The effects of exergaming on pain, postural control, technology acceptance and flow experience, in older people with chronic musculoskeletal pain: a randomised controlled trial

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Abstract

Background: Previous studies of exergaming for older people have reported mixed findings, but, overall, there is a broad indication of potential benefit. The purpose of this study was to assess the effects of exergaming, comparing the Interactive Rehabilitation and Exercise System (IREX®) with traditional gym-based exercise with no virtual stimuli (TGB), on pain, postural control, technology acceptance and flow experience in older people with chronic musculoskeletal pain.

Methods: 54 older adults (age: 71 ± 5 years) with chronic musculoskeletal pain were randomised (stratified, blind card) to one of two groups: (a) completed exergaming using IREX® and (b) completed TGB exercise. Both groups completed two, 40-minute, exercise sessions (matched for intensity, duration and movement patterns) a week for six weeks. The sensory, emotional and motivational dimension of pain was measured using the Multidimensional Affect and Pain Survey (MAPS) questionnaire and intensity, with a numeric rating scale. Postural Control was measured as sway using a Kistler™ force platform. Technology acceptance was measured with the Unified Theory of Acceptance and Use of Technology (UTAUT) and flow experience with the Flow State Scale (FSS) questionnaires. Rating of Perceived Exertion (BORG RPE) and HR were also recorded during all sessions.

Results: There were no significant differences in objective or subjective measures of physical demand and hence the exercise groups were matched. There were significant improvements in pain and balance in the exergaming group compared to the TGB group. Although significant intervention effects on technology acceptance were found in social influence and behavioural intention in the TGB group, both groups demonstrated significant increases in all of the technology acceptance variables over time. In terms of flow experience, concentration at task was significantly influenced in the TGB group and significant increases in flow experience variables were observed in both groups (TGB and exergaming).

Conclusion: Exergaming has potential to alleviate pain and improve balance in older people with chronic musculoskeletal pain. Both forms of exercise are acceptable, intrinsically motivating and show evidence of benefit to older people with chronic musculoskeletal pain.

Background

Chronic pain is a widespread and debilitating condition; in the UK, in 2017, 34% of adults had chronic pain and in the US, in 2016, 20.4% [1]. Quality of life and health deteriorate, mobility and independence reduce, anxiety and depression increase, as does dependence on medication [2–5]. Not only the pain, but, commonly associated symptoms, such as muscle and joint stiffness, make moving and exercising difficult [6]. Chronic, painful, musculoskeletal conditions, such as low back pain and arthritis also increase the risk of impaired postural control [7] and consequently falls [8–10].

Unsurprisingly, exercise is often recommended for older people, especially for those with chronic pain [11, 12] in the hope of increasing activity and independence [13–15]. Despite the many known benefits, however, older people are often reluctant to take up exercise, citing reasons such as fatigue [16], fear the
movements will increase their pain [17], or simply a lack interest in exercising [18]. Recently, exergaming has been explored as an alternative mode of exercise to encourage physical activity among older people [19]. Exergaming, using virtual technologies, offers the advantage of not being weather-affected and the reassurance that intensity and demand (gaming level) can readily be controlled and customised by the user, or their health professional. Several studies of older people's involvement in exergaming [20–22] report health and wellbeing benefits comparable to those of regular exercise, particularly in balance [23], muscle strength [24], ease of physical movement and psychosocial well-being [25]. There is also some evidence suggesting that older people are beginning to welcome the use of technology for exercise [25], but few have studied the important psychological aspect of exergaming, in particular user acceptance and flow experience. Most studies also tested commercially available – not exercise or rehabilitation specific – gaming platforms (such as the Nintendo Wii [24–26], Sony PlayStation II [27, 28], the X-box Kinect [29], and open-source DDR games [30, 31].

The aim of this study was to assess the effects of exergaming comparing GestureTek's Interactive Rehabilitation and Exercise System (IREX™) [32], with traditional gym-based exercise, with no virtual stimuli (TGB), for older people with chronic musculoskeletal pain on: the sensory, emotional and motivational dimensions of pain, pain intensity, postural control, technology acceptance and flow state experience.

Methods

Design

A prospective, randomized, controlled two-arm trial design was used with these groups: (a) exergaming with IREX® and (b) traditional gym-based exercise (TGB). All testing was carried out by the first author who was not blind to participant allocation.

Setting and participants

Ethical approval was granted by the Teesside University Research Governance and Ethics Committee and the study was conducted in the University's physiotherapy laboratory. Participants were recruited from nine local community groups from October to December 2010. Inclusion criteria were male or female, aged 65 years or over, able to walk unassisted (i.e. did not use, or require, any walking aids) for at least 0.5 of a mile and having musculoskeletal pain in two or more joints of more than 12 weeks duration.

Exclusion criteria were diagnosis (or suspicion) of any systemic conditions that may cause pain in two or more joints, of more than 12 weeks duration (such as cancer, rheumatic or neurological disease, or condition), self-report of current (or history) of any condition or injury which would contra-indicate participation in the exercises under study, inability (or any doubt of ability) to give informed consent and inability to read and write English.
Sixty-one potential participants were screened for eligibility. Four were excluded due to not meeting the eligibility criteria and three could not attend scheduled sessions. Fifty-four (42 females and 12 males, age: 71 ± 5 years) were allocated to either exergaming with the IREX™ (n = 27), or TGB (n = 27) (see CONSORT flow diagram, Fig. 1). Chronic pain areas were hips, hands/wrists and/or back.

**Procedure**

After written informed consent, demographic information and baseline outcome data were collected and participants were randomly allocated, by stratified blind-card allocation. Appointments for twice weekly, 40 minute sessions were arranged for both groups. All exercises were completed on a one-to-one basis, with the first author supervising the sessions (and exercising with the TGB group).

The exergaming group played five IREX® exergames (see Appendix 1 for details). Those in the TGB group performed exercises that were matched to the IREX® exergames for movement patterns required, physiological demands, sequence, duration and mode of exercise, by adopting open and closed kinetic chain movements, in the same range and loading, across both groups. Each IREX® exergame was played for two minutes and was repeated three times within a session. TGB exercise was conducted in sets of two minutes duration and was repeated three times within a session. In both groups participants were given rest periods of 10 to 30 seconds, or longer, if required, between exergames, or TGB exercise sets.

**Outcome measures**

The primary outcome measures were pain and balance (postural control/sway) - measured at baseline and after the six-week intervention period, and technology acceptance and flow experience - measured at baseline, after each exercise session and after the six-week intervention period.

Pain intensity experienced within 30 days and at present was recorded using a numerical pain rating scale (NPRS) at baseline and after the six week intervention period [33]. The NPRS ranges from 0 “no pain” to 10 “worst possible pain” [34, 35]. The sensory, emotional and motivational dimensions of pain were measured using the Multi Affect and Pain Survey (MAPS) questionnaire [36, 37]. MAPS comprises 101 pain descriptors which reflect three major aspects of pain: somatosensory, emotional and well-being. The somatosensory pain supercluster contains 17 clusters with 57 descriptors of painful sensory qualities; the emotional pain supercluster has 8 clusters with 26 descriptors of negative emotional qualities; and the well-being supercluster has 18 descriptors of positive affect, and health, grouped into five clusters.

