Exergaming and Virtual Reality for Health: Implications for Cardiac Rehabilitation

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Abstract: Cardiac Rehabilitation (CR) programs, focused on improving the health trajectory of patients with cardiovascular disease, strive to increase physical activity (PA) and cardiorespiratory fitness. However, historically low compliance with recommended PA has prompted exploration of alternatives to traditional courses of exercise therapy. One alternative, exergaming, or the requirement of physical exercise inherent to a video game's activities, has shown to have a promising impact in improving patient self-efficacy for exercise training using digital hardware (eg, the Wii or the Xbox Kinect). Furthermore, novel technologies in virtual reality can provide an engaging, immersive environment for exergaming techniques, maximizing goal-oriented training and building self-efficacy for patients during CR. Many groundbreaking institutions are already calculating energy expenditure of commercially successful virtual reality games and finding promise in the cardiometabolic responses to a number of virtual reality games. Research is still limited in establishing the efficacy of these games, but virtual reality and exergaming are quickly proving to be appropriate and equivalent alternatives to traditional exercise programs. Though studies have examined the impact of prescriptive exergaming on PA, they have yet to examine the

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potential for genuine integration of game-based motivational techniques and immersive environments into clinical interaction. The purpose of this review is to describe the current body of evidence and the impact and future potential of virtual reality and exergaming. Further, we will introduce the concept of a "Clinical Arcade" as a new approach to integration of these techniques in CR care. (Curr Probl Cardiol 2021;46:100472.)

Introduction

While there are many well-established health behaviors and clinical factors that contribute to the development of cardiovascular (CV) disease (CVD), physical inactivity and a low cardiorespiratory fitness (CRF) have been identified to be among the strongest predictors of future CVD events.[1-9] Exercise rehabilitation facilitated through supervised programs, such as cardiac rehabilitation (CR), are the mainstay of secondary prevention of CVD, using multidisciplinary behavioral lifestyle modification approaches including structured aerobic-based physical activity (PA), with the goal of improving CRF and other clinical prognostic metrics, reducing hospital readmissions, and enhancing patients' quality of life.[10-18] Despite receiving a class IA indication from the American Heart Association,[19] coverage by Centers for Medicare and Medicaid Services and cost-effective payments for private payers with CVD, referral and participation in CR remain dismally low.[20] Accordingly, in efforts to bolster CR participation, many organization and agency-wide initiatives, most notably the "Million Hearts Cardiac Rehabilitation Collaborative Initiative" have been created with action plans that aim to increase CR referral, enrollment, and participation rates from its current state of 20%-30% to 70% by 2022.[21] Despite overwhelming attention and support from the medical community at large, enrollment and adherence to CR continues to be a challenge. Psychological factors, such as self-efficacy to perform exercise or misinterpreting the physical demands of expected PA, have been identified as intrinsic barriers that may preclude enrollment or adherence to CR.[22] Therefore, alternative forms of exercise therapy that aim to increase exercise engagement and ultimately improve CRF should be available to patients that may be less inclined to start programs using traditional modes of exercise (eg, treadmill training, cycle ergometry).

Exergaming and Clinical Applications

As an alternative to traditional exercise therapy, *exergaming*, or the requirement of physical exercise inherent to a video game's structure, is not entirely novel with respect to clinical application. With the modern explosion in the popularity of video games and virtual reality, researchers have looked to exergaming as a potential solution to patient motivational struggles with PA and compliance with a structured exercise regimen.[23-27] Studies examining exercise expenditure (EE) in a variety of age groups have shown that exergames are well received as models for introducing PA, increasing or meeting EE at the appropriate levels for moderate to vigorous PA (MVPA).[23,28-30] Incidentally, patients using exergames rather than traditional exercise routines (eg, walking, running, or cycling) have been reported to exercise for longer periods, meeting MVPA levels, with the perception of lower "work",[26,31,32] highlighting the potential for improved compliance and motivated connection to PA. Outside of clinical recommendation, exergames have found commercial success in adults and children alike, improving at-home PA and contributing to healthy lifestyle initiatives.[33] However, even commercially successful exergames have not always maintained long-term interest[23] equivalent to larger-scale multiplayer online games and, as such, must still address societal concerns, including sedentary lifestyle and video game addiction that is applicable to the traditional video game culture. Outside of the societal stigma on games and sedentary lifestyles, games themselves are not inherently linked to total lack of movement.[34] Rather, exergames have existed since the early 1980s; prior game culture had not required seating or sedentary activity. Early arcade cabinets required standing, not sitting, at the booth to be the absolute best at any game,[34] and the culture of physical arcade spaces encouraged players to stay, stand, and replay for extensive periods of time to champion each game. That said, modern exergames must balance a number of variables in self-efficacy and design to contribute meaningfully to higher user EE.

