ORIGINAL RESEARCH

Virtual Feedback for Compliance to Prescribed Exercise: A Randomized Crossover Trial

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ABSTRACT

Background: To investigate the effect of a virtual feedback environment on compliance to prescribed session exercise load and to understand the user experience related to exercise participation.

Methods: Adult clients referred to an exercise physiology clinic wore a heart rate monitor while performing prescribed exercise twice per week over 2 intervention blocks of 2 weeks each. Participants undertook aerobic exercise both with and without a virtual feedback environment in random order. Compliance to prescribed exercise was assessed as heart rate relative to prescribed levels both within and across sessions. Participants reported average pain and rating of perceived exertion for the session and completed the PACES-8 enjoyment of exercise questionnaire at session completion. Treatment effects were assessed longitudinally using mixed-effects linear regression. At study completion, 2 focus groups (n = 12) were conducted and reported using thematic analysis.

Results: Participants (n = 14) demonstrated higher mean compliance to prescribed exercise under the treatment (101 ± 10%) compared to control (50 ± 10%) condition (MD = 51%; 95% CI: 21–80; $P = 0.001$). Similar scores were observed under both the treatment and control conditions for rating of perceived exertion (12.3 vs. 12.2: $P = 0.86$), pain (2.37 vs. 0.85: $P = 0.29$), and enjoyment of exercise (41.2 vs. 38.6: $P = 0.49$). Focus groups identified themes related to biofeedback, interactivity and engagement, goal setting, and the visual environment.

Conclusion: Immersive feedback technologies can be effective to assist individuals with chronic clinical conditions to perform aerobic exercise within prescribed intensity ranges. Wide acceptability requires linking the exercise modality to the immersive environment and developing clear and meaningful goals. *J Clin Exerc Physiol*. 2022;11(3):91–98.

Keywords: exercise interventions, aerobic exercise, older adults, exercise intensity

Physical inactivity is a major contributor to ill health accounting for 9% of premature mortality globally (1) with the cost of physical inactivity on health care systems estimated at 53.8 billion international dollars annually (2). Despite the well-recognized benefits of physical activity (PA), 31% of adults worldwide do not meet minimum recommendations to maintain health (3). Lifestyle interventions including exercise prescription are effective at improving PA participation and associated health outcomes; however, ongoing support and feedback is required to maintain these changes (4). Technological solutions such as activity trackers and exergames are useful and effective ways of providing support with multiple reviews demonstrating their benefits for PA participation in a range of populations including older adults and those diagnosed with chronic conditions (5,6).

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Exercise is safe and effective for individuals at higher risk of acute medical events such as those with stable chronic medical conditions including multimorbidity or complex clinical status, the prevalence of which is higher in older adults (7). Exercise reduces incidence of falls and bone fractures, risk of cardiovascular and metabolic diseases, and assists independence while aging (8,9). However, it is important that risk assessments are conducted, and exercise prescribed and supervised using methods that mitigate potential risks of adverse events (10). A common way of minimizing risk is prescribing exercise within heart rate (HR) zones predetermined as safe and effective for the client, taking into account their age and clinical status. However, for this to be effective the client must have a means of monitoring HR during exercise and either understand the importance of staying within prescribed zones or for the supervising exercise professional to monitor HR and provide feedback as warranted.

E-health (i.e., electronic delivery of health care or commonly termed *telehealth*) has the potential to enhance health care services, particularly for those with chronic health issues (11) and has gained prominence as an important method for safe provision of treatment during the COVID-19 pandemic (12). E-health is increasingly considered a viable means of health care delivery to improve access to primary health care for those experiencing health inequity (13). Such disadvantages include but are not limited to a lack of transport, living in regional and remote areas, and low socioeconomic status (13,14). Older adults (>65 year) are especially vulnerable to disadvantage, and thus barriers in primary health care access (14). Furthermore, with an aging population we may see continual increase in strain on the primary health care system (11). The last decade has seen the introduction of a broad range of e-health projects and programs ranging from web-based information portals to wearable technologies designed to remotely monitor individuals for a range of physiological functions (11,15–17) and to guide treatment (18). Program reviews suggest that such systems may motivate clients to undertake home-based exercise programs (11,16). However, for this to be achieved, individuals with chronic health conditions (often older adults) must be willing to use the technologies (19).