Postural control was measured as Centre of Pressure (CoP) displacement and velocity, using a portable Kistler™ force platform (Model 9286AA, W 40 x L 60 x H 3.5 cm) with a sampling rate of 1000 Hz [38]. Participants stood barefoot on the Kistler™ force plate and looked directly ahead at a visual target (black 100 mm diameter circle) positioned 3 m from the centre of the force plate at eye level [33, 39, 40]. Participants were asked to stand as still as possible on their dominant leg (preferred kicking), with their eyes open and arms by their side, for three periods of 30 s. Between trials, participants stepped off the
force plate, to allow calibration of the equipment, which also allowed a 30 s rest. This testing sequence was then repeated but with participant’s eyes open.

Technology acceptance was measured using the Unified Theory of Acceptance and Use of Technology (UTAUT) \[41\] questionnaire. The UTAUT comprises a series of 7-point Likert scales ranging from 1 (strongly disagree) to 7 (strongly agree), measuring six domains. The domains are: performance expectancy (PE), the degree to which a person believes that using a system will help them attain gains in their performance, effort expectancy (EE), the degree of ease in using the technology, social influence (SI), the degree to which a person perceives that important others believe they should use the technology, facilitation conditions (FC), the degree to which a person believes they should use the technology, self-efficacy (SE), the degree to which a person believes they are capable of using the technology and behavioural intention (BI), intention to use the intervention again.

Flow experience was measured using the Flow State Scale questionnaire (FSS) \[42\]. Flow is the degree to which people experience an optimal psychological state associated with complete absorption in the task that they are doing (a concept widely researched in various fields \[26, 39, 43, 44\]). The FSS consists of 36 questions with nine subscales and response options on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The subscales are: autotelic experience (AE), the intrinsically rewarding experience doing a task, clear goals (CG), clearly confident of action, challenge-skill-balance (CB), balance between skills and challenge, concentration at task (CT), complete control on performing a task, paradox of control (PC), at full focus at the task, unambiguous feedback (UF), feedback on performing a task, action-awareness-merging (AM), immediate, direct and clear observations whilst performing a task, transformation of time (TT), time either speeds up, slows down, becomes irrelevant or out of one’s awareness and loss of consciousness (Loss), a sense of not being concerned with oneself while engaging in the activity and in the process; the individual becomes one with the activity, or a part of it.

In addition – to enable analyses of the degree to which the groups were matched, in terms of both objective and subjective measures of physiological demand – participant’s heart rate, perceived levels of physical exertion and subjective mental effort - were recorded during each exercise session.

Heart rate (HR) was recorded using a Polar™ heart rate monitor (FS2C), recording watch and T31 coded chest strap (Polar Electro, Oy, Finland). Mean HR was calculated for each exercise session and recorded as percentage of Age-predicted maximum heart rate (220 - age) (APMHR).

Perceived levels of physical exertion were measured using the Borg Rating of Perceived Exertion (RPE) scale \[45\]. Participants subjectively rated their levels of physical intensity and effort based on the physical sensations that they experienced during the exercise session. The scale consists of numbered categories, 6–20 with verbal cues from “very, very light” to “very, very hard”.

Subjective mental effort was measured using the Subjective Mental Effort Questionnaire (SMEQ) (also referred to as the Rating Scale for Mental Effort) \[46\]. The SMEQ consists of a single scale with nine labels from “Not at all hard to do” to “Tremendously hard to do”.

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Exergaming system

Exergaming was performed using five games from the IREX™ system (GestureTek, Toronto, Canada), consisting a computer installed with virtual-reality (VR) software, a television monitor with widescreen plasma screen (37”, Hanspree, Type T73B, Netherlands), a digital camera, a green fabric screen (W 3 m x H 2.6 m) and red gloves.

Data extraction

Range and standard deviation of CoP displacements in the anterior-posterior (AP) and medio-lateral (ML) directions (CoP<sub>AP</sub> SD, CoP<sub>AP</sub> range, CoP<sub>ML</sub> SD, CoP<sub>ML</sub> all mm) and the resultant CoP velocity (mm/sec<sup>-1</sup>) were extracted from the force platform using Bioware software (Kistler™), after low-pass filtering of the raw data at 10 Hz. CoP velocity (mm/sec<sup>-1</sup>) was calculated using methods described by Raymakers, Samson and Verhaar (2005) [47].

Statistical analysis

The data were analysed with Version 19 of the Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA). Variables that demonstrated internal reliability by Cronbach's alpha were analysed. Analysis of covariance (ANCOVA) was used to assess between-group final scores for each outcome measure used with baseline scores as covariate. Variables that did not meet the assumption of homogeneity of variance were analysed by two-way independent measures ANOVA with blocking using mean splits of scored pre-measures. Mixed analysis of variance (ANOVA) was used to determine any within-subject changes over time. All analyses used a significance level of 0.05. Results showing levels of significance at 0.01 and 0.001 were also included. The effect size measure epsilon squared was used, where values of 0.01, 0.06 and 0.14 were interpreted as small, moderate and large [48].

Sample calculation

G*Power version 3.1 [49, 50] was used to conduct a power analysis for a two-group comparison using analysis of variance to detect a large effect (f = 0.40) for the postural sway outcome measure and 0.80 power. The results showed that the required sample size was 52.

Results

Descriptive statistics Mean (SD), for all outcome measures are presented in Table 1.
Table 1
Descriptive statistics, Mean (SD), for all outcome measures