Like any game, an exergame is comprised of structural elements encouraging a player to engage in tasks for prolonged periods with increasing challenge. *Game mechanics* refer specifically to the rules, goals, and structure of a game, including all user interaction as well as all stipulations on "win states" and "loss states" and are designed to keep the player consistently challenged and building skill, encouraging each user to "try again" until the next goal has been met and a new challenge has been initiated. Exergame mechanics hold the dual responsibility of maintaining novelty and challenge with each playthrough while inherently requiring physical movement to reach a win state. When successful, exergames can seamlessly present the rules and goals of a game without a player necessarily approaching the task from the viewpoint of prescriptive exercise.

A number of prior and ongoing studies have examined EE and exergames using a range of demographics, including pediatric age groups,[29,35-37] college-aged adults,[28,30,31,38] and older adults, or rehabilitation patients.[23-25,39-43] Research on exergames in strategic programs for children have shown increased levels of CRF using exergames and overall PA in addition to EE, measuring MVPA for both an understanding of EE and qualitative enjoyment from the context of engagement and motivation.[35-37] These studies indicate exergames are a way to engage children in movement which is historically a challenge through traditional exercise regimens. In college students, subjects were able to reach recommended MVPA levels with exergames and indicated significant preference for games over treadmill walking[38]; even at higher intensities of exercise using the exergames, young adult subjects perceived exergames as less intense and more enjoyable.[31,38] Further, prescriptive use of exergames in patients with heart failure have been associated with significant improvements in energy expenditure and functional capacity based on the 6-minute walk test (6MWT),[23,39] indicating promising implications for clinical application. Exergames have shown enormous potential in at-home patient exercise compliance, measuring metabolic equivalents (METs), heart rate, and oxygen consumption (VO_2) to calculate exercise capacity/CRF.[30,32,33]

Though these games can be wildly diverse in aesthetics, audience, and motivational tactics, all require physical motion. That being said, the intensity, practicality, and success of exergames can vary as well, often but not always reaching recommended MVPA levels.[23,28,30,37] Exergaming studies have made progress in improving at-home exercise compliance but have faced challenges in understanding how to translate at-home practice into long-term habit, noting that prescriptive exercise has not always resulted in PA greater than the recommended minimum.[23,40] Further limitations regarding the technology, including space for the equipment in the home and the costly barrier to entry[34] cannot be ignored from the patient perspective in order to gain traction. Moreover, research has been widely limited in examining the application of these technologies in a CR environment. Though CR programs fundamentally encourage PA through conventional instruments (eg, cycle ergometry, treadmill), clinically-housed exergames have been commonly overlooked. Even in studies in which exergames have shown significant success in at-home exercise compliance, subjects frequently indicated that greater integration of the exergame activities with their clinical healthcare providers would improve comfort with the recreational technology and potentially long-term engagement.[23,44] Other evidence gaps reported in traditional clinical rehabilitation environments include limited patient engagement, efficacy, and enjoyment in the clinical environment, providing missed opportunities for healthcare professionals and CR to connect with patients and their health goals strategically using the motivational tactics of the games. The potential for integration of exergaming in CR is presented comparatively in Figure 1.