While barriers exist for older adults to use e-health applications (20,21), their adoption has the potential to assist independent living (14,22). Technologies are more likely to be used if they are engaging, nonintrusive and easily accessible (22). This points to the need to consult with proposed users, to ensure that proposed applications meet intended health and well-being goals while addressing client needs (16,23). Appropriately designed technology has the potential to support clients to comply with prescribed exercise by assisting them to exercise at effective and safe intensities. There is currently little evidence supporting the use of technology in facilitating compliance to prescribed exercise intensities.

The purpose of this study was to assess the compliance of a group of clinical exercise physiology clients with chronic medical conditions to a prototype immersive virtual feedback environment monitoring system developed by the researchers. Using a randomized, controlled, longitudinal, crossover design, this study aimed to investigate the effect of use of the virtual feedback environment on compliance to prescribed exercise load and understand the user experience of the virtual feedback environment on factors affecting exercise participation.

The primary hypothesis was that the virtual feedback environment would improve compliance to prescribed exercise compared to a no feedback control condition.

METHODS

This study was a randomized, controlled, longitudinal, crossover design. Adult participants were recruited from clients undergoing treatment for a variety of chronic medical conditions at the University of Tasmania Exercise Physiology Clinic. Each intervention period lasted for 2 weeks with 2 supervised exercise sessions per week for a total of 8 exercise sessions over 4 weeks. The sessions were monitored by a member of the research team to ensure participant safety and effective operation of exercise equipment. The team member provided no feedback on the performance of the exercise during the sessions. This project received ethical approval from the Tasmanian Health and Medical Research Ethics Committee (H0015313).

Participants attended an initial screening and exercise assessment session to inform exercise prescription. The submaximal YMCA cycling test (24) was used to prescribe HR levels and align prescribed HR with rating of perceived exertion (RPE). Exercise prescription for the intervention was prescribed using HR zones based on clinical exercise guidelines (25) and the accredited exercise physiologist's clinical judgment to ensure safe and effective exercise intensity individualized for each participant based on their clinical conditions and current activity levels. The participants were instructed to exercise in a range of RPE that corresponded to their prescribed target HR zones as is common exercise prescription practice for clients exercising without a heart rate monitor.

Individuals were excluded if they were clinically unstable with contraindications to exercise, already engaged in high levels of PA, or had a cognitive impairment preventing them from providing informed consent. Participants for whom HR was an inappropriate or potentially unsafe way of prescribing exercise intensity (e.g., beta blocker medication) were also excluded.

Treatment Intervention

Participants undertaking the treatment intervention were fitted with a HR monitor (Equivital EQ02 Sensor, Cambridgeshire, UK), which inputted real time data directly into the virtual environment software, and were asked to complete their prescribed exercise using the immersive software providing visual feedback (described below). The exercise involved cycling on an exercise bike (Monark Ergomedic 828E, Vansbro, Sweden) at the prescribed RPE with the

software open on a large screen in front of them. Participants progressed through the software storyline according to their instantaneous compliance (HR within prescribed training zone) to the prescribed exercise. At the end of each session participants received feedback via the software of their achievement towards the prescribed daily, weekly, and program exercise goals.

Control Intervention

Participants in the control intervention underwent the same exercise protocol as the treatment intervention; however, they did not use the virtual software and received no feedback other than the time spent exercising in that session. During the control intervention a HR monitor was worn for data collection but feedback on HR was not provided to participants.