|                              | Baseline |          |          |          |          |
|------------------------------|----------|----------|----------|----------|----------|
|                              | TGB      | IREX®    | TGB      | IREX®    |
| Pain intensity               |          |          |          |          |
| Experienced within 30 days   | 6.00 (2.34) | 5.52 (2.24) | 5.85 (2.43) | 5.04 (2.21) |
| At the time of testing       | 3.33 (2.82) | 2.96 (1.87) | 3.48 (3.03) | 2.07 (2.11) |
| MAPS (pain descriptors in parenthesis) |          |          |          |          |
| Somatosensory pain           |          |          |          |          |
| Cutaneous                    | 1.13 (1.00) | 0.67 (0.53) | 1.08 (1.05) | 0.63 (0.51) |
| (itchy, irritating, crawling, tickling, tingling) |          |          |          |          |
| Autonomic distress           | 0.80 (1.37) | 0.09 (0.24) | 0.67 (1.35) | 0.19 (0.49) |
| (disgusting, nauseating)     |          |          |          |          |
| Thermal                      | 1.41 (1.80) | 0.93 (1.30) | 1.25 (1.78) | 0.56 (0.97) |
| (burning, hot)               |          |          |          |          |
| Pain extent                  | 2.00 (1.52) | 1.29 (0.99) | 1.80 (1.59) | 1.29 (1.03) |
| (spreading, persistent, worsening, pervasive) |          |          |          |          |
| Intense pain qualities       | 2.12 (1.79) | 0.98 (1.16) | 1.91 (1.84) | 0.87 (1.20) |
| (vicious, excruciating, nasty, overwhelming) |          |          |          |          |
| Intermittent pressure        | 1.46 (1.74) | 0.63 (1.11) | 1.27 (1.69) | 0.71 (1.28) |
| (throbbing, pounding)       |          |          |          |          |
| Brightness                   | 0.56 (1.19) | 0.07 (1.18) | 0.63 (1.27) | 0.19 (0.49) |
| (stinging, smarting)         |          |          |          |          |
| Incisive pressure            | 1.68 (1.32) | 0.20 (0.62) | 1.53 (1.28) | 0.84 (0.81) |
| (sharp, shooting, biting, deep, tearing, stabbing, gnawing) |          |          |          |          |
| Traction/abrasion            | 1.12 (1.31) | 0.26 (0.70) | 0.96 (1.28) | 0.54 (0.92) |
| (pulling, grinding, squeezing, pressing, cramping, tugging, crushing) |          |          |          |          |
| Numb                         | 1.28 (1.84) | 0.64 (0.68) | 1.13 (1.74) | 0.40 (0.92) |
| (numb, numbing)              |          |          |          |          |
| Emotional pain               |          |          |          |          |
| Physical illness             | 1.61 (1.38) | 0.57 (0.76) | 1.38 (1.42) | 0.90 (0.88) |
| (ailing, suffering)          |          |          |          |          |
|                          | Baseline           | Post Intervention |
|--------------------------|--------------------|-------------------|
| **Depressed mood**       | 0.91 (0.99)        | 1.35 (1.11)       |
| (lousy, rejected, depressed, discouraged, miserable, lonely) | (0.99)             | (0.90)            | 0.40 (0.45) |
| **Self-blame**           | 0.48 (0.90)        | 1.24 (1.12)       |
| (guilty, negligent)      | (1.12)             | (1.04)            | 0.40 (0.74) |
| **Anger**                | 0.83 (1.32)        | 2.67 (1.36)       |
| (angry, outraged, upset, annoyed) | (1.36)             | (1.19)            | 0.43 (0.66) |
| **Fear**                 | 0.78 (1.34)        | 0.26 (0.46)       |
| (alarming, Startling, frantic, terrified) | (0.46)             | (1.26)            | 0.13 (0.36) |
| **Physical avoidance**   | 2.14 (1.50)        | 1.24 (1.12)       |
| (exhausting, sleepy, tiring, sluggish) | (1.12)             | (1.40)            | 1.13 (1.00) |

**Well-being**

|                          | Baseline           | Post Intervention |
|--------------------------|--------------------|-------------------|
| **Physically engaged**   | 2.46 (1.65)        | 2.28 (1.56)       |
| (active, vigorous)       | (1.56)             | (1.49)            | 2.62 (1.42) |
| **Affiliative feelings** | 3.41 (1.44)        | 2.71 (1.30)       |
| (loved, forgiving, affectionate, sympathetic) | (1.30)             | (1.40)            | 3.14 (1.40) |
| **Positive affect**      | 3.11 (1.51)        | 2.74 (1.15)       |
| (hopeful, happy, relaxed, encouraged, cheerful, satisfied, calm) | (1.15)             | (1.04)            | 2.90 (0.94) |

**Postural sway with eyes open**

|                          | Baseline           | Post Intervention |
|--------------------------|--------------------|-------------------|
| **AP SD**                | 4.44 (1.40)        | 5.45 (2.06)       |
| **AP range**             | 21.42 (5.89)       | 25.92 (6.25)      |
|                          | (18.02 (7.54)      | (21.25 (6.79)     |
| **ML SD**                | 2.13 (0.83)        | 3.15 (1.89)       |
| **ML range**             | 12.42 (4.46)       | 17.82 (10.24)     |
|                          | (10.17 (3.78)      | (13.97 (7.72)     |
| **CoP velocity**         | 29.47 (6.72)       | 32.69 (10.73)     |
|                          | (31.48 (10.43)     | (32.38 (9.58)     |

**Postural sway with eyes closed**

|                          | Baseline           | Post Intervention |
|--------------------------|--------------------|-------------------|
| **AP SD**                | 4.83 (1.56)        | 5.45 (1.40)       |
| **AP range**             | 24.88 (8.12)       | 28.69 (8.19)      |
|                          | (21.24 (8.29)      | (27.70 (9.17)     |
| **ML SD**                | 2.27 (1.31)        | 2.62 (1.45)       |
| **ML range**             | 12.42 (4.46)       | 17.82 (10.24)     |
|                          | (10.17 (3.78)      | (13.97 (7.72)     |
| **CoP velocity**         | 29.47 (6.72)       | 32.69 (10.73)     |
|                          | (31.48 (10.43)     | (32.38 (9.58)     |
|                         | Baseline  | Post Intervention |
|-------------------------|-----------|-------------------|
| **Baseline**            |           |                   |
| **ML range**            | 14.45 (9.27) | 15.06 (7.76)  |
|                         | 10.86 (4.02) | 12.92 (4.38)   |
| **CoP velocity**        | 30.69 (8.27) | 37.32 (9.91)  |
|                         | 30.83 (10.40) | 33.89 (10.16) |
| **UTAUT**               |           |                   |
| Performance expectancy  | 4.16 (2.22) | 3.54 (1.56)     |
|                         | 6.67 (0.48) | 6.13 (1.09)   |
| Effort expectancy       | 4.04 (1.95) | 3.23 (1.46)     |
|                         | 6.26 (0.82) | 5.70 (1.16)   |
| Social influence        | 3.54 (2.41) | 3.19 (1.71)     |
|                         | 6.13 (1.28) | 4.70 (1.84)   |
| Facilitating conditions | 4.08 (2.12) | 3.77 (1.81)     |
|                         | 6.21 (0.91) | 5.56 (1.29)   |
| Self-efficacy           | 3.70 (1.93) | 3.17 (1.52)     |
|                         | 5.90 (1.05) | 5.22 (1.46)   |
| Behavioural intention   | 3.55 (2.11) | 2.88 (1.99)     |
|                         | 6.58 (0.68) | 5.85 (1.47)   |
| **FSS**                 |           |                   |
| Autotelic experience    | 3.00 (1.43) | 3.41 (1.28)     |
|                         | 4.16 (0.54) | 4.10 (0.80)   |
| Clear goals             | 3.05 (1.27) | 2.92 (1.25)     |
|                         | 4.53 (0.46) | 4.36 (0.76)   |
| Concentration at task   | 2.96 (1.22) | 3.31 (1.26)     |
|                         | 4.53 (0.44) | 4.31 (0.74)   |
| Paradox of control      | 2.82 (1.36) | 2.84 (1.24)     |
|                         | 4.40 (0.66) | 4.08 (1.01)   |
| Challenge-skill-balance | 2.93 (1.06) | 3.04 (1.01)     |
|                         | 4.42 (0.51) | 4.04 (0.76)   |
| Unambiguous feedback    | 2.81 (1.26) | 2.91 (1.12)     |
|                         | 4.41 (0.62) | 4.21 (0.76)   |
| Action-awareness-merging| 2.46 (1.03) | 2.67 (1.01)     |
|                         | 4.09 (1.02) | 3.89 (0.84)   |
| Transformation of time  | 2.55 (1.16) | 3.05 (1.21)     |
|                         | 3.75 (1.28) | 3.56 (1.19)   |
| Loss of self-consciousness| 3.09 (1.42) | 3.31 (1.25)  |
|                         | 4.52 (0.56) | 4.40 (0.74)   |
Objective and subjective measures of physiological demand

|                           | Baseline       | Post Intervention |
|---------------------------|----------------|-------------------|
| **Objective and subjective measures of physiological demand** |               |                   |
| Perceived physical effort (RPE) | 10.48(1.85)  | 9.41 (1.31)       |
|                           |                | 10.77 (1.65)      |
|                           |                | 9.81 (2.07)       |
| Subjective mental effort  | 39.47 (11.57)  | 32.46 (9.95)      |
|                           |                | 55.93 (15.70)     |
|                           |                | 40.96 (16.28)     |
| Heart rate                | 77.41 (5.69)   | 77.67 (4.45)      |
|                           |                | 82.23 (11.00)     |
|                           |                | 81.80 (9.58)      |

