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

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

4  
5     **ABSTRACT**

6     **Background:** Older people with chronic musculoskeletal pain are at risk of falls. This  
7     study aimed to investigate the effects of exergaming on pain and postural control in older  
8     people with chronic musculoskeletal pain. Secondary outcomes were technology  
9     acceptance, flow experience, perceived physical exertion, expended mental effort and  
10    heart rate.

11   **Methods:** 54 older adults (age:  $71 \pm 5$  years) with chronic musculoskeletal pain were  
12   randomised into 2 groups. Group 1 received exergaming training using the Interactive  
13   Rehabilitation and Exercise System (IREX®). Group 2 undertook traditional gym-based  
14   exercise (TGB). Both groups completed twice weekly 40-minute exercise sessions for  
15   six weeks. Perceived pain was measured using a numeric pain rating scale and the  
16   Multidimensional Affect and Pain Survey questionnaire. Postural control was measured  
17   as sway using a Kistler™ force platform. Technology acceptance was measured with  
18   the Unified Theory of Acceptance and Use of Technology questionnaire and flow  
19   experience with the Flow State Scale. Physiological measures of perceived physical  
20   exertion, expended mental effort and heart rate were recorded during all sessions.

21   **Results:** The exergaming group demonstrated significant reductions in pain intensity  
22   and thermal pain including a near significant approach in physical engagement in  
23   comparison to TGB group. Although no intervention effects on postural control were

1 found, the exergaming group showed significant improvements in three sway measures  
2 (AP SD, ML SD and AP range) over time whereas significant improvements in ML range  
3 were found in the TGB group. Relating to technology acceptance, significant  
4 intervention effects on social influence and behavioural intention were found in the TGB  
5 group instead, although both groups demonstrated increases of acceptance over time.  
6 Regarding flow experience, concentration at task was significantly influenced in the TGB  
7 group and significant increases in flow variables over time were observed in both groups.  
8 Significant increases over time in perceived physical exertion and expended mental  
9 effort were found in both groups.

10 **Conclusion:** Our findings support the potential of exergaming to alleviate pain and  
11 improve balance in older people with chronic musculoskeletal pain. Both forms of  
12 exercise are acceptable, intrinsically motivating and show evidence of benefit to older  
13 people with chronic musculoskeletal pain.

14  
15 **Trial registration:** ClinicalTrials.gov Identifier: NCT04029285 (retrospectively  
16 registered, July 23, 2019)

17 [https://clinicaltrials.gov/ct2/show/study/NCT04029285?term=Alasdair+MacSween&draw=2&r](https://clinicaltrials.gov/ct2/show/study/NCT04029285?term=Alasdair+MacSween&draw=2&rank=2)  
18 [ank=2](https://clinicaltrials.gov/ct2/show/study/NCT04029285?term=Alasdair+MacSween&draw=2&rank=2)

19 **Keywords:** Exergaming, Exercise Therapy, Musculoskeletal Pain, Aged, Aged 80 and  
20 Over, Postural Balance, Heart Rate, Flow state experience, Technology acceptance.

## 1 BACKGROUND

2

3 Chronic pain is a widespread and debilitating condition; in the UK, in 2017, 34% of adults  
4 had chronic pain and in the US, in 2016, 20.4% [1]. Quality of life and health deteriorate,  
5 mobility and independence reduce, anxiety and depression increase, as does  
6 dependence on medication [2–5]. Pain along with commonly associated symptoms, such  
7 as muscle and joint stiffness make moving and exercising difficult [6]. Chronic  
8 musculoskeletal conditions, such as low back pain and arthritis also increase the risk of  
9 impaired postural control [7–9]. Furthermore, there is evidence to show that older people  
10 with two or more body locations of musculoskeletal pain are at risk of falls [10–12].

11 Unsurprisingly, exercise as a non-surgical, non-pharmacological option is often  
12 recommended for older people, especially for those with chronic pain [13, 14] in the hope  
13 of increasing activity and independence [15–17] and improving their balance [18–20].  
14 Despite many known benefits, older people are often reluctant to take up exercise, citing  
15 individual-level barriers such as fatigue [21], fear the movements will increase their pain  
16 [22], or simply a lack interest in exercising [23]. System level barriers such as the lack of  
17 infrastructure facilitating exercise for older people also impede uptake amongst them  
18 [24, 25].

19

20 “Virtual” is defined as something that does not exist physically [26]. When applied to  
21 technology, software relevant to these technologies will make the target object appear  
22 as if it were physically real [27]. “Virtual reality” is defined as an environment generated

1 by artificial means or computer simulations akin to real-life situations [28, 29].  
2 Exergaming applies digital game technology in a virtual reality environment [30].

3

4 Recently, exergaming has been explored as an alternative mode of exercise to  
5 encourage physical activity among older people [31–33]. Exergaming systems are  
6 currently used for several purposes [34]. Examples of commercial, entertainment based  
7 exergaming systems are the Nintendo Wii, Sony PlayStation II and X-box Kinect [35]  
8 whereas rehabilitation-specific exergames comprise systems such as the Interactive  
9 Rehabilitation and Exercise System (IREX®) [36]. While both types of exergaming  
10 systems combine exercise with gaming features, rehabilitation-specific exergames  
11 provide feedback on users' progress, identify impairments and may be personalised [37,  
12 38]. The IREX® [36] uses video capture technology that enables users to see a real-  
13 time image of themselves when interacting with the exergames, as opposed to seeing  
14 an avatar, as is common in commercial exergaming systems. Whilst commercial  
15 exergaming systems have developed and marketed exergames for healthy gamers, the  
16 IREX® was designed, developed and adapted with rehabilitation in mind [39, 40]. It  
17 provides clinicians with feedback comprising metrics of speed, duration and intensity of  
18 workout [36]. Moreover, users do not need to wear, hold or touch anything when playing  
19 the exergames [36].