Description of the Virtual Feedback Environment

The prototype software involves an immersive visual environment developed by the researcher team using real-time participant HR during exercise to direct user experience. Participants experience a first-person view from inside a submarine within an aquatic environment. The visual environment represents a forward window on the submarine, with an instrument panel underneath (Figure 1). The submarine is *powered* by the participant's HR (normalized to the prescribed exercise HR), which determines the speed of the submarine. The purpose of this feature is to create a natural approach to prescribed HR, so the submarine slows as HR lowers and *overheats* (warning lights, auditory alarm, and stops) when HR exceeds prescribed levels. A power bar on the instrument panel represents normalized HR as submarine power, with colored zones for HR below, within, and above prescribed levels. The design was informed by exercise physiology client feedback following demonstration of an earlier design concept, which emphasized the importance of engagement and an intuitive approach to the prescribed HR (20). It was also considered important that the feedback be neutral to the type of aerobic exercise undertaken to allow it to be more flexibly used in combination with a variety of exercise equipment (e.g., rowing machine, treadmill, exercise bike, stepper).

FIGURE 1. Participant view of instrument panel and external environment.

Each session has specific environmental features, including flora, fauna, and a novel end point or *goal*. Session compliance is represented as progress through this environment with the goal reached at completion of prescribed session exercise load. Participants experience a narrative journey which progresses through a storyline arc both within and across exercise sessions, with individual sessions comprising story chapters. Session goals include unique aquatic features such as a whale or a shipwreck. Once the goal is reached, the user can choose to continue their exercise, with the submarine circling the goal. This design aimed to improve adherence to exercise through both enhanced engagement and increased time spent in prescribed HR zones. The software was designed to be immersive and intuitive with a natural interface.

Outcome Measures

Compliance to Prescribed Exercise Duration and Intensity

Compliance was measured using HR relative to prescribed levels as well as consistency of HR and total time within an individual session. Compliance was determined by the time exercised within the prescribed HR zone as a fraction of prescribed exercise time. Periods of exercise outside the HR zone (either above or below) did not contribute to compliance. For example, exercise at a constant HR at the prescribed HR for a period of the prescribed exercise corresponds to 100% compliance. A compliance of greater than 100% was achievable if the client maintained a HR in the target zone for longer than the prescribed time.

$$Compliance(\%) = \frac{Total\ Exercise\ Time - Exercise\ Time\ outside\ prescribed\ HR\ zone}{Prescribed\ Exercise\ Time} \times 100$$

Enjoyment of Exercise

The Physical Activity Enjoyment Scale-8 (PACES-8) (26), a validated 8-item questionnaire modified from the Physical Activity Enjoyment Scale to suit older adults, was used to determine enjoyment levels after each exercise session. PACES-8 is based on a 7-level bipolar rating scale where higher scores reflect greater levels of enjoyment.

Pain and Perceived Exertion

Pain and perceived exertion were assessed using self-reported scales. At the end of each session, participants reported the pain experienced during the exercise session on a scale of 0 to 10, where 0 indicates "no pain" and 10 indicates "the worst pain experienced" by the participant. Participants also reported their session RPE using the 6 to 20 point Borg scale (27).

Focus Group Interviews

At the completion of the study, 2 focus groups were conducted and digitally recorded. Five to 7 participants attended each group. Focus groups (mean duration 43.6 min), were