Virtual Reality (VR) for Health Initiatives

Among the growing research on exergames for PA outcomes, VR applications have emerged in the "active games" category as one of the strongest contenders for increased motivation in PA.[32,42] As a technology reliant on the impression of total immersion, VR fundamentally asks users to move through their environment as though they are physically present within the immersive world, and as such, could be asked to do any number of PAs in accordance with the game's mechanics. Studies have already sanctioned VR applications for use in fall-risk training, given appropriate compliance with best practices of functional mobility training.[27] Further, the novelty and uniquely engaging nature of VR has the potential to increase motivation in poststroke rehabilitation, particularly for repetitive motion exercises.[43] At the innovative *Virtual Reality Institute of Health and Exercise*, researchers are using metabolic carts to measure VO_2 (ie, METs) and estimated calorie expenditure to rate a library of commercially available VR games.[45] Researchers measure peak sustained METs throughout subject participation in each exergame, as well as recording average observed METs over the duration of the entire game to best understand the program's impact, often testing a game multiple times.[45] Though these variables cannot indicate any health impact outside of EE, the potential strength in a rehabilitation setting lies in the captured measurements and the commercial successes of the rated games.[45] It is noted that the physical tasks that most prompt increases in VO_2 and energy expenditure are rooted in the VR application's game mechanics,[32] speaking to the strength of well-designed games connected to a user's self-efficacy.

The VR for health initiative, though holding enormous potential for impact, is limited in its capacity in the clinical setting. At this time, only a few studies can verify significant motivational increases with the use of

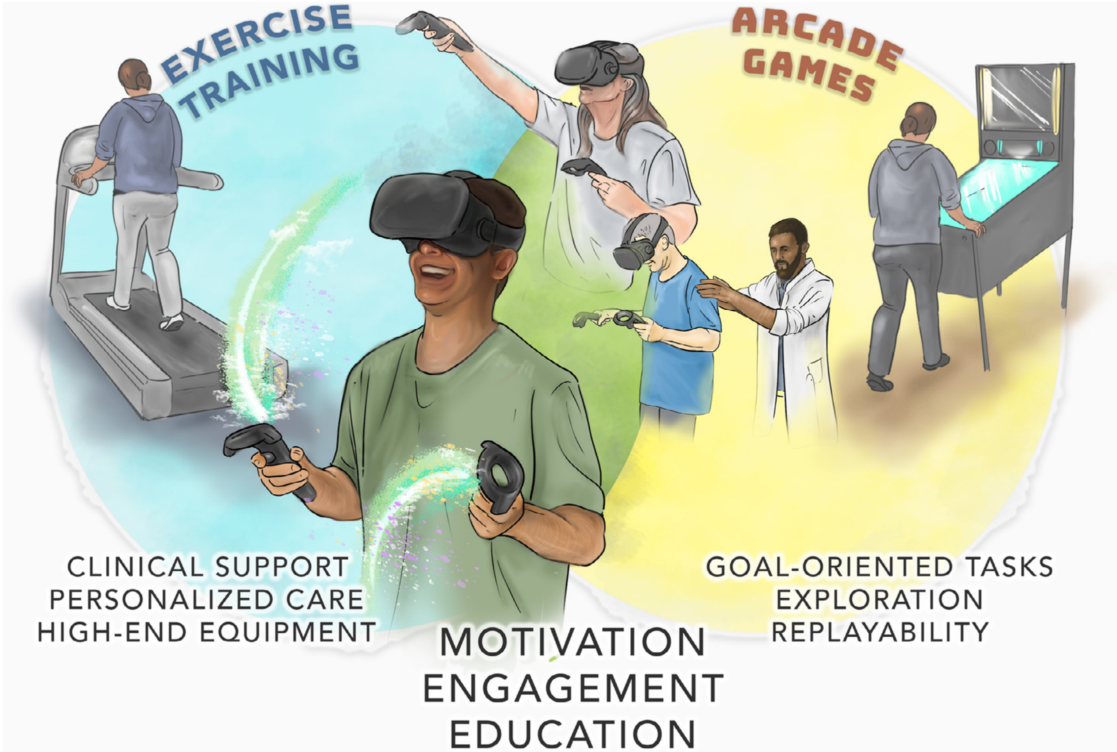

Figure 1. An argument for the integration of exergames within clinical support.

