website.

II. Exergaming: A New Solution?

In the last decade, several gaming platforms and videogames have been designed and released commercially to let the user be more physically active while playing indoor, and has subsequently been a useful training and rehabilitation tool on Earth (Figs. 1–5). There is an ongoing debate on how to best define exergames giving the appropriate relevance to the exercise and gaming components [24]. Despite the lack of an official recognized definition, exergames are currently described as an interactive video gaming system that requires bodily movement to play and function, thereby stimulating a form of physical activity [24]. While virtual reality (VR) is a broader term for an experience that can have multiple uses (entertaining, training, communication, etc.) including exercise, exergame refers to

Fig. 3. Exergaming platform requiring only a screen and a manual device, nintendo ring fit adventure ©. Image taken from nintendo's official website.

Fig. 4. Exergaming platform allowing running, jumping, and crouching, omnione virtuix ©. Image taken from omnione virtuix's official website.

Fig. 5. NASA astronaut megan mcarthur (expedition 65, 2021) using a VR device for inflight operational training onboard the ISS. Image taken from NASA's official website.

interactive video games (often in a VR environment) specifically designed to require physical activity or exercise to be played. In exergames, the user or player performs activities and movements that mimic those of well-known sports, such as basketball, golf, tennis, bowling, boxing, dancing, archery, biking, in front of a screen or using a VR device. In the VR environment, an avatar replicates the user's actual movements to avoid virtual obstacles, defeat "enemies", or follow a track. These exergames can be played individually or with other persons, together in the same room or online, with or without any additional equipment (like racquets, weights, VR headsets, etc.), to unlock and overcome new challenges and achieving new records. The gaming atmosphere encourages the user to be progressively more engaged in a physical activity environment while being entertained and incentivized to face challenges and play with peers simultaneously. Based on the characteristics of the sport or activity displayed, the user will consequently perform specific movements and actions to respond to the presented situation, like squats, lunges, jumps, arm-presses, skips, pulls, bending, and many other muscle-group or whole-body functional movements that stimulates both the cardiovascular and musculoskeletal system.

Research has shown that exergames can improve several physiological (muscle strength, balance, cardiovascular, metabolic), cognitive (executive functioning, visuospatial skills, attention, processing speed, etc.), psychological, and psychosocial functions and aspects on Earth [25], [26], and can meet the levels of physical activity recommended by health authorities [27], [28]. In these studies, exergame protocols are typically assigned for several weeks (8–12) with 3–4 sessions per week. Then, the results are often compared to a control population or to other physical training interventions. Here, physiological improvements are specific to the activity performed by the user or player, and specific stimuli or load parameters are necessary. Hence, it is paramount to choose an exergame modality (e.g.,: type of exergame like rowing for upper limbs and core muscles, dancing for lower limbs and whole-body coordination, etc.; volume; intensity; etc.) that targets the desired muscle groups, body movements, and physiological mechanisms. The game modalities of exergames may vary and can be set at easy (light physical load) or hard (heavy physical load) levels. Exergames can improve several strength and balance parameters in some populations [29], [30], and can be used to reach higher workloads while perceiving less exertion due to a higher enjoyment of the activity than traditional exercise protocols [31]. Previous demonstrations show that an acute bout of high intensity interval training (HIIT) is more enjoyable when delivered using an exergaming platform relying on VR [32]. These participants were shown to achieve higher intensities when competing against their own previous performance as a target [32]. In particular, Farrow et al. showed that participants managed to reach up to 84% of their personal maximum power output during a HIIT cycling exergaming protocol [32]. This is an important finding because HIIT protocols have been shown to be an effective method to improve cardiovascular health, neuromuscular functionality, muscle power, with the advantage of being a more efficient time-saving activity than other lower-intensity exercise protocols [33], [34], [35], [36]. Similarly, Keller et al. [37] showed that a rowing exergame HIIT protocol elicited more positive outcomes for some cognitive and psychological metrics (motivation, affect, mood restoration, visual short-term memory, reaction times) than the control condition (simple physical exercise without VR). Bronner et al. demonstrated that dancing exergames allowed to reach moderate and vigorous metabolic equivalents (MET) with a maximum value of 9.18 (MET levels can range from low values of 2.0 for light activities such as walking, to high values above 10.0 for vigorous activities such as rope jumping), and the users' engagement and flow were positively associated with the intensity level reached during the activity [38].