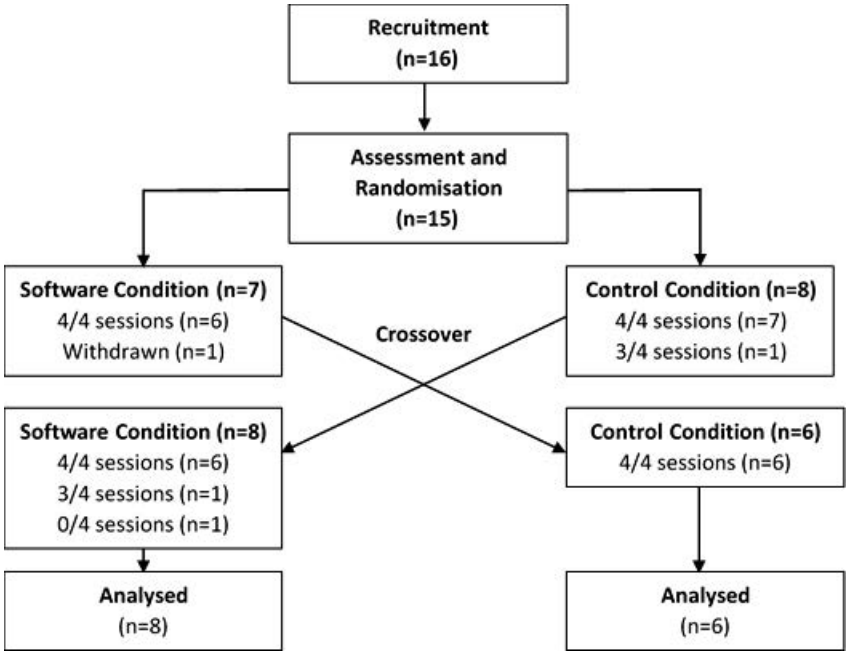

FIGURE 2. CONSORT flow diagram for study progression.

transcribed verbatim, producing 31 pages (Arial, size 11) of raw transcription data for further analysis. Both focus groups were run by a researcher (JOB) with experience in facilitating focus groups, who had not previously had any direct contact with the research participants, to ensure participants felt comfortable expressing their opinions.

Statistical Design

An a priori sample size calculation indicated 13 participants would be required to demonstrate a clinically meaningful between-group difference of 20% in exercise compliance with coefficient of variation of 25% and 80% power. To allow for a 10% anticipated withdrawal rate, 16 participants were recruited. All participants were assigned to complete both control and treatment interventions, with assignment performed using computer-generated randomization conducted by a person not directly involved in the study and recorded in sealed opaque envelopes.

Treatment effects were assessed on an intention-to-treat basis for compliance to prescribed exercise, pain, and RPE, using mixed-effects linear regression with repeated measures for sessions. Carry-over effects were controlled by including intervention order as a covariate. Analyses were performed using Stata 14.2 (Stata, College Station, Texas).

Transcription was performed using an online transcription service (Smartdocs.com.au, Queenland, Australia). Transcripts were coded and thematically analyzed using a qualitative descriptive approach using MS Office (Microsoft, Redmond, Washington) (28). Coding was completed in 2 stages. During the initial stage, 2 researchers (AW and JOB) independently coded transcripts inductively to ensure themes were organically identified without researcher bias. In stage 2 these 2 researchers generated a preliminary list of themes that were discussed and refined to ensure all themes captured those previously coded.

RESULTS

Sixteen individuals expressed an interest in the study, with 15 assessed as eligible to participate after initial assessment. Participants were randomized to either software (n = 7) or control (n = 8) interventions in the first period of the crossover design (Figure 2). One participant began the first session before being identified as having a cardiovascular condition meeting the exclusion criteria and was withdrawn. Twelve completed 8/8 sessions over the 4-week intervention. One participant attended 7/8 sessions (3 software and 4 control), and another attended 3/8 sessions (3 control and 0 software) with data from both participants included in the analysis. In total, data from 14 participants (9 female) were analyzed (Figure 2), and the statistical significance of the results were not different when participants with missing data were excluded in a sensitivity analysis. While the inclusion criteria were for adults (age ≥ 18 years), participants were mostly older adults (64 ± 8 years) ranging in age from 44 to 74 years. As the participants were recruited from a clinical exercise physiology clinic, many had chronic conditions including cardiovascular disease, metabolic disease, arthritis, chronic pain, cancer, asthma, and mental health conditions. Many participants had more than 1 chronic condition with the mean number of conditions of 2.2 ± 1.1 (Table 1).

Quantitative outcome measures (Table 2) demonstrate higher mean compliance ($P = 0.001$) to prescribed exercise for the treatment condition (mean = 101 ± 10%) compared to the control condition (mean = 50 ± 10%). The mean weekly session compliance for each order group demonstrated higher mean compliance at each week of the study for the

TABLE 1. Participant demographics and prescribed exercise parameters.