VR in active gaming, and those studies are often limited by sample size or game selection; it is difficult to determine whether an active VR game can enhance PA motivation due to the nature of VR or simply the quality of the game's design. Additional physical and technological limitations must also be taken into account when studying VR applications in exercise testing. For example, popular VR devices, including the HTC Vive and the Oculus Rift, may limit users based on grip strength and finger reach required to access all of the hardware's functionalities. Though massive ergonomic strides have been made for VR in the last few years, the headsets alone can weigh nearly 1.2 pounds[46] and put an unnecessary strain on the neck and shoulders during exercise testing. Even further, the headsets will characteristically cover the user's eyes and much of the nose and face. When performing cardiopulmonary exercise testing (ie, ventilatory expired gas analysis plus traditional exercise testing procedures), potential patient discomfort must be taken into consideration as a logistical challenge for the assessment of VR in the research setting.

The Overlap Between Exergaming and VR for Health

Though VR is still in its infancy stage, the technological developments and larger design considerations behind VR and exergaming systems have fundamentally progressed healthcare innovation, particularly in the realm of care delivery and patient adherence to treatment. On a macroscopic level, the technological underpinnings of VR and exergaming systems appear to be quite similar. That is, both provide a simulation of real world and virtual environments, allowing the user, often presented as an avatar, to interact with the game by simulating limb movements or instructed tasks that vary in intensity and skill level. Movement is detected using a variety of technologies embedded in consoles, including motion sensors (such as gyroscopes and accelerometers), pressure sensors, or GPS sensors, which also help to facilitate positioning in the 3-dimensional space. Exergames, which rely predominantly on motion-based controllers, have increased in popularity due to development of commercialized consoles (eg, Nintento Wii, Playstation EyeToy, Microsoft Kinect, Dance Dance Revolution); whereas, VR systems are viewed as being more adaptable in clinical settings, allowing users to feel immersed into an environment or into any activity. The use of high-frame display technologies (head-mounted display) in VR systems generates images and sounds, further providing users a realistic perception that they are physically present in the imaginary environment and enable interaction with their surroundings.

The development of adaptable virtual systems and accessibility of commercial exergame consoles provides an ideal platform for creating an engaging and enjoyable learning environment within the CR setting. Education delivery through these devices may be facilitated through example (eg, demonstrating the correct way to conduct the exercise), or through exposure (eg, providing visualized feedback in real time on a monitor). Pedagogical frameworks that support the design (and appeal) of these technology-driven interventions are based on repetitive, goal-orientated and task-specific activities which are necessary to achieve neuromotor changes (motor enhancement, task enhancement in client task).[47,48] VR systems in particular can utilize their immersive qualities thought to bridge the technological and psychological experiences of learning in virtual environments (eg, conceptualize, develop a sense of presence, reflect and engage).[48] In CR, VR immersion tools have been applied to create environments that may replicate traditional exercise procedures conducted on the treadmill or cycle ergometry but provide a more intensive therapeutic exercise experience to patients.[49] For example, a patient who is immersed in an environment such as a running track or at the bottom of a hill, may be instructed to simulate jogging or cycling tasks performed at submaximal or maximal conditions to determine level of fitness, and hemodynamic responses to varying intensity levels. Other programs may require patients to exert physical effort through a series of whole-body movements (eg, squatting, jumping, and punching) that is sufficient to achieve moderate intensity PA levels. It is important to note that even in the virtual environment, the delivery of the exercise training (duration and intensity) is being controlled by the clinician.

The engaging mechanics of VR and exergames allow users to progressively learn new and more challenging tasks, and the sense of competitiveness that develops from real-time feedback regarding task performance have been suggested as the primary drivers of change in patient motivation, engagement and adherence to CR[25,44,49,50] factors that remain to be an important challenge for the CR population.[51] Other psychological benefits such as decreased depression symptoms associated with enjoyment when playing games on VR or exergames symptoms have also been reported in CV patients.[25] Qualitative analyses have suggested that the enjoyment associated with using both VR and exergaming devices for therapeutic purposes offer patients a distraction from their diagnosis and its sequalae, which may in turn alter the overall perception that exercise is work.[52-54] Accordingly, prior studies in healthy adults[32,52,53,55] showed that the perception of physical exertion or EE while actively engaging in a well-designed game was lower than actual energy expenditure, suggesting that an individual can engage in PA for longer durations while being immersed in a game than during traditional exercises (eg, treadmill walking). Whether psychological factors such as perception of exertion and enjoyment when engaging in VR or exergames is a determinant of long-term behavior change in the form of greater recreational PA engagement remains to be an important question for future research. While, the short-term benefits of these interactive technologies hold promise in enhancing various spheres of clinical care (physical, physiological, and psychological) to maximize patient benefit.