A systematic review and meta-analysis reported that people often achieved up to moderate intensity (calculated as % of their maximal Heart Rate - HR - , VO_2, and MET) during boxing exergames [39]. However, it has been warned that available exergaming modalities may not always allow elite athletes to reach their personal maximal power output and therefore their needed training load [40]. This highlights that a careful analysis should always be made regarding whether the planned and desired physiological and metabolic outcomes can be achieved with a given exergaming platform, device, or protocol [40]. Specifically, Chung et al. reported that elite athletes could reach only 57–64% of personal maximum HR in males, and 67–82% in females in a rowing exergame, while VO_2 max reached only 40% of the athletes' personal maximum [40].

Interestingly, research has also shown that playing exergames with other players, known as multiplayer modalities, where it is possible to cooperate and/or to compete together bears some physiological and psychosocial advantages compared to the single modality, thanks to enhanced social interaction, interactivity, and immersion [41], [42]. For instance, it was reported that playing football and boxing exergames against another player elicited higher physiological outcomes than playing alone (minute ventilation, oxygen uptake and HR at least 18% higher; energy expenditure 21% higher), even though the absolute intensity remained low (probably due to the backwardness of the exergame device used in that study) [43]. The authors suggested that the increase could be explained by psychological (more enjoyment and engagement), and technical reasons (human competitor's actions are more unpredictable than artificial intelligence's (AI), making the game more intense). In the most recent study, it was found that a cycling exergame elicited slightly higher HR and VO_2 values when performed against a competitor than alone, suggesting the superiority of exergaming with other people as a more effective training tool [44]. Mackintosh et al. found that while no differences in energy expenditure were found between single and multiplayer conditions in a 30-minute boxing exergame, female players reported higher perceived vitality in the multiplayer scenario [45]. Similar results were also obtained by McDonough et al., who reported no differences in physiological variables between single and double player exergaming modalities in elite athletes, but a lower perceived exertion in the double condition [46]. It is also possible that higher loads and physiological outcomes can be elicited only when participants compete with each other and not just exercise together (cooperative modality, like performing the same dance) [47]. This is supported by the findings of Giancotti et al., who found no differences in physiological and metabolic outcomes between individual vs couple exergaming modalities [47].

Alongside the physical and psychological considerations and beyond the already mentioned effects on enjoyment of the exercise, the psychological side of practicing exergames has been deeply considered, with several studies investigating the impacts on enjoyment, flow, and/or immersion [41].

But how can exergames be applied in a space environment, in microgravity or hypogravity conditions, inside an orbital spacecraft or on a surface base?

III. Implementation of Exergames and Virtual Reality in Current and Future Space Stations

The astronauts' exercise schedule depends on the available equipment and devices, which, in turn, depends on the characteristics and specifications of the given space station or spacecraft (volume, mass, power availability, etc.), as well as the environmental conditions (microgravity, hypogravity, etc.). For instance, the ISS has access to several exercise devices (ARED, treadmill, cyclo ergometer, plus prototype rowing machines and elastic bands) [1]. Whilst smaller spacecrafts, such as the new Orion Multi-Purpose Crew Vehicle, will only have a small but efficient rowing machine, and future planetary bases will have more available volume allowing the implementation of more complex activities and exercise devices [21], [48], [49].