Table 2
Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for objective and subjective measures of physiological demand

|                           | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|---------------------------|----------------------------------------------------------------|------------------------------------------|
| IREX® – TGB               | IREX®                                                           | TGB                                      |
| Rating of Perceived Exertion | 0.29 (-0.68 to 1.25)                                        | 0.99+ (-0.06 to 2.04)                    |
|                           |                                                                | 1.00** (-0.43 to 1.57)                   |
| Subjective Mental Effort  | 5.69 (-4.01 to 15.38)                                        | 14.24*** (5.51 to 22.96)                 |
|                           |                                                                | 5.80* (-0.03 to 11.56)                   |
| % of Age Predicted Maximal Heart Rate\(^a\) | 1.43 (-1.41 to 4.27)                                        | 0.88 (-1.26 to 3.02)                    |
|                           |                                                                | 0.42 (-1.98 to 2.82)                    |

\(^a\) Variable that has violated homogeneity of regression

\(+ p < 0.10.\)

\(* p < 0.05, ** p < 0.01, *** p < 0.001.\)

**Objective and subjective measures of physiological demand**

There were no significant differences, between the groups, in either objective (% of APMHR), or subjective (RPE and SMEQ) measures of physiological demand of exercising. This supports the premise that the exercises were successfully matched and hence any differences, between the groups, could be attributed to the different exercises they undertook.
The within-group analysis showed that both RPE (F[1, 46] = 11.24, p < 0.01, $\varepsilon^2 = 0.07$) and SMEQ (F[1, 46] = 15.12, p < 0.001, $\varepsilon^2 = 0.09$) increased over the intervention period in both groups: RPE increased by 0.40, from 9.41 (1.31) to 9.81 (2.07) in the IREX® group and 0.29, from 10.48 (1.85) to 10.77 (1.65) in TGB and SMEQ by 8.5, from 32.46 (9.95) to 40.96 (16.28) in the IREX® group, and 16.46, from 39.47 (11.57) to 55.93 (16.28) in TGB. These increases being significant for SMEQ in both groups and RPE in the TGB – with the increase in RPE for the IREX® group approaching significance at p < 0.10.

HR did not alter significantly, for either group over the intervention period; being stable and similar, for both groups, at 77% of APMHR. This places exercise intensity, in both groups, (just) within the Vigorous classification (77–95% of HR Max) of the ACSM [51]. Although the participants RPE levels, of around 10, would be associated with light exercise. This apparent anomaly suggest participants may have underrated their exertion levels, compared to normative values and expectations for RPE. It also appears that while both groups were exercising at a high aerobic physiological demand, which did not alter (as reflected by % of APMHR), participants felt the exercise was somewhat easier throughout, and, despite the perception of effort increasing over the intervention period, it remained below levels normally associated with vigorous exercise (RPE 14–17) [51].

**Pain intensity**

Pain intensity score, within 30 days, reduced for participants in both groups, before/after the intervention – TGB scores decreased 0.15, from 6.00 (2.34) to 5.85 (2.43), while the IREX® group decreased by 0.48, from 5.52 (2.24) to 2.04 (2.21). Pain at the time of testing, however, increased for the TGB Group by 0.15 (3.33 [2.82] to 3.48 [3.03]) over the intervention period, but, reduced by 0.89 in the IREX® group (2.96 [1.87] to 2.07 [2.11]) (see Table 1). While greater reductions occurred, in the unadjusted values for both of the Pain intensity measures, in the IREX® group the between-group analysis shows that these were not statistically significantly different, from the changes seen in the TGB group (See Table 3). The within-group testing, however, showed the degree of reduction in pain experienced at the time of testing, was statistically significant in the IREX® group, (F[1. 52] = 3.98, p = 0.05, $\varepsilon^2 = 0.46$).

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Table 3
Adjusted post-intervention between group difference (ANCOVA) and within-group change over time (mixed ANOVA); Mean differences (95% CI) for both measure of pain intensity

| Outcome                                                                 | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|------------------------------------------------------------------------|---------------------------------------------------------------|--------------------------------------------|
|                                                                        | IREX® - TGB                                                   | IREX®                                      | TGB                                        |
| Overall pain intensity experienced within 30 days before and after the intervention | -0.45 (-1.25 to 0.36)                                        | -0.48 (-1.30 to 0.34)                      | -0.15 (-0.51 to 0.21)                      |
| Pain intensity experienced at baseline and after the intervention      | -1.12 (-2.15 to -0.09)                                       | -0.89** (-1.52 to -0.26)                   | 0.15 (-0.71 to 1.01)                       |

*p < 0.05, **p < 0.01, ***p < 0.001.

**Multidimensional affect and pain variables (MAPS)**

Statistically significant positive changes were observed, in both groups, over the intervention period, in three MAPS variables. There was a decrease in thermal pain score (part of the somatosensory pain supercluster) of 0.37 in the IREX® group (from 0.93 [1.30] to 0.56 [0.97]) and 0.16 in TGB (from 1.41 [1.80] to 1.25 [1.78]) (see Table 1). While the between-group analysis showed the magnitude of reduction in thermal pain score in the IREX® group was significantly greater than that seen in the TGB Group (F [1, 48] = 14.43, p = 0.00, $\varepsilon^2 = 0.09$) (see Table 4) the degree of reduction in neither group was significant when subject to the within-group model.
Table 4
Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for Multidimensional Affect and Pain Survey (MAPs) measures

| MAPS                           | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|--------------------------------|---------------------------------------------------------------|--------------------------------------------|
|                                | IREX® – TGB          | IREX®            | TGB                          |
| Somatosensory pain supercluster|                                                                |                                            |
| Cutaneous                      | -0.34 (-0.22 to 0.15) | -0.06 (-0.16 to 0.03) | -0.06 (-0.21 to 0.09) |
| Autonomic distress             | 0.17 (-0.15 to 0.49) | 0.10 (-0.08 to 0.27) | -0.10 (-0.24 to 0.06) |
| Thermal\(^a\)                  | -1.06*** (-1.62 to -0.50) | -0.38 (-0.82 to 0.05) | -0.08 (-0.29 to 0.13) |
| Pain extent                    | -0.42 (-0.85 to -0.04) | -0.05 (-0.34 to 0.25) | -0.17 (-0.42 to 0.07) |
| Intense pain qualities         | -0.15 (-0.71 to 0.40) | -0.12 (-0.49 to 0.26) | -0.20 (-0.59 to 0.19) |
| Intermittent pressure          | 0.04 (-0.59 to 0.68)  | 0.12 (-0.38 to 0.61) | -0.23 (-0.66 to 0.20) |
| Brightness                     | 0.10 (-0.32 to 0.51)  | 0.12 (-0.06 to 0.29) | 0.08 (-0.18 to 0.33) |
| Incisive pressure              | -0.09 (-0.53 to 0.34) | -0.06 (-0.30 to 0.19) | -0.12 (-0.46 to 0.22) |
| Traction/abrasion              | 0.16 (-0.23 to 0.55)  | 0.02 (-0.22 to 0.26) | -0.14 (-0.44 to 0.16) |
| Numb                           | 0.15 (-0.37 to 0.66)  | 0.13 (-0.15 to 0.42) | -0.19 (-0.57 to 0.18) |
| Emotional pain supercluster    |                                                                |                                            |
| Physical illness\(^a\)        | -0.13 (-0.74 to 0.49) | -0.12 (-0.44 to 0.20) | -0.15 (-0.37 to 0.06) |
| Depressed mood\(^a\)           | -0.57 (-1.23 to 0.09) | -0.22* (-0.39 to -0.05) | -0.10 (-0.23 to 0.04) |