20

21 Several exergaming studies report health and wellbeing benefits comparable to those of  
22 regular exercise in older people, particularly in balance [41], improvement in age-related  
23 kyphosis [42], muscle strength [43], ease of physical movement and psychosocial well-

1 being [44, 45]. In spite of increasing evidence suggesting that that older people are more  
2 receptive to using exergaming for exercise [44, 46, 47], majority of exergaming users  
3 are young people [48–50]. Gerontology studies have highlighted learned helplessness  
4 in older people in using technology [51, 52]. Furthermore, advertising campaigns for  
5 exergames tend to target younger age groups with gaming themes that do not appeal to  
6 older people [53]. In addition, most studies tested commercially available gaming  
7 platforms [43, 54–60] rather than exercise and rehabilitation-specific platforms. Few  
8 have studied the effects of exergaming on older people’s chronic musculoskeletal pain  
9 and balance using a rehabilitation-specific platform. Furthermore, majority of the studies  
10 involving older people used the IREX® [36] to investigate stroke recovery [61–63] and  
11 physical rehabilitation [61, 63–66] but none have examined chronic pain and centre of  
12 pressure as a measure of postural control in older people with chronic musculoskeletal  
13 pain [67].

14  
15 As such, the primary aim of this study was to assess the effects of exergaming via the  
16 IREX® on pain and postural control amongst older people with chronic musculoskeletal  
17 pain in comparison with traditional gym-based exercise, with no virtual stimuli (TGB), for  
18 older people with chronic musculoskeletal pain. We also wanted to find out if, after having  
19 completed an intervention of either exergaming or TGB, our participants found  
20 exergaming technology to be acceptable, and whether they experienced flow during the  
21 intervention and would consider themselves to continue taking part in that form of  
22 exercise. Consequently, secondary aims were to evaluate their technology acceptance,  
23 flow state experience and perceived physiological measures during the intervention.

## **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, School of Health and Social Care Research Governance and Ethics Committee, reference number 059/09. The study was conducted in the University's physiotherapy laboratory.

### **Eligibility criteria**

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. The inclusion criteria for age follows definitions from Orimo et al. (2006) [68] where 65 years and older constitute "elderly", equivalent to "older people" in this study, 65 through 74 years constitute "early elderly" and over 75 years constitute "late elderly". Participants with chronic musculoskeletal pain in two or more joints are at risk of falls [10–12]. Therefore participating in this study may elucidate potential benefits for them in terms of balance and improvement in pain.

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,

1 rheumatic or neurological disease, or condition), self-report of current condition or self-  
2 report of history of any condition or injury which would contra-indicate participation in the  
3 exercises under study, inability (or any doubt of ability) to give informed consent and  
4 inability to read and write English.

## 6 **Sample calculation**

7 G\*Power version 3.1 [69, 70] was used to conduct a power analysis for a two-group  
8 comparison using analysis of covariance to detect a large effect ( $f = 0.40$ ) for the postural  
9 sway outcome measure and 0.80 power. The results showed that the required sample  
10 size was 52.

## 12 **Recruitment**

13 Participants were recruited from nine local community groups from October to December  
14 2010 (see CONSORT flow diagram, Figure 1). Sixty-one potential participants were  
15 screened for eligibility. Four were excluded due to not meeting the eligibility criteria and  
16 three could not attend scheduled sessions. Fifty-four (42 females and 12 males, age:  
17  $71 \pm 5$  years) were allocated to either exergaming with the IREX™ ( $n = 27$ ), or TGB ( $n =$   
18 27) (see Table 1). Chronic pain areas were hips, hands/wrists and/or back.

## 20 **Procedure**

21 After written informed consent, demographic information and baseline outcome data  
22 were collected and participants were randomly allocated, by stratified blind-card  
23 allocation. Appointments for twice weekly, 40 minute sessions were arranged for both



1 groups. All exercises were completed on a one-to-one basis, with the first author  
2 supervising the sessions (and exercising with the TGB group). All participants began  
3 with the same exergames or exercises and progressed at their own pace.

4  
5 The exergaming group played five IREX® exergames (see Appendix 1 for details).  
6 Those in the TGB group performed exercises that were matched to the IREX®  
7 exergames for movement patterns required, physiological demands, sequence, duration  
8 and mode of exercise, by adopting open and closed kinetic chain movements, in the  
9 same range and loading, across both groups. Each IREX® exergame was played for  
10 two minutes and was repeated three times within a session. TGB exercise was  
11 conducted in sets of two minutes duration and was repeated three times within a session.  
12 In both groups participants were given rest periods of 10 to 30 seconds, or longer, if  
13 required, between exergames, or TGB exercise sets.

#### 14 15 **Primary outcomes**

16 The primary outcome measures were pain and postural control/sway measured at  
17 baseline and after the six-week intervention period. The duration of six weeks was  
18 selected based on evidence of indications of minimal clinical effects from six-week  
19 interventions from previous studies [71].

20  
21 Pain intensity experienced within 30 days and at present was recorded using a numerical  
22 pain rating scale (NPRS) at baseline and after the six week intervention period [72]. The  
23 NPRS ranges from 0 “no pain” to 10 “worst possible pain” [73, 74]. The sensory,

1 emotional and motivational dimensions of pain were measured using the Multi Affect and  
2 Pain Survey (MAPS) questionnaire [75, 76]. MAPS comprises 101 pain descriptors  
3 which reflect three major aspects of pain: somatosensory, emotional and well-being. The  
4 somatosensory pain supercluster contains 17 clusters with 57 descriptors of painful  
5 sensory qualities; the emotional pain supercluster has 8 clusters with 26 descriptors of  
6 negative emotional qualities; and the well-being supercluster has 18 descriptors of  
7 positive affect, and health, grouped into five clusters. MAPS has been widely validated  
8 in pain studies [77–81] and its reliability demonstrated [80].

9  
10 Postural control was measured as Centre of Pressure (CoP) displacement and velocity,  
11 using a portable Kistler™ force platform (Model 9286AA, W 40 x L 60 x H 3.5cm) with a  
12 sampling rate of 1000 Hz [82]. Participants stood barefoot on the Kistler™ force plate  
13 and looked directly ahead at a visual target (black 100 mm diameter circle) positioned 3  
14 m from the centre of the force plate at eye level [72, 83, 84] . Participants were asked to  
15 stand as still as possible on their dominant leg (preferred kicking), with their eyes open  
16 and arms by their side, for three periods of 30s. Between trials, participants stepped off  
17 the force plate, to allow calibration of the equipment, which also allowed a 30s rest. This  
18 testing sequence was then repeated but with participant's eyes closed.

## 19 20 **Secondary outcome measures**

21 The secondary outcome measures were technology acceptance, flow experience,  
22 perceived levels of physical exertion, subjective mental effort and heart rate, measured  
23 at baseline, after each exercise session and after the six-week intervention period.