	Value[a]	Range
Participant demographics		
Age (years)	64.4 ± 8.2	44–74
Female sex	9 (64)	
Clinical conditions	2.2 ± 1.1	0–4
Cardiovascular disease	9 (64)	
Metabolic disease	5 (36)	
Arthritis	5 (36)	
Chronic pain	7 (50)	
Cancer	2 (14)	
Asthma	2 (14)	
Mental health	1 (7)	
Prescribed exercise parameters		
Duration (min)	23.5 + 5.0	15–30
Heart rate (b·min^{-1})		
Lower bound	105 ± 12	75–130
Upper bound	124 ± 11	100–150

[a]Mean ± SD or n (%)

treatment condition (Figure 3). According to the real-time calculation of compliance under both treatment and control conditions, this increase in compliance could be due to an increased proportion of time spent exercising within the prescribed HR zones, and/or increased total exercise time. While the data collection method did not allow for these 2 possibilities to be assessed separately, they both relate to improved exercise adherence.

There were no significant differences observed between treatment and control conditions in RPE, pain, or enjoyment of exercise. Mean scores for RPE were 12.3 ± 0.4 for treatment and 12.2 ± 0.5 for control conditions, corresponding to "somewhat hard" under both conditions (P = 0.86). Pain scores were "mild" under both treatment (2.27 ± 0.85) and control (mean = 1.3 ± 0.6) conditions (P = 0.29). PACES-8 results demonstrate moderate enjoyment of exercise for both treatment (41.2 ± 3.6) and control (38.6 ± 2.6) conditions (P = 0.49). The scores for both groups had the same clinically relevant reporting for the measures of pain, RPE, and PACES-8 indicating that differences were not clinically significant. Order effects were tested for each outcome measure with no effects observed.

Participants reported varying experience and interest in technology, for example some used it for work, while most used it for basic functions at home. Only 1 participant was not interested in technology.

Analysis of the focus groups identified 4 themes (Supplemental Table):

- Relationship between game visuals and actual activity are important;
- Interactivity of the software influences engagement;
- Ability to set or recognize goals affected engagement; and
- Biofeedback is important to achieve exercise compliance.

DISCUSSION

A major finding of this study was that under the control condition, the compliance to exercise was only half the load prescribed by the accredited exercise physiologist, while under the software intervention prescribed load was met. The greater compliance when using the software was related to better maintenance of HR in the prescribed range for the individual and/or increased exercise time. Better maintenance of HR using the feedback environment occurred without providing the instantaneous HR explicitly. Importantly, this higher compliance did not result in higher perceived exertion and was not associated with negative outcomes for participants in terms of increased pain or decreased enjoyment of the exercise sessions. These results were observed over the short timeframe of the study, with further investigation required to assess the long-term effects on compliance to an exercise program. The improved compliance was compared to a no-feedback control condition and hence demonstrate the benefits of the virtual feedback compared to no feedback.

The control results indicate that even in controlled and monitored environments participants have difficulty maintaining their HR within prescribed zones. Without external feedback, clients rely on subjective RPE to guide their exercise intensity, which may not reflect HR. However, RPE correlates well with exercise HR across a range of ages including older adults (29), and preliminary exercise tests in this study used both RPE and HR with the prescribed zones directly related with the target exercise RPEs given to each participant. The differences in compliance with no differences in RPE may be due to greater within-session variation

TABLE 2. Mixed-effects linear regression results for treatment effects.

	Control[a]	Treatment[a]	Mean Difference[a]	95% CI	*P* Value
Compliance (%)	50 ± 10	101 ± 10	51 ± 15	21.2, 80.3	0.001
RPE	12.2 ± 0.4	12.3 ± 0.5	0.1 ± 0.6	−1.1, 1.3	0.86
Pain	1.3 ± 0.6	2.3 ± 0.7	1.0 ± 9.5	−0.9, 2.9	0.29
PACES-8	38.6 ± 2.7	41.2 ± 3.6	2.6 ± 3.7	−4.7, 9.9	0.49