\(^a\) Variable that has violated homogeneity of regression for ANCOVA

\(^+\) p < 0.10.

\(^*\)p < 0.05, \(^**\)p < 0.01, \(^***\)p < 0.001.
| MAPS                      | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|--------------------------|----------------------------------------------------------------|-------------------------------------------|
| Self-blame               | -0.02 (-0.23 to 0.19)                                          | 0.00 (-0.10 to 0.10)                      |
|                          |                                                                 | 0.02 (-0.18 to 0.21)                      |
| Anger                    | -0.06 (-0.37 to 0.25)                                          | -0.16 (-0.38 to 0.05)                     |
|                          |                                                                 | -0.17 (-0.46 to 0.11)                     |
| Fear                     | -0.21 (-0.53 to 0.11)                                          | -0.13 (-0.28 to 0.01)                     |
|                          |                                                                 | -0.12 (-0.41 to 0.18)                     |
| Physical avoidance       | -0.13 (0.56 to 0.31)                                           | -0.14 (-0.43 to 0.15)                     |
|                          |                                                                 | -0.21 (-0.56 to 0.14)                     |
| Well-being supercluster  |                                                                 |                                           |
| Physically engaged\*     | 0.13\* (-0.29 to 0.56)                                         | 0.33 (-0.13 to 0.79)                      |
|                          |                                                                 | 0.13 (-0.02 to 0.29)                      |
| Affiliative feelings     | 0.16 (-0.27 to 0.59)                                           | 0.42\* (-0.004 to 0.85)                  |
|                          |                                                                 | 0.14\* (0.02 to 0.27)                     |
| Positive affect          | -0.16 (-0.56 to 0.24)                                          | -0.17 (-0.21 to 0.54)                     |
|                          |                                                                 | 0.11 (-0.26 to 0.48)                      |

\* Variable that has violated homogeneity of regression for ANCOVA
\*\ p < 0.10.
\*\* p < 0.05, \*\*\* p < 0.001.

There was a decrease in the depressed mood variable (part of the emotional pain supercluster), of 0.95 in the IREX® group (from 1.35 [1.11] to 0.40 [0.45]) and 0.17 in TGB (from 0.91 [0.99] to 0.74 [0.90]) (see Table 1). While a greater reduction occurred, in the unadjusted values for depressed mood rating, in the IREX® group, the between-group analysis shows that these were not statistically significantly different, from the changes seen in the TGB group (See Table 4). The within-group testing, however, showed the degree of reduction in the IREX® group was statistically significant (F [1, 50] = 9.09, p = 0.004, \( \varepsilon^2 = 0.67 \)).

There was an increase in the affiliative feelings variable (part of the well-being supercluster), of 0.43 in the IREX® group (from 2.71 [1.30] to 3.14 [1.40]) and 0.27 in TGB (from 3.41 [1.44] to 3.57 [1.40]) (see Table 1). While a greater increase occurred, in the unadjusted values for affiliative feelings rating, in the IREX® group, the between-group analysis shows that these were not statistically significantly different, from the changes seen in the TGB group (See Table 4). The within-group testing, however, showed the degree of increase was statistically significant in both groups F [1, 50] = 6.92, p = 0.01, \( \varepsilon^2 = 0.03 \).

Both groups also reported increases in the physically engaged variable scores (part of the well-being supercluster) – the IREX® group 0.34 (from 2.28 [1.56] to 2.62 [1.42]) and TGB 0.23 (from 2.46 [1.65] to
2.69 [1.49]) (see Table 4). While the between group comparison was non-significant (at p < 0.05) the difference was approaching significance (F [1, 48] = 3.76, p = 0.06, $\varepsilon^2 = 0.01$) in favour of the IREX® group.

Three other variables, thermal pain (F [1, 50] = 3.85, p = 0.06, $\varepsilon^2 = 0.01$), anger (part of the emotional pain supercluster), (F [1, 50] = 3.76, p = 0.06, $\varepsilon^2 = 0.68$) and physically engaged (F [1, 50] = 3.82, p = 0.06, $\varepsilon^2 = 0.85$) also approached significance. Again, in favour of in favour of the IREX® group towards greater reduction in perceived pain after exergaming albeit with a small effect size.

**Postural control**

An improvement occurred in postural control in both groups over the intervention period under the eyes open Condition with the sole exception of CoP Velocity - which increased in the TGB group. All changes (bar the increase in CoP Velocity in the TGB group) were positive, in that they indicated improved postural control (reduced sway). There were no significant between-group effects observed under either condition (eyes open or closed) (see Table 5). The improvements observed, under the eyes open condition, were statistically significant, in within-group analysis, for, both groups, in AP SD and in ML SD and AP Range for the IREX® group (see Table 5).
Table 5
Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for Postural Control

| Postural control          | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|---------------------------|-----------------------------------------------------------------|-------------------------------------------|
|                           | IREX® – TGB                                                      | IREX®                                    |
|                           |                                                                 | TGB                                       |
| Bipedal – eyes open       |                                                                  |                                           |
| AP SD                     | 0.32 (-0.63 to 1.28)                                            | 0.63* (-0.42 to 1.67)                    |
|                           |                                                                 | 0.83* (-0.23 to 1.47)                    |
| ML SD                     | 0.19 (-0.33 to 0.71)                                            | 0.58* (1.06 to 0.00)                     |
|                           |                                                                 | 0.24 (-0.06 to 0.54)                     |
| CoP velocity              | -1.10 (-6.00 to 3.77)                                           | 0.36 (2.69 to 3.41)                      |
|                           |                                                                 | 2.33 (1.79 to 6.45)                      |
| AP range                  | 1.70 (-2.54 to 5.94)                                            | 4.58* (1.14 to 8.02)                     |
|                           |                                                                 | 2.88 (-0.62 to 6.38)                     |
| ML range                  | 1.94 (-1.94 to 5.82)                                            | 3.74 (-1.04 to 8.53)                     |
|                           |                                                                 | 1.37 (-0.46 to 3.19)                     |
| Bipedal – eyes closed     |                                                                  |                                           |
| AP SD                     | 0.52 (-0.48 to 1.52)                                            | 0.49 (-0.64 to 1.62)                     |
|                           |                                                                 | 0.15 (-0.31 to 0.62)                     |
| ML SD                     | 0.29 (-0.11 to 0.70)                                            | 0.19 (-0.28 to 0.66)                     |
|                           |                                                                 | 0.32 (-0.16 to 0.79)                     |
| CoP velocity              | 0.11 (-5.63 to 5.84)                                            | 2.31 (-1.10 to 5.72)                     |
|                           |                                                                 | -0.56 (-5.56 to 4.45)                    |
| AP range                  | 4.10 (-0.90 to 9.09)                                            | 0.08 (-3.44 to 3.61)                     |
|                           |                                                                 | 2.85 (-1.09 to 6.79)                     |
| ML range                  | 2.13 (-0.13 to 4.40)                                            | 3.72 (-0.05 to 7.48)                     |
|                           |                                                                 | 1.32* (-1.14 to 3.79)                    |

*p < 0.05, **p < 0.01, ***p < 0.001.