1 Technology acceptance was measured using the Unified Theory of Acceptance and Use  
2 of Technology (UTAUT) [85] questionnaire. The UTAUT comprises a series of 7-point  
3 Likert scales ranging from 1 (strongly disagree) to 7 (strongly agree), measuring six  
4 domains. The domains are: *performance expectancy* (PE), the degree to which a person  
5 believes that using a system will help them attain gains in their performance, *effort*  
6 *expectancy* (EE), the degree of ease in using the technology, *social influence* (SI), the  
7 degree to which a person perceives that important others believe they should use the  
8 technology, *facilitation conditions* (FC), the degree to which a person believes they  
9 should use the technology, *self-efficacy* (SE), the degree to which a person believes they  
10 are capable of using the technology and *behavioural intention* (BI), intention to use the  
11 intervention again.

12  
13 Flow experience was measured using the Flow State Scale questionnaire (FSS) [86].  
14 *Flow* is the degree to which people experience an optimal psychological state associated  
15 with complete absorption in the task that they are doing (a concept widely researched in  
16 various fields [58, 83, 87, 88]. The FSS consists of 36 questions with nine subscales and  
17 response options on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The  
18 subscales are: *autotelic experience* (AE), the intrinsically rewarding experience doing a  
19 task, *clear goals* (CG), clearly confident of action, *challenge-skill-balance* (CB), balance  
20 between skills and challenge, *concentration at task* (CT), complete control on performing  
21 a task, *paradox of control* (PC), at full focus at the task, unambiguous feedback (UF),  
22 feedback on performing a task, *action-awareness-merging* (AM), immediate, direct and  
23 clear observations whilst performing a task, *transformation of time* (TT), time either

1 speeds up, slows down, becomes irrelevant or out of one's awareness and *loss of*  
2 *consciousness* (Loss), a sense of not being concerned with oneself while engaging in  
3 the activity and in the process; the individual becomes one with the activity, or a part of  
4 it.

6 Perceived levels of physical exertion were measured using the Borg Rating of Perceived  
7 Exertion (RPE) scale [89]. Participants subjectively rated their levels of physical intensity  
8 and effort based on the physical sensations that they experienced during the exercise  
9 session. The scale consists of numbered categories, 6-20 with verbal cues from "very,  
10 very light" to "very, very hard".

12 Subjective mental effort was measured using the Subjective Mental Effort Questionnaire  
13 (SMEQ) (also referred to as the Rating Scale for Mental Effort) [90]. The SMEQ consists  
14 of a single scale with nine labels from "Not at all hard to do" to "Tremendously hard to  
15 do".

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

## **Exergaming system**

Exergaming was performed using five games from the IREX<sup>®</sup> 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 3m x H 2.6m) and red gloves.

## **Postural control 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<sup>™</sup>), 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) [91].

## **Statistical analysis**

The data were analysed with Version 19 of the Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA). Cronbach's alpha was computed to assess internal reliability for the subscales of the UTAUT, FSS and MAPS questionnaires, respectively. 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

1 over time. All analyses used a significance level of 0.05. The effect size measure epsilon  
2 squared was used, where values of 0.01, 0.06 and 0.14 were interpreted as small,  
3 moderate and large [92].

## 4 5 **RESULTS**

6 Participant demographics are shown in Table 1. Descriptive statistics are presented at  
7 Table 2. Subscales from the UTAUT [85] and FSS [86] questionnaires demonstrated  
8 high internal-consistency reliability exceeding the minimum Cronbach's alpha of 0.7 [93].  
9 Seventeen clusters from the MAPS questionnaires were deemed reliable having  
10 exceeded 0.7. Clusters that did not show internal reliability were temporal pain, faint  
11 pain, muscle/joint pain, mental distress, respiratory distress, cold pain, pain restriction,  
12 anxiety, emotional avoidance, treatable illness and mentally engaging, with Cronbach's  
13 alpha values ranging from 0.16 to 0.63, respectively.

### 14 15 **Primary outcomes**

#### 16 **Pain intensity**

17 No effect of intervention was found on self-reported pain intensity experienced within 30  
18 days before and after the intervention, and pain intensity at the time of testing, as  
19 determined by the ANCOVA with pre-measures as the covariate (see Table 3). Although  
20 the mixed ANOVA did not show any significant differences in pain intensity over time,  
21 the interaction effect between time and intervention was significant for pain intensity  
22 experienced at the time of testing in favour of exergaming ( $F [1, 52] = 3.98, p = 0.05, \epsilon^2$   
23  $= 0.46$ , large effect). The 30% significant reduction in perceived pain intensity in the

1 exergaming exceeded the appropriate cut-off point for determining the minimal clinically  
2 important differences (MCID) of changes in pain intensity of 15%, where a numerical  
3 rating change score of -2.0 and a percent change score of -33% are best associated  
4 with the concept of “much better improvement” [94].

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

7 ANCOVA revealed that the variable physically engaged; ( $F [1,48] = 3.76, p = 0.06, \epsilon^2 =$   
8  $0.01$ , small effect) from the well-being subcluster approached significance in favour of  
9 exergaming (see Table 4). This suggests meaningful increases in older people’s feelings  
10 of being active and vigorous after exergaming. Thermal pain ( $F [1,48] = 14.43, p = 0.00,$   
11  $\epsilon^2 = 0.09$ , medium effect) showed a significant effect of intervention in favour of  
12 exergaming.

14 The mixed ANOVA revealed significant effects of time on depressed mood ( $F [1, 50] =$   
15  $9.09, p = 0.004, \epsilon^2 = 0.01$ , small effect) and affiliative feelings ( $F [1, 50] = 6.92, p = 0.01,$   
16  $\epsilon^2 = 0.03$ , small effect) in favour of exergaming. Moreover, three variables approached  
17 significance also in favour of exergaming. They were thermal pain ( $F [1,50] = 3.85, p =$   
18  $0.06, \epsilon^2 = 0.01$ , small effect), anger ( $F [1,50] = 3.76, p = 0.06, \epsilon^2 = 0.01$ , small effect) and  
19 physically engaged ( $F [1,50] = 3.82, p = 0.06, \epsilon^2 = 0.01$ , small effect).