[a]Mean ± SE

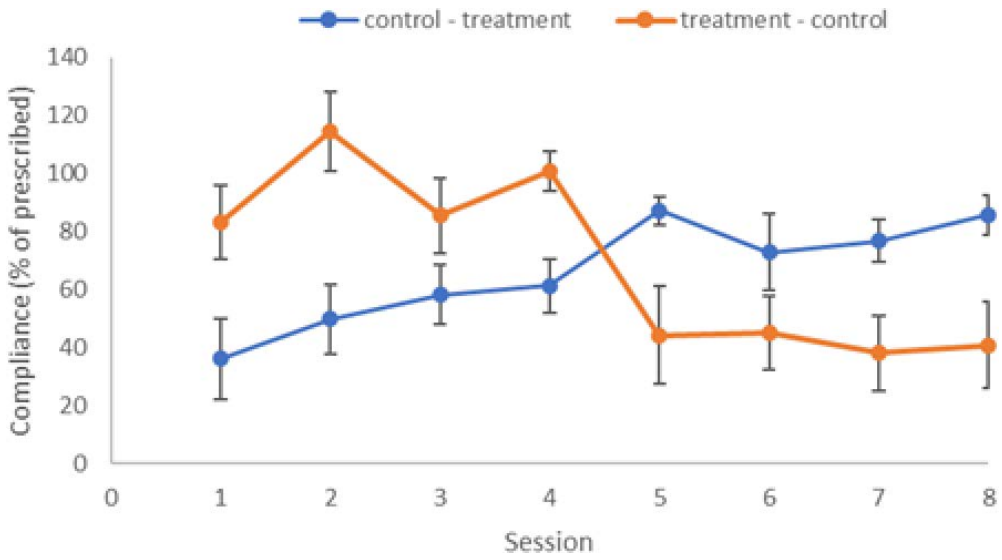

FIGURE 3. Mean compliance by intervention order group with standard error (SE) bars.

in RPE (above and below prescribed), which did not affect average session RPE during the control intervention.

The use of biofeedback related to HR zones allowed participants in the treatment intervention to intuitively modify their exercise intensity to match prescribed HR zones. Biofeedback was provided when the HR was too high (for safety) with more intuitive feedback for low HR related to slower submarine movement. The submarine speed represents the current HR, not the power of the exercise. The submarine was chosen as its motion in water relates to the relationship between exertion and HR. The changes in a submarine's speed are delayed from changes in power. This relationship was chosen to naturally relate to changes in HR lagging changes in exercise intensity. The aquatic environment was used to support continuous PA at a relatively constant load, with a relaxing environment chosen rather than maximizing the excitement of visual effects, in part to minimize nonexercise related sympathetic nervous system stimulation. The environmental features were selected to allow for an increasingly rich and continuously novel environment within and across sessions to assist with engagement.

Focus group results provided important user experience information related to the acceptability of this type of immersive feedback approach. Participants found the visuals of the software important; however, most participants did not link the visuals of the software (submarine) to the exercise activity (cycling). While this affected participant engagement, it was a deliberate design feature to allow for the use of multiple exercise modalities (e.g., treadmill) rather than being limited to the exercise bike, and to relate the feedback to HR rather than exercise intensity. Participants also indicated that the software was limited in terms of interactivity, which may have affected their engagement. Participants made several references to the importance of goals. They expressed that goals and improved biofeedback could have been linked to the software visuals or from an understanding perspective linking the purpose of compliance.

Most participants expressed frustration with the visuals and lack of perceived interactivity of the software. Specifically, the biofeedback received in conjunction with the software was inadequate for many participants to consciously understand its purpose, so even though they were receiving biofeedback and achieving compliance there was a disconnect with understanding the visuals. However, 1 participant was able to understand the purpose of the software and the importance of the regulation of exercise intensity. This may indicate that the improved compliance achieved during the treatment intervention was the result of the intuitive biofeedback process that did not require an explicit connection by the participant.

Participant feedback indicates that the immersive nature of the technology in this intervention was limited. A recent scoping review (30) found that the more immersive the technology, the greater the beneficial effects for user experience during exercise. While the software produced improved compliance in this clinical study, the user feedback indicates likely issues with the take-up of the software outside the laboratory setting. Understanding the user experience is essential to the design of immersive technologies to support uptake and maintenance of prescribed exercise over the long term.