Under the eyes open condition: AP SD reduced by 0.81 in the IREX® Group (from 5.45 [2.06] to 4.64 [2.03]) and 0.52 in TGB (from 4.44 [1.40] to 3.92 [1.66]) (see Table 1). The degree of improvement was significant for both groups (within-group tests F [1, 46] = 8.29, p = 0.01, ε² = 0.09) (see Table 5).

ML SD reduced by 0.56 in the IREX® Group (from 3.15 [1.89] to 2.56 [1.52]) as did AP Range by 4.67 (from 25.92 [6.25] to 21.25 [6.79]) (see Table 1). These improvements in both postural control variables
were significant (within-group) at $F[1, 46] = 8.37 \ p = 0.01, \ \varepsilon^2 = 0.05$ and $F[1, 45] = 9.91, \ p = 0.003, \ \varepsilon^2 = 0.16$) respectively (see Table 5).

When tested with eyes closed, the only significant effect observed occurred in within-group tests of ML range in the TGB Group. ML range decreased by 3.59 (from 14.45 [9.27] to 10.86 [4.02]) ($F[1, 45] = 4.12, \ p = 0.05, \ \varepsilon^2 = 0.06$).

This indicates there was a degree of improvement in the great majority of postural control variables (and hence balance), with significant improvement in more (three) variables with exergaming than (one) TGB, when visual input was available to the balance system. Improvement was also observed in all variables, when visual input was not available, but this was only significant in one variable for the TGB Group.

**Technology acceptance**

UTAUT scores increased in all six domains, for both groups, over the intervention period (see Table 1). These increases were all significant under within-group testing for both groups. Social influence and behavioural intention were significant in between-group testing, with greater increases seen in the TGB Group (see Table 6). Social influence ($F[1, 44] = 5.16, \ p = 0.03, \ \varepsilon^2 = 0.58$) and behavioural intention ($F[1, 44] = 4.99, \ p = 0.03, \ \varepsilon^2 = -0.73$).

**Table 6**

Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for technology acceptance

| UTAUT | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|-------|---------------------------------------------------------------|-------------------------------------------|
|       | IREX® – TGB                                                  | IREX®                                     | TGB                             |
| Performance expectancy | -0.55 (-1.04 to -0.05) | 1.40** (0.67 to 2.13) | 2.14*** (1.32 to 2.96) |
| Effort expectancy     | -0.48 (-1.04 to 0.08) | 1.49*** (0.88 to 2.10) | 1.80*** (1.04 to 2.65) |
| Social Influence      | -1.39* (-2.24 to -0.54) | 1.06** (0.30 to 1.82) | 2.46*** (1.65 to 3.27) |
| Facilitating conditions | -0.66 (-1.31 to -0.01) | 1.02* (0.23 to 1.80) | 1.98*** (1.10 to 2.85) |
| Self-efficacy         | -0.63 (-1.39 to 0.13) | 1.22* (0.28 to 2.16) | 1.89*** (1.08 to 2.70) |
| Behavioural intention | -0.69* (-1.35 to -0.03) | 1.65*** (0.88 to 2.43) | 2.17*** (1.26 to 3.09) |

*p < 0.05, **p < 0.01, ***p < 0.001.
For within group testing, the mixed ANOVA revealed a statistically significant increases over time for all the UTAUT measures – performance expectancy (F [1, 46] = 45.04, p < 0.001, $\epsilon^2 = 0.36$), effort expectancy (F [1, 46] = 49.40, p < 0.001, $\epsilon^2 = 0.37$), social influence (F [1, 46] = 42.69, p < 0.001, $\epsilon^2 = 0.34$), facilitating conditions (F [1, 46] = 28.07, p < 0.001, $\epsilon^2 = 0.27$), self-efficacy (F [1, 46] = 26.27, p < 0.001, $\epsilon^2 = 0.27$) and behavioural intention (F [1, 46] = 43.96, p < 0.001, $\epsilon^2 = 0.38$).

A significant interaction effect was between time and intervention was found for social influence (F [1, 46] = 6.73, p = 0.01, $\epsilon^2 = 0.41$) in favour of standard exercise.

**Flow**

Flow State Scale scores increased, in all nine subscales, for both groups, over the intervention period (see Table 1). These increases were significant, under within-group testing, for both groups, in seven subscales: autotelic experience, challenge-skill-balance, concentration at task, paradox of control, unambiguous feedback, action-awareness-merging and loss of self-consciousness. The remaining two subscales: Clear Goals and Transformation of time, were significant (within-group), only for the IREX® group participants (see Table 7).
### Table 7
Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for flow

| FSS                        | Adjusted post-intervention difference between groups (ANCOVA) | Within-group change over time (mixed ANOVA) |
|----------------------------|---------------------------------------------------------------|---------------------------------------------|
|                            | IREX® – TGB                                                   | IREX®                                       | TGB                                         |
| Autotelic experience       | -0.16* (-0.47 to 0.15)                                       | 0.79*** (0.40 to 1.18)                      | 1.16*** (0.65 to 1.68)                      |
| Clear goals<sup>a</sup>     | -0.07 (-0.43 to 0.30)                                        | 1.44*** (0.97 to 1.9)                       | 0.93 (-0.36 to 2.23)                       |
| Challenge-skill-balance    | -0.36 (-0.73 to 0.02)                                        | 1.06*** (0.61 to 1.51)                      | 1.46*** (0.94 to 1.98)                      |
| Concentration at task      | -0.24* (-0.59 to 0.11)                                       | 1.09*** (0.59 to 1.59)                      | 1.54*** (0.94 to 2.15)                      |
| Paradox of control         | -0.30† (-0.79 to 0.19)                                       | 1.33*** (0.79 to 1.87)                      | 1.49*** (0.83 to 2.15)                      |
| Unambiguous feedback       | -0.20 (-0.60 to 0.21)                                        | 1.38*** (0.91 to 1.85)                      | 1.52*** (0.93 to 2.12)                      |
| Action-awareness-merging<sup>a</sup> | -0.20 (-0.73 to 0.32)                               | 1.28*** (0.87 to 1.69)                      | 1.55*** (0.87 to 2.24)                      |
| Transformation of time     | -0.72 (-2.05 to 0.60)                                        | 0.55* (0.08 to 1.02)                        | 1.25 (-0.33 to 2.83)                       |
| Loss of self-consciousness | -0.14 (-0.52 to 0.25)                                        | 1.15*** (0.63 to 1.67)                      | 1.40*** (0.76 to 2.04)                      |

<sup>a</sup> Variable that has violated homogeneity of regression

<sup>+</sup> Approaching significance, p < 0.10.