## 21 **Postural control**

22 Although the ANCOVA did not reveal any effect of intervention on postural control, the  
23 mixed ANOVA showed that there were significant reductions over time for AP SD ( $F [1,$

46]= 8.29,  $p = 0.01$ ,  $\epsilon^2 = 0.09$ , medium effect), ML SD (F [1, 46]= 8.37  $p = 0.01$ ,  $\epsilon^2 = 0.05$ , nearly medium effect), AP range (F [1, 45]= 9.91,  $p = 0.003$ ,  $\epsilon^2 = 0.16$ , large effect) and ML range (F [1, 45]= 4.12,  $p = 0.05$ ,  $\epsilon^2 = 0.06$ , medium effect) during bipedal standing with vision, and for CoP excursion in the medio-lateral direction (F [1, 47]= 5.43,  $p = 0.03$ ,  $\epsilon^2 = 0.08$ , medium effect) during pedal standing without vision (see Table 5).

### **Technology acceptance**

UTAUT scores increased in both groups which indicated moderate-to-high acceptance for both exergaming and TGB. The ANCOVA found significant effects of intervention in favour of TGB for social influence (F [1, 44] = 5.16,  $p = 0.03$ ,  $\epsilon^2 = 0.06$ , medium effect) and behavioural intention (F [1, 44] = 4.99,  $p = 0.03$ ,  $\epsilon^2 = 0.08$ , medium effect) (see Table 6). Higher mean values occurred in the control group indicating a greater level of acceptance towards TGB rather than exergaming.

The mixed ANOVA revealed a statistically significant increases over time for all the UTAUT measures – performance expectancy (F [1, 46] = 45.04,  $p < 0.001$ ,  $\epsilon^2 = 0.36$ , large effect), effort expectancy (F [1, 46] = 49.40,  $p < 0.001$ ,  $\epsilon^2 = 0.37$ , large effect), social influence (F [1, 46] = 42.69,  $p < 0.001$ ,  $\epsilon^2 = 0.34$ , large effect), facilitating conditions (F [1, 46] = 28.07,  $p < 0.001$ ,  $\epsilon^2 = 0.27$ , large effect), self-efficacy (F [1, 46] = 26.27,  $p < 0.001$ ,  $\epsilon^2 = 0.27$ , large effect) and behavioural intention (F [1, 46] = 43.96,  $p < 0.001$ ,  $\epsilon^2 = 0.38$ , large effect). A significant interaction effect was between time and intervention was found for social influence (F [1, 46] = 6.73,  $p = 0.01$ ,  $\epsilon^2 = 0.05$ , almost medium effect) in favour of TGB.



## 1     **Flow**

2     The ANCOVA (shown in Table 7) revealed a significant effect of intervention on  
3     concentration of task ( $F [1, 44] = 5.67, p = 0.02, \epsilon^2 = 0.09$ , medium effect) favouring TGB  
4     whereas autotelic experience ( $F [1, 44] = 4.06, p = 0.05, \epsilon^2 = 0.04$ , small effect) and  
5     paradox of control ( $F [1,44] = 3.63, p = 0.06, \epsilon^2 = 0.05$ , medium effect) approached  
6     significance, also in favour of TGB. Nevertheless, the results showed a direction of  
7     increase in post-intervention scores for these variables. No effect of intervention was  
8     found on the other variables: challenge-skill-balance ( $F [1,44] = 3.21, p = 0.08, \epsilon^2 = 0.04$ ),  
9     transformation of time ( $F [1, 44] = 2.09, p = 0.16, \epsilon^2 = 0.02$ ), loss of consciousness ( $f [1,$   
10      $44] = 1.29, p = 0.26, \epsilon^2 = 0.01$ ), feedback ( $F [1, 44] = 1.96, p = 0.17, \epsilon^2 = 0.02$ ). The same  
11     was found for variables that did not meet homogeneity of regression as determined by  
12     mixed ANOVA by blocking: clear goals ( $F [1, 44] = 1.25, p = 0.27, \epsilon^2 = 0.01$ ) and action-  
13     awareness-merging ( $F [1, 44] = 0.47, p = 0.50, \epsilon^2 = 0.00$ ).

14  
15     Mixed ANOVA found significant increases over time in all of the flow variables – autotelic  
16     experience ( $F [1, 46] = 40.20, p < 0.001, \epsilon^2 = 0.23$ , large effect), clear goals ( $F [1, 46] =$   
17      $13.57, p < 0.001, \epsilon^2 = 0.16$ , large effect), challenge-skill-balance ( $F [1, 46] = 57.69, p <$   
18      $0.001, \epsilon^2 = 0.32$ , large effect), concentration at task ( $F [1, 46] = 49.27, p < 0.001, \epsilon^2 =$   
19      $0.32$ , large effect), paradox of control ( $F [1, 46] = 47.46, p < 0.001, \epsilon^2 = 0.33$ , large effect),  
20     unambiguous feedback ( $F [1, 46] = 63.12, p < 0.001, \epsilon^2 = 0.37$ , large effect), loss of  
21     consciousness ( $F [1, 46] = 56.01, p < 0.001, \epsilon^2 = 0.35$ , large effect), transformation of  
22     time ( $F [1, 46] = 21.96, p < 0.001, \epsilon^2 = 0.16$ , large effect) and loss of self-consciousness  
23     ( $F [1, 46] = 41.39, p < 0.001, \epsilon^2 = 0.29$ , large effect).

## 1     **Physiological outcomes**

2     The ANCOVA did not reveal significant effect of interventions on the physiological  
3     measures, although heart rate was higher in the exergaming group. The mixed ANOVA  
4     however, revealed significant increases over time in perceived physical effort ( $F [1, 46]$   
5      $= 11.24$ ,  $p = 0.002$ ,  $\epsilon^2 = 0.07$ , medium effect) and perceived subjective mental effort ( $F$   
6      $[1, 46] = 15.12$ ,  $p = 0.00$ ,  $\epsilon^2 = 0.09$ , medium effect) (see Table 8). Post-intervention scores  
7     for perceived physical exertion and mental effort were lower in the exergaming group  
8     compared to the control group (as earlier shown in Table 2). These scores suggest that  
9     exergaming may be less strenuous and require less effort compared to TGB.