Implications for CR

Exergaming, as a form of PA in patients with CVD is receiving growing attention as an alternative or supplementary mode to traditional CR.[49,56] During the introduction of exergaming to the population, little was known regarding its acceptance by older adults with CVD. Early studies examined the feasibility of incorporating commercial exergaming systems into regular exercise programs. An initial, small scale study of 14 heart failure patients, between the age of 56 and 81 years provided mixed perceptions.[57] Patients reported enjoying the option of being active at home, rather than walking alone outside under the perception that they would not be able to tolerate PA. Others did not enjoy the isolated aspect and would rather have engaged in activities with a group. Most patients were adherent to exergaming 30 minutes per day during the initial phases of the observation period but then participation was reported to have become more intermittent. Individualizing the exergaming experience may be necessary to maintain interest and in turn long-term adherence to its use in patients,[58] but it appears as though early reports support the feasibility of applying exergaming to older patients with CVD.

The health benefits associated with exergaming in CVD patients also looks promising. From the available studies to date, many have noted exergaming to contribute to improvements in physical function, balance and PA.[23,39,49] When exergames (ie, Wii boxing and canoeing) are added as a supplement to traditional CR, additive effects do not seem to be apparent when comparing performance on a graded exercise test.[56] However, due to limitations in study design and small sample sizes across the few studies that have tested the effects of exergaming on CRF, it is too early to determine whether additive effects are possible when combined with CR. Moreover, there are comparatively fewer, if any studies that have tested the feasibility and efficacy of VR in enhancing CRF in CR populations.

Currently, substantial knowledge gaps remain with respect to effectively applying exergaming or VR in CVD patients. Thus, studies that objectively compare the acute cardiometabolic responses to exergaming/VR with traditional aerobic exercise performed at moderate to vigorous intensities on a treadmill or cycle ergometer are needed to understand the implications of these systems on important clinical measures. Furthermore, considering that exercise volume (through increasing intensity and/or time of exercise) progression is a key principle of improving CRF, studies need to examine the range of cardiometabolic responses to various exergames and VR programs to help guide the progress of exergame/VR participants. This field of study also presents many fruitful opportunities to quantify other acute vascular, skeletal muscle, hemodynamic, and metabolic responses to exergame/VR sessions. Studies examining the chronic effects of exergame/VR sessions are also needed, focusing on the potential to favorably alter key aspects of a patient's physiology and clinical trajectory. Similarly, randomized studies have not yet evaluated the efficacy of improving clinically significant health parameters, nor has a study investigated the implications of exergaming and/or VR in increasing overall device measured PA on exergaming and nonexergaming days, or the long-term compliance to a physically active lifestyle. Lastly, if future studies establish the efficacy of these forms of exercise training, the clinical translation must be explored to provide feasible and affordable infrastructural designs that would allow for these platforms to exist in clinics. Taken together, data from these proposed studies will need to be used to better understand general gaming design to elicit the necessary intensity and duration of activity to confer health benefits similar to or greater than what is achieved through traditional CR programs and be able to promote long-term adherence to the PA guidelines.