*<sup>p</sup> < 0.05, **<sup>p</sup> < 0.01, ***<sup>p</sup> < 0.001.

There was only one subscale where a significant between-group effect was observed. Concentration of task improved significantly, in both groups with an increase of 1.0 in the IREX® Group (from 3.31 [1.26] to 4.31 [0.74]) and 1.57 in TGB (from 2.96 [1.22] to 4.53 [0.44]) (see Table 1). The degree of increase observed was significantly greater (F [1, 44] = 5.67, p = 0.02, $\varepsilon^2 = 0.75$) in TGB (see Table 7).

Autotelic experience and paradox of control also improved significantly in both groups (within-group analysis). Here, the between-group comparisons for autotelic experience was significant (F [1, 44] = 4.06, p = 0.05, $\varepsilon^2 = 0.51$) and approached significance for paradox of control F [1, 44] = 3.63, p = 0.06, $\varepsilon^2 = 0.81$ respectively), again in favour of TGB.
Mixed ANOVA found significant increases over time in all of the flow variables – autotelic experience ($F_{[1, 46]} = 40.20, p < 0.001, \varepsilon^2 = 0.23$), clear goals ($F_{[1, 46]} = 69.50, p < 0.001, \varepsilon^2 = 0.16$), challenge-skill-balance ($F_{[1, 46]} = 57.69, p < 0.001, \varepsilon^2 = 0.32$), concentration at task ($F_{[1, 46]} = 49.27, p < 0.001, \varepsilon^2 = 0.32$), paradox of control ($F_{[1, 46]} = 47.46, p < 0.001, \varepsilon^2 = 0.33$), unambiguous feedback ($F_{[1, 46]} = 63.12, p < 0.001, \varepsilon^2 = 0.37$), action-awareness-merging ($F_{[1, 46]} = 56.01, p < 0.001, \varepsilon^2 = 0.35$), transformation of time ($F_{[1, 46]} = 21.96, p < 0.001, \varepsilon^2 = 0.16$) and loss of self-consciousness ($F_{[1, 46]} = 41.39, p < 0.001, \varepsilon^2 = 0.29$).

**Discussion**

The aim of this study was to investigate the effects of exergaming comparing GestureTek's Interactive Rehabilitation and Exercise System (IREX™) [32] with traditional gym-based exercise, with no virtual stimuli (TGB), for older people with chronic musculoskeletal pain on the sensory, emotional and motivational dimensions of pain, pain intensity, postural control, technology acceptance and Flow State experience.

Before considering any comparison, of any outcome measures, between groups (TGB versus exergaming) it is essential to consider if the physical demands on participants, in each group, were matched, or not. To facilitate this, we recorded both objective and subjective measures of physiological demand.

There were no significant differences, between the groups, in either objective (% of APMHR), or subjective (RPE and SMEQ) measures of the physiological demand of exercising. Therefore, the premise is supported that the exercises were successfully matched and hence any differences, between the groups, could be attributed, with some confidence, to the different modes of exercise they undertook.

It is also important to consider if the intensity and load of the exercise was sufficient to meet current recommendations - and - if it changed over the intervention period. HR did not alter significantly, for either group over the intervention period; being stable and similar, for both groups, at 77% of APMHR. This places exercise intensity, in both groups, (just) within the Vigorous classification (77–95% of HR Max) of the ACSM [51]. Both RPE and SMEQ increased over the intervention period in both groups. The increases in SMEQ were significant in both groups. RPE increased significantly in the TGB group and the increase in the IREX® group was approaching significance (at $p < 0.10$). These significant increases over time in perceived physical exertion and expended subjective mental effort in both groups suggest that our participants invested more physical effort and concentration into their respective exercise sessions as they progressed. Barry et al. [39], however, reported significantly lower post-intervention physical exertion scores in their study comparing Xbox Kinect™ with traditional gym-based exercise in healthy younger active adults. Their findings suggested that their exergaming group perceived the Xbox Kinect™ to be less physically demanding and of lower intensity compared to traditional gym-based exercise.
Participants’ RPE levels, both before and after the intervention, while increased, remained associated with light exercise (at approximately 10). Therefore, while our participants rated their exertion levels higher after the exercise period, they remained underrated, compared to normative values and expectations for RPE. In essence while both groups were, objectively, exercising at a high aerobic physiological demand, which did not alter (as reflected by % of APMHR), participants felt the exercise was somewhat easier than that throughout the intervention period, in both groups. Despite increasing over the intervention period, perceived exertion remained below levels normally associated with vigorous exercise (RPE 14–17) [51]. This would be encouraging for the likely efficacy of both forms of exercise, as working harder (objectively), when exercising, than it feels, can be beneficial.

Pain

In our study, participants reported pain intensity, at the end of the intervention, was reduced in both groups. The reduction was significantly greater, however, in those in the exergaming group. This broadly echoes the existing (limited) body of previous evidence; despite evidence of therapeutic benefits from exergaming [21, 24, 52], published studies on the effects of exergaming on pain are varied and inconsistent [53]. Many suggest an association between exergaming and pain reduction [54] but few previous studies have reported significant changes in pain after exergaming [54, 55]. Kim et al. [56] found significant improvements in the Oswestry low-back pain disability index (ODI) scores amongst middle-aged women with low back pain after a three-times weekly 4-week exergaming intervention using Wii Fit Yoga. Sobral Monteiro-Junior et al. [54] found significant reductions in chronic low back pain amongst older women after a three-times weekly 8-week using both exergaming and strength exercises, but failed to find an intervention effect.

We are the first to use the MAPS questionnaire across exergaming and standard exercise. In terms of the multidimensional aspects of pain, we observed significant improvement in thermal pain (pain related to heat sensations) and feelings of physical engagement (active, vigorous) in the exergaming group. This suggests that exergaming alleviated these particular aspects of pain experience. Significant improvements in depressed mood and affiliative feelings also were observed in our exergaming group. The TGB group also showed improvements in depressed mood over time; the reduction was significantly higher in the exergaming group. Therefore, meaningful increases occurred in our participants’ feelings of being active and vigorous and benefits in emotional well-being after exergaming. Again, these findings accord with the premise that exergaming may induce positive mood states in users [57, 58].

It would seem logical to consider that the virtual-reality aspect of exergaming may alter pain perception to some extent through active distraction [59, 60]. It would also seem logical to speculate that the distraction and consequent improvement in pain perception, with exergaming, may encourage people who do not exercise, to take it up, or, those who do exercise, to exercise more.

Postural control
While decreases occurred, in all postural control variables, under the eyes open Condition, in both groups, over the intervention period (with the sole exception of CoP Velocity - which increased in the TGB group), these changes (bar the increase in CoP Velocity in the TGB group) were positive, in that they indicated improved postural control (reduced sway). There were no significant between-group effects observed under either condition (eyes open or closed). In our study, we did not find significant post-intervention differences between the exergaming and standard exercise groups for either condition (eyes open, or closed). The across-the-board improvement in postural control (and hence balance) observed here, is similar to that reported by Sobral Monteiro-Junior et al. [54] and Bisson et al. [61].