## 11    **DISCUSSION**

12    The primary aim of this present study was to investigate the effects of exergaming on  
13    pain and postural control amongst older people with chronic musculoskeletal pain.  
14    Exergaming with the IREX® [36] was compared with TGB in two groups. Overall, results  
15    suggested that exergaming was beneficial in terms of ameliorating pain and improving  
16    balance in older people in this population. The secondary aim of the study was to  
17    investigate technology acceptance and flow experience of the intervention including  
18    perceived physiological outcomes, enabling us to understand if older people with chronic  
19    musculoskeletal pain would find exergaming (or TGB) to be acceptable and considered  
20    themselves willing to use it. Henceforth, our results showed that older people with  
21    chronic musculoskeletal pain were receptive to exergaming and TGB, and had  
22    experienced flow in both forms of exercise.

## **1 Pain**

2 Despite evidence of therapeutic benefits from exergaming [43, 95, 96], published studies  
3 on the effects of exergaming on pain are varied and inconsistent [97]. Many suggest an  
4 association between exergaming and pain [98] but few report significant changes in pain  
5 after exergaming [98, 99]. Kim et al. (2014) [100] found significant improvements in the  
6 Oswestry low-back pain disability index (ODI) scores amongst middle-aged women with  
7 low back pain after a three-times weekly 4-week exergaming intervention using Wii Fit  
8 Yoga. Sobral Monteiro-Junior et al. [98] found significant reductions in chronic low back  
9 pain amongst older women after a three-times weekly 8-week using both exergaming  
10 and strength exercises, but failed to find an intervention effect. According to Witmer and  
11 Singer [101], higher levels of presence in users may be attained by a virtual environment  
12 that produces a greater sense of immersion. When interacting with the exergame, the  
13 user becomes immersed in the virtual world. Hence, their attention shifts from their  
14 natural state of being. In our study, perceived pain intensity when tested at the end of  
15 the intervention was significantly reduced in favour of exergaming despite the prevalence  
16 of chronic pain throughout the six-week intervention (as shown earlier in Table 2). Our  
17 results broadly support the view that the virtual reality aspect used in exergaming may  
18 alter pain perception to some extent through active distraction [102, 103].

19  
20 We are the first to use the MAPS questionnaire across exergaming and standard  
21 exercise. In terms of the multidimensional aspects of pain, we observed significant  
22 improvement in thermal pain (pain related to heat sensations) and feelings of physical  
23 engagement (active, vigorous) in the exergaming group. This suggests that exergaming

1 may have alleviated the experience of pain to some extent [104]. Over time, significant  
2 improvements in depressed mood and affiliative feelings were also in favour of  
3 exergaming. While the control group also showed improvements in depressed mood  
4 over time, the reduction was significantly higher in the exergaming group. This suggests  
5 meaningful increases of older people's feelings of being active and vigorous and benefits  
6 in emotional well-being after exergaming. Our findings agree with the premise that  
7 exergaming may induce positive mood states in users [105, 106].

## 8 9 **Postural control**

10 In our study, we did not find significant post-intervention differences between the  
11 exergaming and TGB groups for both conditions of eyes open and eyes closed.  
12 However, our findings show improvements in balance similar to those reported by Sobral  
13 Monteiro-Junior et al. [98] and Bisson et al. [107], where we identified significant within-  
14 groups differences over time for some postural sway measures as determined by mixed  
15 ANOVA. While of the postural control measures decreased over time in both groups with  
16 eyes open and closed, statistically significant reductions over time were observed on ML  
17 SD, AP SD and the CoP excursion in the anterior-posterior and medio-lateral direction  
18 in the exergaming group with vision, indicating better postural control. These  
19 improvements in balance are encouraging in comparison with those reported by Barry  
20 et al. [83]. They found significant improvements over time in ML SD, ML range and CoP  
21 velocity in healthy adults who had participated in a three-times weekly exergaming  
22 intervention for four weeks. Our findings are also consistent with those of Whyatt et al.  
23 [108] who found significant increases in Berg Balance Scale (BBS) scores, higher

1 balance confidence and increased performance in levels of CoP displacement in the  
2 anterior, right and left CoP test locations after exergaming.

3  
4 We also found significant reductions over time observed in the CoP excursion in the  
5 medio-lateral direction for the TGB group under eyes closed condition similar to those of  
6 Nicholson et al. [109], who reported significant reductions in medio-lateral CoP range in  
7 older people following twelve weeks of balance training. ML postural sway is associated  
8 more with fall risks in older people compared to AL postural sway [110]. The effect of  
9 exercise on postural control becomes more apparent when the balance task is  
10 performed without vision [111]. When the eyes are closed, balance relies solely on  
11 efferent neuromuscular and sensorimotor input [112], which can be improved with  
12 exercise [113]. Our finding reinforces the premise that TGB exercise (in this case), has  
13 the potential to improve balance in older people when performed safely. There were no  
14 adverse events, reactions or report of motion sickness amongst participants in our study.  
15 Both forms of exercise appeared to yield some benefit. Although we are unable to  
16 confirm the postural control mechanisms that were improved with exergaming in this  
17 study, our results reflect the underlying positive effect of exergaming on postural control.  
18 We suggest that exercising using exergames can potentially contribute to improving  
19 balance and reducing fall risks in older people with chronic musculoskeletal pain [111].

## 20 21 **Technology acceptance**

22 Our results showed that all UTAUT scores increased in both groups but significance was  
23 achieved only in social influence and behavioural intention in the TGB exercise group.

24 We speculate that the increase in all UTAUT scores indicated high acceptance for both

1 forms of exercise and favourable response from participants in both groups. This could  
2 be due to several factors. Firstly, the affective state of a user plays an important role in  
3 their acceptance of a new activity or technology [114]. How users feel when they perform  
4 the exercises determines their appraisal of the exercise and whether they would continue  
5 with it [115]. Kwan and Bryan [116] found that affective response influenced exercise  
6 behaviour, particularly intention to exercise. In the case of exergaming, Billis et al. [31]  
7 found that game content in exergames adapted according to older people's affective  
8 states would influence their acceptability to exergaming. Secondly, if older people found  
9 the type of exercise to be both useful and easy to follow, they were more likely to express  
10 intention to continue the activity [117]. Thirdly, verbal or non-verbal social behaviour  
11 nurtures change in any particular behaviour [118, 119]. This would include  
12 encouragement, feedback or supervision and even the mere presence of the researcher  
13 during the sessions [120].