Introducing the Clinical Arcade

VR and exergaming already have a presence in at-home exercise regimens and significant potential for clinical use, particularly in CR settings. That said, there remain to be gaps in the evidence regarding the preliminary effectiveness of VR training on EE for patients during their CR visits and the potential for improved self-efficacy utilizing immersion and motivational game mechanics. At the University of Illinois at Chicago (UIC) Physical Therapy Faculty Practice, researchers work alongside healthcare providers to seek out innovations in clinical practice. In the coming year, the practice's CR program will be introducing the first ever *Clinical Arcade*: a novel approach to integrating commercial successful VR technology and rehabilitation utilizing the metrics from programs like the

Virtual Reality Institute for Health and Exercise (Fig 2). Based in the outpatient clinical setting, patients will be able to engage in the benefits of VR exergames with the support and structure of the CR professionals, customizing hardware with CR-centric modifications like weighted hand controllers and support to select individually appropriate game levels. CR is based on the fundamental principles of not only supervised exercise training, but structured education and counseling. Given the potential

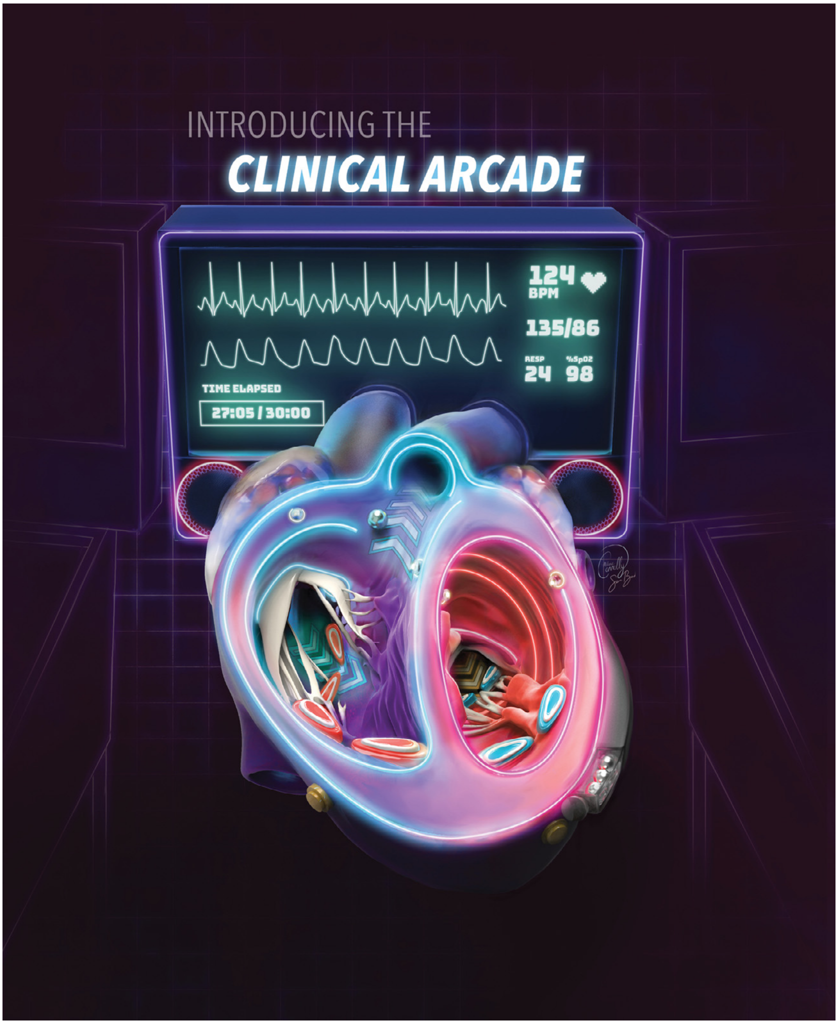

Figure 2. An editorial poster to describe the engagement and excitement of UIC's upcoming novel Clinical Arcade, featuring the use of commercially successful games for cardiac rehabilitation.

impact of exergames and VR for not one, but each of these three pillars of CR, the Clinical Arcade will aim to integrate the foundational support of inpatient rehabilitation practices and commercially successful innovations in immersive movement.

Conclusions

While exergaming and VR are still limited in understanding efficacy for CR exercise training, these technologies have massive promise for improving patient self-efficacy for PA in the CVD population. With advanced understanding of game-based learning, motivational game design, and immersive movement, VR exergames hold the potential to change how patients engage with their exercise training and CR as a whole. By introducing the Clinical Arcade, it is our hope to connect the CR practice with at-home understanding, letting the patient become the *Player One* of their own healthcare.

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