To kick off the exergaming era during the space missions and to start providing astronauts with similar psychosocial benefits as those mentioned above, the first step would be integrating the VR in already existing and operational devices, for example within the treadmill and the cyclo ergometer on board the ISS, resulting in an immersive training [50]. The implementation of VR would simply consist of a VR headset and a software update of the existing exercise devices, thereby resulting in the previously described exergaming training scenario [31], [32], [51], [52], [53]. This same VR approach can be applied to the rowing equipment planned for the upcoming Orion spacecraft, which will host astronauts for a short duration orbital mission around the Moon [40], [48], [54]. Such implementations in exercise protocols have also been suggested and welcomed by astronauts themselves [21]. Although the ISS, Orion, and future Lunar Gateway environments would not allow the crew to exercise together at the same time on site, the astronauts would still benefit from social and competitive stimuli because of the nature of exergames, which provide challenges to be overcome, achievements to be unlocked, and records to be beaten among crewmembers. In other words, the system could provide daily or weekly challenges in several different VR scenarios, that astronauts should achieve individually or as a team by summing all individual performances. Moreover, the new telecommunication capabilities could allow astronauts to perform an exergame like cycling, running, or rowing with a family member on Earth within the same VR scenario (with shared environmental location and tasks), alongside the added possibility to communicate with one another at the same time. Talking and sharing moments with their families has been indicated by astronauts as precious and meaningful psychological source of support for their mission [23]. These opportunities would benefit astronauts' physiology, psychology, and social interactions [41], [51]. Murray et al. demonstrated benefits of cooperative rowing exergame when the user plays with another person in a VR scenario [54]. Here, the VR environment displayed the river and the participants' boats, and participants had common tasks to be achieved [54]. The study showed that cooperative rowing leads to better performance, higher physiological load, and more enjoyable than rowing without VR [54]. Nunes et al. reported a similar outcome when participants ran on a treadmill in a competitive exergame context [53]. The competition involves the player and a competitor running on a treadmill simultaneously within the same shared VR environment [53].

We think that exergaming might have a greater impact on incoming activities of human exploration of space for the following reasons. First, the humans will land on the Moon and live in a surface base with a reduced gravitational pull. Second, human settlements might have higher habitable volume than a spacecraft. Several concepts and proposals regarding future Moon bases have been released, including a Base Camp resulting from the upcoming Artemis missions [55], the transformation of a SpaceX Starship Human Landing System into a horizontal habitable volume after its landing [49], and a detailed long-term roadmap by the Moon Village Association [56]. A higher available volume would result in an increased number of exercise devices and equipment that can be stored and used by the astronauts, also allowing crewmembers to train together, with all the related psychosocial [45] and physiological benefits [43], [54]. Exercising with cooperative and competitive exergames amongst crew members can be a useful tool to cultivate a more cohesive and multicultural environment [57]. This is an important aspect because astronauts typically have different nationalities and cultures. Sport benefits team cohesion and increases opportunities for socializing between groups [57]. The reduced gravitational pull might allow astronauts to perform new general exercises and, therefore, Earth-based sport exergames. For example, exergames designed for human settlements may likely have additional features than those designed for orbiting spacecraft, such as the ISS. Such new features may allow astronauts to conduct a wider variety of activities, such as dancing [38] and boxing [39] that, in turn, may increase the benefits they can get, and comply with their psychological necessities [21], [23]. Moreover, additional weight could be applied to astronauts with the use of weighted-vests or elastic/rigid harnesses attached to floors or walls, and training sessions could be performed with crewmembers or via internet with family members on Earth, within the same VR environment. By using the proper equipment, plyometric activities could also be performed, thereby stimulating an increase in bone strength, neuromuscular functionality, and cardiovascular efficiency [58]. Plyometric activities are cyclical movements characterized by short-duration and high-force loading that can counteract hypogravity-related decrements, primarily muscle power and bone strength [58].

It is important for astronauts to be able to break monotony and have access to more interesting activities when deployed [21], [23]. There have been reports of improvised games, such as a sort of Quidditch (a fictional team-sport made popular by the fantasy novel series Harry Potter, where players fly and try to score points by throwing or catching different flying balls) and a sort of jumping/flying-exercise within ISS' modules [21]. Due to the physical and psychological demands required of astronauts during missions, the activities provided by mission planners must attempt to closely resemble an astronaut's daily routine on Earth [23]. However, these exercises must also exploit the unique environment observed during spaceflight whilst also being engaging and entertaining for the astronauts.