14  
15 Our results indicated high acceptance for both forms of exercise and favourable  
16 response from participants in both groups. However, significance was observed only in  
17 social influence and behavioural intention in the TGB group. Several factors could have  
18 influenced this increase. The standard exercise movements did not involve complex  
19 movements or high physical intensities [121]. The higher scores in effort expectancy in  
20 the standard exercise group is presumably because the movements did not involve  
21 interaction with an external source. The TGB exercise routine comprised planned and  
22 structured repetitive physical movements [122]. Therefore, the participants were  
23 exercising with themselves instead of having to engage with visual or auditory stimuli (as

1 in exergaming). This could have made the exercising process easier. We also observed  
2 that the change in behavioural intention was larger in the exergaming group although it  
3 did not reach significance. We speculate that our sample experienced positive affect and  
4 engagement during exergaming, which could have brought on the larger increase in  
5 behavioural intention [123]. This would require verification with a larger-scale study.

6

## 7 **Flow**

8 We found significant between-group differences in the concentration aspect of flow state,  
9 favouring the TGB group. Two other dimensions, autotelic experience, and paradox of  
10 control approached significance, also favouring the TGB group. While our results  
11 showed a trend of increased scores in all flow dimensions from baseline to the end of  
12 the intervention, significance increases over time were achieved in eight of the nine  
13 dimensions of flow state in both groups, except transformation of time, supporting the  
14 notion of the flow phenomenon in sport [124, 125].

15

16 Similar results have been reported in previous studies [58, 83], which suggests that the  
17 immersive environment during exergaming can facilitate distortion of time amongst  
18 users. Distortion of time during exercise implies that users experience deep involvement  
19 when exercising and become fully invested in the exercise experience [126]. The largest  
20 effect size demonstrated in the significant increase in unambiguous feedback in the  
21 exergaming group suggests that the exergaming group received more direct and  
22 immediate feedback when exercising in an immersive environment compared to  
23 performing standard exercises. This feedback is akin to successes and failures when

1 playing the exergames so that a clear idea and continuity of feedback is provided for the  
2 next action [127].  
3

#### 4 **Physiological measures**

5 Significant increases over time in perceived physical exertion and expended subjective  
6 mental effort in both groups suggested that our participants invested more physical  
7 effort and concentration into their respective exercise sessions. In the comparison of  
8 post-intervention scores between the two groups, scores for perceived physical exertion  
9 and mental effort were lower in the exergaming group. Barry et al. [83] also reported  
10 significantly lower post-intervention physical exertion scores in their study comparing  
11 Xbox Kinect™ with traditional gym-based exercise. The higher scores in expended  
12 mental effort in our study reflect the role of cognition in performing motor skills required  
13 in physical activity [128]. Where thought processes involved in exercise tends to get  
14 easier with practice [129], more mental effort invested seen in our study could be due  
15 to a factor of time because it was a short-term study for participants to learn the  
16 movements.

17  
18 While both groups recorded increases in heart rate over time, heart rate values were  
19 slightly higher in the exergaming group. This is speculative of higher physical intensity  
20 when exercising with the exergames [130]. Nevertheless, the lack of significant  
21 differences in heart rate for either group at 77% of APMHR places exercise intensity in  
22 both groups within the *Vigorous* classification (77-95% of HR Max) of the ACSM [131]  
23 even though the participants RPE levels (of around 10) is associated with light exercise.



1 Interestingly, this apparent anomaly suggests that participants may have underrated  
2 their exertion levels compared to normative values and expectations for RPE. It also  
3 appears that while both groups were exercising at a high aerobic physiological demand,  
4 which did not alter (as reflected by % of APMHR), participants felt the exercise was  
5 somewhat easier throughout, and, despite the perception of effort increasing over the  
6 intervention period, their RPE remained below levels normally associated with vigorous  
7 exercise (RPE 14-17) [131].

8  
9 We did not find evidence of significant post-intervention differences in perceived  
10 physical exertion, expended subjective mental effort and heart rate between the  
11 exergaming group and the control group. Our results show that required movements for  
12 the exercises were successfully matched and hence any differences mentioned earlier  
13 between the groups could also be attributed to the different exercises they undertook.  
14 Future research could include exergaming intensity at different levels to evaluate  
15 physiological effects in older people with chronic musculoskeletal pain.

## 17 **Limitations**

18 We acknowledge that our results are based on a limited number of participants. As such,  
19 the study was not sufficiently powered to generate fully definitive results for the other  
20 comparisons (for example, some of the MAPS subclusters etc.). There was no follow up  
21 to evaluate long term effects amongst participants. As this research was conducted as  
22 part of the completion of a PhD, it was also restricted by staffing, time and funding. For  
23 practical reasons, neither the researcher nor the participants were blind to the conditions

1 being tested. In future, this research would benefit from further verification from a larger  
2 sample.

## 4 **CONCLUSION**

5 Exergaming was found to be comparable to standard exercise in terms of acceptance  
6 and its effects on pain and postural control, in addition to flow experience. This could be  
7 potentially attributed to its aspect of virtual reality. Our study shows that older people  
8 with chronic musculoskeletal pain could benefit from at least subtle improvements in  
9 balance after taking part in short-term exergaming. Although significantly higher post-  
10 intervention flow state scores were found in the standard exercise group, there was no  
11 evidence to show absence of flow experience in exergaming. In exergaming  
12 programmes run by certain healthcare or rehabilitation centres, clients are supported by  
13 their physiotherapist in terms of setting suitable exergaming levels for them, monitoring  
14 and prescribing rehabilitative movements for them [132, 133]. With this, another  
15 consideration is the potential advantage that after initial instruction, exergaming may  
16 require less supervision by physiotherapy staff and rely on continuous direct feedback  
17 to each patient. This implies that users may gradually become more independent in  
18 performing their prescribed body movements into game-play. Overall, our findings  
19 suggest that exergaming is potentially effective and may be suitable for older people with  
20 chronic musculoskeletal pain.

## 1     **Future directions**

2     Future research could include a follow-up to assess the duration of any effects,  
3     investigate gender differences in pain and balance outcomes and evaluate exergaming  
4     without supervision. Postural control mechanisms could also be evaluated in depth. In  
5     addition, the gap in the literature regarding the lack of minimally clinically difference in  
6     postural control measures via CoP could also be addressed. This research could be  
7     extended to include using commercial exergaming technology such as the Sony  
8     Playstation®4 [134], Nintendo Wii Plus and selected exergames in Nintendo Switch  
9     [135]. Further work could also evaluate the effects of exergaming in a sample of older  
10    people who are affected to a greater extent of chronic musculoskeletal pain and hence,  
11    are more disabled than of those in this study.