While all bar one of the balance measures decreased over time in both groups, with eyes open and closed, statistically significant reductions over time were observed on ML SD, AP SD and the CoP excursion in the anterior-posterior and medio-lateral direction in the exergaming group with vision, indicating better postural control. These improvements in balance measures are suggestive of benefit from exergaming, as was reported by Barry et al. [39]. They found significant improvements over time in ML SD, ML range and CoP velocity in healthy adults who had participated in a three-times weekly exergaming intervention for four weeks. Our findings are also consistent with those of Whyatt et al. [62] who found significant increases in Berg Balance Scale (BBS) scores, higher balance confidence and increased performance in levels of CoP displacement in the anterior, right and left CoP test locations after exergaming.

We also found significant reductions over time in the CoP excursion in the medio-lateral direction for the TGB group, under eyes closed condition, similar to those of Nicholson et al. [63], who reported significant reductions in the medio-lateral CoP range in older people following twelve weeks of balance training. ML postural sway is associated more with fall risks in older people compared to AP postural sway [64]. It is accepted that any effect of exercise, on balance, is likely to be more apparent when the balance task is performed under eyes closed condition [65]. When the eyes are closed, balance relies on solely on efferent neuromuscular and sensorimotor input [66], which can be improved with exercise [67].

Our findings reinforce the premise that exercise, of many types, has the potential to improve balance in older people if performed safely. There were no adverse events or reactions in our study and both forms of exercise appeared to yield some benefit. We did not explore the postural control mechanisms affected, nor observe anything other than a trend to greater benefit from exergaming. It would appear, though that exercising using exergames can potentially contribute to improving balance and reducing fall risks in older people with chronic musculoskeletal pain [65].

Technology acceptance

Our results showed that all UTAUT scores increased in both groups but significant increase occurred only in social influence and behavioural intention in the TGB group. The increase in all UTAUT scores indicates high acceptance for both forms of exercise and favourable response from participants in both groups. This could be due to several factors. Firstly, the affective state of a user plays an important role in their acceptance of a new activity or technology [68]. How users feel when they perform the exercises determines their appraisal of the exercise and whether they would continue with it [69]. Kwan and Bryan
found that affective response influenced exercise behaviour, particularly intention to exercise. In the case of exergaming, Billis et al. [71] found that game content in exergames adapted according to older people’s affective states would influence their acceptance of exergaming. Secondly, if older people found the type of exercise to be both useful and easy to follow, they were more likely to express intention to continue the activity [72]. Thirdly, verbal or non-verbal social behaviour nurtures change in any particular behaviour [73, 74]. This would include encouragement, feedback or supervision and even the mere presence of the researcher during the sessions [75].

The higher scores observed in effort expectancy in the TGB group may arise from the absence of any active distraction (the activity did not involve interaction with an external source). The standard exercise routine comprised planned and structured repetitive physical movements [76]. Therefore, the participants were exercising with themselves instead of having to engage with visual or auditory stimuli (as in exergaming). While this could have made mastering the movements initially easier, the absence of distraction may not encourage concordance over the longer term.

We also observed that the change in behavioural intention was larger in the exergaming group although it did not reach significance. It may be that the group experienced positive affect and engagement during exergaming, which could have brought on the larger increase in behavioural intention [77].

Flow

We found significant between-group differences in the concentration aspect of flow state, favouring the TGB group. Two other dimensions, autotelic experience, and paradox of control approached significance, also favouring the TGB group of standard exercise. While our results showed a trend of increased scores in all flow dimensions from baseline to the end of the intervention, significance increases over time were achieved in eight of the nine dimensions of flow state in both groups, except transformation of time, supporting the notion of the flow phenomenon in sport [78, 79].

Regarding the observation on the significant increase in transformation of time for the exergaming group, similar results have been reported in previous studies [26, 39]. This suggests that the immersive environment during exergaming can facilitate distortion of time amongst users. Distortion of time during exercise implies that users experience deep involvement when exercising and become fully invested in the exercise experience [80]. The largest effect size was observed in the significant increase in unambiguous feedback in the exergaming group suggests that the exergaming group received more direct and immediate feedback when exercising in an immersive environment compared to performing standard exercises. This feedback is akin to successes and failures during exergame play, so that a clear idea and continuity of feedback is provided for the next action [81].

Limitations

We acknowledge that our results are based on a limited number of participants and may lack sufficient power to provide fully definitive results from some of the compared outcomes. As this research was
conducted as part of the completion of a PhD, it was also restricted by staffing, time and funding. For practical reasons, neither the researcher nor the participants were blind to the conditions being tested. In future, this research would benefit from further verification from a larger sample.

**Conclusion**

While we did not find definitive evidence that exergaming or TGB was superior, exergaming was found to be – at the very least – comparable to standard exercise in terms of acceptance with some aspect of pain perception improving more in the exergaming group than TGB. Participants also did not report any adverse events or side effects from exergaming. Our findings support the argument that older people with chronic musculoskeletal pain could benefit from taking part in a short-term exergaming programme. Although significantly higher post-intervention flow state scores were found in the standard exercise group, there was no evidence to show absence of flow experience in exergaming. There is also a potential benefit that after the initial instruction that is required for any new exercise, exergaming would require less direct personal supervision as the feedback and progression process can occur through game structure and progression. Overall, our findings suggest that exergaming is potentially effective and may be suitable for older people with chronic musculoskeletal pain.

**Abbreviations**

AE, autotelic experience; AM, action-awareness-merging; APMHR, age-predicted maximum heart rate (220 - age); AP, anterior-posterior; BI, behavioural intention; CB, challenge-skill-balance; CG, clear goals; CoP, centre of pressure; CT, concentration at task; EE, effort expectancy; FB, facilitating conditions; FSS, flow state scale questionnaire; HR, heart rate; IREX®, GestureTek, Interactive Rehabilitation and Exercise System; LOS limits of stability; ML, medial-lateral; NPRS, numerical pain rating scale; OSI, overall stability index; PE, performance expectancy; PC, paradox of control; RPE, Borg Rate of Perceived Exertion; SE, self-efficacy; SI, social influence; SMEQ, Subjective Mental Effort Questionnaire; TGB, traditional gym-based exercise with no virtual stimuli; TT, transformation of time; UF, unambiguous feedback; UTAUT, the Unified Theory of Acceptance and Use of Technology questionnaire; VR, virtual-reality

**Declarations**

**Ethics approval**

Ethical approval was granted by the Teesside University Research Governance and Ethics Committee. Written informed consent was obtained from the participants.

**Consent for publication**
Availability of data and materials

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

One of the authors, JD is a member of the Editorial Board (Section Editor for Surgery, traumatology, and rehabilitation). The other authors (JLD, PvS, AM and DM) have none to declare.

Authors’ contributions

JLD, PvS, JD, AM and DM conceived the study and participated in its design. JLD collected the data and inputted the data. JLD and PvS conducted the statistical analysis. JLD, PvS, DM, JD and AM compiled the data and drafted the manuscript. All authors read and contributed to the approved final manuscript.

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Figures

**Figure 1**

CONSORT flow diagram illustrating recruitment of participants into the study

**Supplementary Files**

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- appendix.docx
- DitchburnEtAlCONSORT2010Checklist.doc