TABLE I
SUMMARY EXAMPLES OF EXERGAME ACTIVITIES (INDIVIDUAL OR GROUP), AND RELATED ESTABLISHED AND POTENTIAL BENEFITS FOR ASTRONAUTS AND PEOPLE ON EARTH

Exergame (Exercise)	Mission type	Potential benefits for astronauts	Established and potential benefits for ground application
Jogging / Track & Field (running) [27], [53]	Orbital / Planetary	Cardiovascular, Coordination, Strength, Cognitive, Psychosocial	Cardiovascular [27], [53], Coordination, Strength, Cognitive, Psychosocial [27], [53]
Cycling [31], [32], [44]	Orbital	Cardiovascular, Cognitive, Psychosocial	Cardiovascular [31], [32], [44], Cognitive [26], Psychosocial [31], [32]
Rowing [37], [40], [54]	Orbital / Planetary	Cardiovascular, Strength, Cognitive, Psychosocial	Cardiovascular [40], [54], Strength, Cognitive [37], Psychosocial [37], [54]
Dancing [38]	Planetary	Cardiovascular, Strength, Coordination, Cognitive, Psychosocial	Cardiovascular [38], Strength, Coordination, Cognitive [26], Psychosocial [38]
Boxing [39], [43], [45]	Planetary	Cardiovascular, Strength, Coordination, Cognitive, Psychosocial	Cardiovascular [39], [43], Strength, Coordination, Cognitive, Psychosocial [45]
Basketball (jumping, throwing, running)	Planetary	Cardiovascular, Strength, Coordination, Cognitive, Psychosocial	Cardiovascular, Strength, Coordination, Cognitive, Psychosocial
Bowling (squats & lunges)	Planetary	Strength, Coordination, Cognitive, Psychosocial	Strength, Coordination, Cognitive, Psychosocial

Moreover, exergames might stimulate the perceptual and cognitive parts of the human brain [26]. The rapid execution of movements in response to unpredicted situations requires the simultaneous use of physiological, cognitive, and biomechanical functions [25], [26], which, in turn, might increase performance in rapid multi-joint, multi-plane, or whole-body functional movements in instability conditions [59], [60], [61]. Published literature shows that practicing physical activities and sports in groups (with teammates and opponents) stimulates perceptions, cognitions, and tactical abilities, because players are in new or unpredictable situations [62], [63]. Studies show increased production of neurotrophic factors such as the brain-derived neurotrophic factor, which regulates several cognitive functions like memory, working memory, inhibition, self-regulation, and goal-oriented behaviors [64], [65].

High intensities are hard to reach with some exergaming protocols [40]. Hence, exergames shall not be the only training methodology and shall be part of a broader exercise program allowing for the variability of the training stimuli and the astronauts' enjoyment [1], [23]. Additionally, such a mixture of methodologies shall account for the specificity of exergames concerning muscle groups, body movements, and physiological mechanisms to target to gain the desired outcome [25], [29].

IV. Conclusion

Exergaming might represent a valuable solution to improve astronauts' psychological and social well-being and health during long-duration missions, in addition to providing valid and novel physiological stimuli. On Earth, the effectiveness of exergames to improve health of people with a variety of conditions as well as the healthy is well established [25], [26], [29], [30], [66], [67], and their implementation in space mission is therefore encouraged. As mentioned previously, astronauts encouraged and welcomed the adoption of new exercise countermeasures focusing on the physiological and psychosocial well-being [21], [23]. Exergames may result in the technology that allows astronauts to conduct variable and enjoyable physical activities [31], [41], [45]. Yet, further studies are needed to assess exergames' technology for use in space and for investigating if alterations of astronauts' performance follow similar trends of that seen in human studies on the ground.

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