12  
13    **Abbreviations:** AE, autotelic experience; AM, action-awareness-merging; APMHR,  
14    age-predicted maximum heart rate (220 - age); AP, anterior-posterior; BI, behavioural  
15    intention; CB, challenge-skill-balance; CG, clear goals; CoP, centre of pressure; CT,  
16    concentration at task; EE, effort expectancy; FB, facilitating conditions; FSS, flow state  
17    scale questionnaire; HR, heart rate; IREX®, GestureTek, Interactive Rehabilitation and  
18    Exercise System; LOS limits of stability; ML, medial-lateral; NPRS, numerical pain rating  
19    scale; OSI, overall stability index; PE, performance expectancy; PC, paradox of control;  
20    RPE, Borg Rate of Perceived Exertion; SE, self-efficacy; SI, social influence; SMEQ,  
21    Subjective Mental Effort Questionnaire; TGB, traditional gym-based exercise with no  
22    virtual stimuli; TT, transformation of time; UF, unambiguous feedback; UTAUT, the  
23    Unified Theory of Acceptance and Use of Technology questionnaire; VR, virtual-reality

## **1 DECLARATIONS**

### **2 Ethics approval**

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

### **5 Consent for publication**

6 Not applicable

### **8 Availability of data and materials**

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

### **12 Competing interests**

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

### **17 Authors' contributions**

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

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1 Appendix 1: Comparison of exercises undertaken by the traditional gym based  
2 exercise group (TGB) and the exergaming (IREX®) group.  
3

Games	TGB	IREX™	Movements required
Volleyball	<p>Stand up straight with knees slightly bend and your feet shoulder width apart. Clasp both hands in front of your abdomen and slowly raise both arms to the front until eye level, and lower both arms. Repeat three times.</p> <p>Following this, stand comfortably with both arms by your side. Raise the right arm away from your body until shoulder level and then lower it down again to your side. Repeat with the left arm. Following this, move two steps to the right and repeat the movement of the arms; repeat with movement to the left.</p>	Land the ball in your opponent's court or outside your court. Either move your body, shoulder or touch the volleyball by hand. Smoother movements allow better contact with the ball.	Full medial and lateral weight shifting. Vertical stretches, moving the upper extremities and whole body movement.
Sharkbait	<p>Stand up straight with knees slightly bent and your feet at a comfortable width apart. Stretch out both arms so that they form a T with your body and slowly bend your knees to a comfortable position. Keep your back straight, while in this position, transfer your weight to the right leg and reach out to the right side with your upper torso and right arm as much as you can. Hold for 2 seconds and gently move your position back as you were before you reached to the right. Repeat with the left side.</p>	<p>You will see yourself virtually deep-sea diving with sea creatures. Catch as many stars as you can. Lean side-by-side, crouch down or raising your arms. To move sideways quickly, step to the side. If you meet a shark, it will virtually swallow you and expel you out of its mouth. Contact with an electric eel virtually temporarily disables your movement.</p>	Full medial and lateral weight shifting of the centre of gravity body movement with bending and stretching.
Formula racing	<p>Stand up straight with knees slightly bent and your feet shoulder width apart. Gently hold both hands in front of your torso with both elbows bent. Look straight ahead while maintaining a relaxed stance, and gently turn your body to the right and back to</p>	<p>You will see yourself virtually driving in a Grand Prix. The course of the track is also visible to you. Drive through the racecourse as best as you can. Steer by stepping to the right or left, by moving your body to the side, or by moving one arm at a time. If you feel that you have not moved on the</p>	Full medial and lateral weight shifting of the centre of gravity body movement by bending and stretching. Left and right trunk movements and movement of the upper torso.

	original position, then to the left and back to original position. Repeat this time with your arms extended.	track, take one small step to the side to move your car.	
Snowboard	<p>Stand up straight with your feet shoulder width apart. Place your hands in front of your body as if to hold an imaginary ball and look straight ahead. Move your pelvis to the front (towards your hands) and hold for 2 to 3 seconds, and to the back. Repeat as many times as you can. Next stand upright and take a comfortable step forward with your right foot (almost into a lunge position). Rest your hands on your hips and gently tilt your body to the right and back to where you started.</p> <p>Repeat this by standing upright again, this time with a step forward with your left foot, resting your hands on your hips and gently tilting your body to the left, and back to where you started. Try to keep your upper body upright and your back as straight as possible.</p>	You will see a red silhouette of yourself standing on a snowboard, coming down a narrow slope, and a virtual image of yourself when you cross the finish line. Begin by stepping sideways until you are centred over the snowboard. Make as many jumps as possible and avoid hitting other objects. Lean to either side, or move your arm to one side.	Full medial and lateral weight shifting of the centre of gravity body. Vertical movements, pelvic tilt and movement for hamstrings.
Birds and ball	Stand up straight with your feet shoulder width apart. Place both arms at your sides. Beginning with the right arm: slowly move your right arm upwards until shoulder level and gently open and close your right hand (this involves movement of the thumb, fingers and palm). Repeat with your left arm. As you progress through the sessions, use both arms at different positions (e.g. to the top of your head, stretching to the top left or right).	You will virtually be in a pastoral background with colourful balls coming at you. Touch the balls with any part of your body e.g. once you have exercised with your right shoulder or arm, you may repeat it with the left.	Anterior and medial-lateral weight shifting of the centre of gravity over base of support. Shoulder rotation and flexion and movement of the upper extremities

Table 1: Participant demographics.