Limitations

This study had several limitations. Testing apparatus, venue, and equipment may have limited a truly immersive environment. The effect of the software was evaluated in a laboratory setting under researcher supervision, and the results observed in this study may not be replicated when exercising alone in a home-based environment for which the virtual feedback approaches may have the most benefit. The visual setup tended to drop out for a second or two every couple of minutes with several participants reporting that this adversely affected their experience. Participants had a tendency to try to chat with the researcher particularly during the control intervention sessions, which may also have affected their attitudes and perceptions of that component of the

intervention. Finally, there were issues with interpreting the rating of pain, with participants frequently reporting discomfort from the cycle ergometer seat as their main source of pain. The study design had a short duration, so the long-term adherence for this intervention was not assessed. This study compared the virtual feedback environment to a no-feedback control condition and did not assess whether virtual feedback provides improvements compared to raw feedback (the real-time HR). The study did not assess whether the improved compliance was because of longer time spent in prescribed HR zones or increased exercise session time, nor did it assess whether clients would be more likely to undertake the prescribed or additional exercise sessions.

CONCLUSIONS

The results from this study demonstrate that use of this novel technology intervention can be effective in assisting older individuals with a range of chronic clinical conditions to perform aerobic exercise independently within individualized prescribed intensity ranges. However, to be widely acceptable to the user outside the laboratory setting, the user experience is vital for software use. Therefore, consideration is required to link the exercise modality more clearly to the immersive environment and develop clear and meaningful goals. Buy-in from participants regarding the purpose of the exercise prescription and the way the technology seeks to deliver this is also required to ensure the solution meets participants needs.

REFERENCES

1. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet. 2012;380(9838):219–29.
2. Ding D, Lawson KD, Kolbe-Alexander TL, Finkelstein EA, Katzmarzyk PT, van Mechelen W, Pratt M, Lancet Physical Activity Series 2 Executive Committee. The economic burden of physical inactivity: a global analysis of major non-communicable diseases. Lancet. 2016;388(10051):1311–24.
3. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U, Lancet Physical Activity Series Working Group. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet. 2012;380(9838):247–57.
4. Muller-Riemenschneider F, Reinhold T, Nocon M, Willich SN. Long-term effectiveness of interventions promoting physical activity: a systematic review. Prev Med. 2008;47(4):354–68.
5. Brickwood KJ, Watson G, O'Brien J, Williams AD. Consumer-based wearable activity trackers increase physical activity participation: systematic review and meta-analysis. JMIR Mhealth Uhealth. 2019;7(4):e11819. doi:10.2196/11819
6. Sween J, Wallington SF, Sheppard V, Taylor T, Llanos AA, Adams-Campbell LL. The role of exergaming in improving physical activity: a review. J Phys Act Health. 2014;11(4):864–70.
7. Thompson PD, Franklin BA, Balady GJ, Blair SN, Corrado D, Estes NA 3rd, Fulton JE, Gordon NF, Haskell WL, Link MS, Maron BJ, Mittleman MA, Pelliccia A, Wenger NK, Willich SN, Costa F; American Heart Association Council on Nutrition, Physical Activity, and Metabolism; American Heart Association Council on Clinical Cardiology; American College of Sports Medicine. Exercise and acute cardiovascular events placing the risks into perspective: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism and the Council on Clinical Cardiology. Circulation. 2007;115(17):2358–68.
8. Agmon M, Perry CK, Phelan E, Demiris G, Nguyen HQ. A pilot study of Wii Fit exergames to improve balance in older adults. J Geriatr Phys Ther. 2011;34(4):161–7.
9. Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev. 2012(9):CD007146. doi:10.1002/14651858.CD007146.pub3
10. Maiorana AJ, Williams AD, Askew CD, Levinger I, Coombes J, Vicenzino B, Davison K, Smart NA, Selig SE. Exercise professionals with advanced clinical training should be afforded greater responsibility in pre-participation exercise screening: a new collaborative model between exercise professionals and physicians. Sports Med. 2018;48(6):1293–302.
11. Brach M, Hauer K, Rotter L, Werres C, Korn O, Konrad R, Gobel S. Modern principles of training in exergames for sedentary seniors: requirements and approaches for sport and exercise sciences. Int J Comput Sci Sport. 2012;11(1). doi:10.13140/RG.2.1.3762.2647
12. Hollander JE, Carr BG. Virtually perfect? Telemedicine for Covid-19. N Engl J Med. 2020;382(18):1679–81.
13. McGrail MR, Humphreys JS. Spatial access disparities to primary health care in rural and remote Australia. Geospat Health. 2015;10(2):358. doi:10.4081/gh.2015.358
14. Demiris G, Rantz M, Aud M, Marek K, Tyrer H, Skubic M, Hussam A. Older adults' attitudes towards and perceptions of "smart home" technologies: a pilot study. Med Inform Internet Med. 2004;29(2):87–94.
15. Hordern A, Georgiou A, Whetton S, Prgomet M. Consumer e-health: an overview of research evidence and implications for future policy. Health Inf Manag. 2011;40(2):6–14.
16. Pfaeffli L, Maddison R, Whittaker R, Stewart R, Kerr A, Jiang Y, Kira G, Carter K, Dalleck L. mHealth cardiac rehabilitation exercise intervention: findings from content development studies. BMC Cardiovasc Disord. 2014;12:36. doi:10.1186/1471-2261-12-36
17. Liao Y, Thompson C, Peterson S, Mandrola J, Beg MS. The future of wearable technologies and remote monitoring in health care. Am Soc Clin Oncol Educ Book. 2019;39:115–21.
18. Ferrua M, Minvielle E, Fourcade A, Lalloué B, Sicotte C, Di Palma M, Mir O. How to design a remote patient monitoring system? A French case study. BMC Health Serv Res. 2020;20(1):434. doi:10.1186/s12913-020-05293-4
19. Whetton S, Visentin D, Rowe R, Rolf D, Johns S, Grayston T, Williams A. Engaging older clients with exercise physiology software: focusing on user-prioritised needs. Int J Technol Hum Interact. 2021;17(4):1–18.