	TGB (n = 27)	IREX® (n = 27)
Male	7	5
Female	20	22
Independent living	26	26
Assisted living	1	1
Retired	26	26
Working part-time	1	1
	Mean (SD)	Mean (SD)
Age (years)	69.78 (4.48)	71.78 (6.10)
Height (cm)	162.16 (6.74)	160.33 (8.60)
Weight (baseline) (kg)	69.27 (13.28)	76.39 (21.61)
Weight (post) (kg)	68.72 (13.03)	77.31 (22.20)

**Table 2:** Descriptive statistics, Mean (SD) for all outcome measures

		Baseline		Post Intervention	
		TGB	IREX®	TGB	IREX®
<b>Primary outcomes</b>					
<b>Pain intensity</b>					
	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)
<b>MAPS</b> (pain descriptors in parenthesis)					
<b>Somatosensory pain</b>					
	Cutaneous (itchy, irritating, crawling, tickling, tingling)	1.13 (1.00)	0.67 (0.53)	1.08 (1.05)	0.63 (0.51)
	Autonomic distress (disgusting, nauseating)	0.80 (1.37)	0.09 (0.24)	0.67 (1.35)	0.19 (0.49)
	Thermal (burning, hot)	1.41 (1.80)	0.93 (1.30)	1.25 (1.78)	0.56 (0.97)
	Pain extent (spreading, persistent, worsening, pervasive)	2.00 (1.52)	1.29 (0.99)	1.80 (1.59)	1.29 (1.03)
	Intense pain qualities (vicious, excruciating, nasty, overwhelming)	2.12 (1.79)	0.98 (1.16)	1.91 (1.84)	0.87 (1.20)
	Intermittent pressure (throbbing, pounding)	1.46 (1.74)	0.63 (1.11)	1.27 (1.69)	0.71 (1.28)
	Brightness (stinging, smarting)	0.56 (1.19)	0.07 (1.18)	0.63 (1.27)	0.19 (0.49)

1		Incisive pressure	1.68 (1.32)	0.20 (0.62)	1.53 (1.28)	0.84 (0.81)
2		(sharp, shooting,				
3		biting, deep,				
4		tearing, stabbing,				
5		gnawing)				
6						
7		Traction/abrasion	1.12 (1.31)	0.26 (0.70)	0.96 (1.28)	0.54 (0.92)
8		(pulling, grinding,				
9		squeezing,				
10		pressing,				
11		cramping, tugging,				
12		crushing)				
13						
14		Numb	1.28 (1.84)	0.64 (0.68)	1.13 (1.74)	0.40 (0.92)
15		(numb, numbing)				
16						
17						
18						
19	Emotional pain					
20		Physical illness	1.61 (1.38)	0.57 (0.76)	1.38 (1.42)	0.90 (0.88)
21		(ailing, suffering)				
22						
23		Depressed mood	0.91 (0.99)	1.35 (1.11)	0.74 (0.90)	0.40 (0.45)
24		(lousy, rejected,				
25		depressed,				
26		discouraged,				
27		miserable, lonely)				
28						
29						
30		Self-blame	0.48 (0.90)	1.24 (1.12)	0.52 (1.04)	0.40 (0.74)
31		(guilty, negligent)				
32						
33		Anger	0.83 (1.32)	2.67 (1.36)	0.65 (1.19)	0.43 (0.66)
34		(angry, outraged,				
35		upset, annoyed)				
36		Fear	0.78 (1.34)	0.26 (0.46)	0.69 (1.26)	0.13 (0.36)
37		(alarming.				
38		Startling, frantic,				
39		terrified)				
40						
41						
42		Physical	2.14 (1.50)	1.24 (1.12)	1.83 (1.40)	1.13 (1.00)
43		avoidance				
44		(exhausting,				
45		sleepy, tiring,				
46		sluggish)				
47						
48						
49	Well-being					
50		Physically	2.46 (1.65)	2.28 (1.56)	2.69 (1.49)	2.62 (1.42)
51		engaged				
52		(active, vigorous)				
53						
54		Affiliative feelings	3.41 (1.44)	2.71 (1.30)	3.57 (1.40)	3.14 (1.40)
55		(loved, forgiving,				
56		affectionate,				
57		sympathetic)				
58						
59						
60		Positive affect	3.11 (1.51)	2.74 (1.15)	3.32 (1.04)	2.90 (0.94)
61						
62						
63						
64						
65						

(hopeful, happy,  
relaxed,  
encouraged,  
cheerful, satisfied,  
calm)

#### Postural sway with eyes open

AP SD	4.44 (1.40)	5.45 (2.06)	3.92 (1.66)	4.64 (2.03)
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)	1.84 (0.59)	2.56 (1.52)
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

AP SD	4.83 (1.56)	5.45 (1.40)	4.42 (1.79)	5.20 (1.96)
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)	1.95 (0.83)	2.32 (0.78)
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)

### Secondary outcomes

#### 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)

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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				
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 3 Adjusted post-intervention between group difference (ANCOVA) and within-group change over time (mixed ANOVA); Mean differences (95% CI) for both measures 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.



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
<b>Somatosensory pain supercluster</b>			
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 <sup>a</sup>	-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)
<b>Emotional pain supercluster</b>			
Physical illness <sup>a</sup>	-0.13 (-0.74 to 0.49)	-0.12 (-0.44 to 0.20)	-0.15 (-0.37 to 0.06)
Depressed mood <sup>a</sup>	-0.57 (-1.23 to 0.09)	-0.22* (-0.39 to -0.05)	-0.10 (-0.23 to 0.04)
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)
<b>Well-being supercluster</b>			
Physically engaged <sup>+</sup>	0.13 <sup>+</sup> (-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 <sup>++</sup> (-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)

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

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

<sup>++</sup>  $p = 0.05$ .

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

Table 5 Adjusted post-intervention between group difference (ANCOVA) and within-group change over time mean differences (95% CI) for postural control

Postural cont	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)	0.84* (0.20 to 1.48)	0.62 (-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 (-3.41 to 2.69)	-2.33(-6.45 to 1.79)	
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)	1.32 (-1.14 to 3.79)	3.72 <sup>+</sup> (-0.05 to 7.48)	

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

\*p = 0.05.

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.

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 <sup>+</sup> (-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 <sup>+</sup> (-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,  $p < 0.10$ .

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

Table 8 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 <sup>+</sup> (-2.04 to 0.06)	-1.00 <sup>**</sup> (-1.57 to -0.43)
Subjective Mental Effort	5.69 (-4.01 to 15.38)	-14.24 <sup>***</sup> (-22.96 to -5.51)	-5.80 <sup>*</sup> (-11.56 to -0.03)
% of Age Predicted Maximal Heart Rate <sup>a</sup>	1.43 (-1.41 to 4.27)	-0.88 (-3.02 to 1.26)	0.42 (-1.98 to 2.82)

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

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

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

**Figure 1 CONSORT flow diagram illustrating recruitment of participants into the study.**