20. Selwyn N, Gorard S, Furlong J, Madden L. Older adults' use of information and communications technology in everyday life. Ageing Soc. 2003;23(5):561–82.
21. Hernandez-Encuentra E, Pousada M, Gomez-Zuniga B. Ict and older people: beyond usability. Educ Gerontol. 2009; 35(3):226–45.
22. Gonzales A, Ramirez M, Viadel V. Attitudes of the elderly toward information and communication technologies. Educ Gerontol. 2012;38:585–94.
23. Greenhalgh T, Wherton J, Sugarhood P, Hinder S, Procter R, Stones R. What matters to older people with assisted living needs? A phenomenological analysis of the use and non-use of telehealth and telecare. Soc Sci Med. 2013;93:86–94.
24. Beekley MD, Brechue WF, deHoyos DV, Garzarella L, Werber-Zion G, Pollock ML. Cross-validation of the YMCA submaximal cycle ergometer test to predict VO2max. Res Q Exerc Sport. 2004;75(3):337–42.
25. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 11th ed. Philadelphia: Wolters Kluwer; 2022.
26. Mullen SP, Olson EA, Phillips SM, Szabo AN, Wójcicki TR, Mailey EL, Gothe NP, Fanning JT, Kramer AF, McAuley E. Measuring enjoyment of physical activity in older adults: invariance of the physical activity enjoyment scale (paces) across groups and time. Int J Behav Nutr Phys Act. 2011;8:103. doi:10.1186/1479-5868-8-103
27. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377–81.
28. Braun V, Clarke V. What can "thematic analysis" offer health and wellbeing researchers? Int J Qual Stud Health Well-being. 2014;9:26152. doi:10.3402/qhw.v9.26152
29. Groslambert A, Mahon AD. Perceived exertion: influence of age and cognitive development. Sports Med. 2006;36(11): 911–28.
30. Mouatt B, Smith AE, Mellow ML, Parfitt G, Smith RT, Stanton TR. The use of virtual reality to influence motivation, affect, enjoyment, and engagement during exercise: A scoping review. Front Virtual Real. 2020;1. doi:10.3389/frvir.2020. 564664