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An Investigation into the Effects of Virtual Reality and Electrical Muscle Stimulation on Mood, Exertion and Muscular Fatigue

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Abstract

The physiological and psychological effects of the Valkyrie EIR system, which combines virtual reality, gamification, and electrical muscle stimulation (EMS), were investigated. A within-subjects design was used, 26 participants took part in two research sessions, one involving a Valkyrie class with EMS and another without. Physiological measures, including heart rate, pressure sensitivity of the biceps and triceps, and delayed onset of muscular soreness (DOMS) were assessed alongside psychological measures, including questionnaires regarding participant experience and mood, as well as rate of perceived exertion (RPE).

Mood significantly increased post-Valkyrie classes, which were deemed enjoyable and fun, with 88.5% of participants favouring the EMS condition due to increased immersion, intensity and challenge. Significant differences were found between the EMS and control conditions, including higher RPE scores, greater DOMS and a higher heart rate, when taking into consideration the interactions of variables. These results show that the EMS induced a higher intensity of exercise, with the potential for greater muscular adaptation. Overall, Valkyrie EIR with EMS was shown to be a promising approach for enhancing exercise intensity in VR whilst encouraging participant engagement.

Introduction

Virtual Reality (VR) has emerged as a transformative technology in the realm of exercise, introducing novel ways to engage individuals in physical activity. The immersive nature of modern VR headsets not only provides a captivating environment for engaging the user, but also distracts the user from pain and reduces perception of exertion (Hoolahan, 2020). Enjoyment is inherently linked with increased participation and adherence, due to its intrinsic motivational aspect, which increases the long term motivation to engage (Teixeira et al., 2012). Combined with gamification, VR exercise experiences become enjoyable, interactive, goal-oriented challenges that can positively impact perception of exercise and commitment to long-term engagement (Deterding et al., 2011; Eynon et al., 2019).

While VR and gamification contribute to the motivational aspects of exercise, the integration of Electrical Muscle Stimulation (EMS) adds an additional physiological dimension to the experience. Numerous studies have highlighted the effectiveness of EMS for increasing strength gains (Filipovic, 2011). Previous VR exergames have primarily focused on cardiovascular exercise, largely overlooking strengthening components due to the inherent challenges of that. The Valkyrie EIR system seamlessly integrates immersive VR, EMS, and gamification, offering a comprehensive platform for both cardiovascular and strengthening exercise. The combination of

VR, gamification, and EMS creates a multifaceted exercise environment that can not only engage users mentally but also augments the physical demands of the workout, increasing the potential benefits.

Physical inactivity is an issue that is estimated to annually cost the NHS £0.9 billion, the UK £7.4 billion annually and is linked to 1 in 6 deaths in the UK (Office for Health Improvement and Disparities [OHID], 2022). In 2021, only 33% of men and 26% of women met the recommendations for physical activity, with a particular lack of participation in muscular strengthening exercises (National Statistics, 2023). According to the OHID (2022) 34% of men and 42% of women are not active enough for good health.

The present study is an exploratory study which delves into a comprehensive examination of physiological and psychological variables influenced by Valkyrie EIR, with and without the integration of EMS. Physiologically, the study investigated heart rate (HR), pressure sensitivity of the biceps and triceps, and delayed onset of muscular soreness (DOMS). Psychological aspects were also explored, including participant experience, mood, perceived effort, and rate of perceived exertion (RPE). Understanding how these components synergize can provide valuable insights into optimising exercise experiences and fostering long-term engagement in VR-based exercise programs. VR combined with EMS provides a potential solution to the debilitating problem of low engagement in muscle strengthening exercises, the present study seeks to assess the impact of VR exercise with EMS compared to without EMS.

Based on previous research by Chaney et al., (2024), it was hypothesised that the EMS condition would induce elevated levels of DOMS, compared to the control condition. Given the more exploratory nature of other aspects investigated in this study, no additional hypotheses were proposed.

Literature Review

It has been well established that the use of EMS has various physiological benefits. For instance, Park et al. (2021) demonstrated significant enhancements in body composition, muscular function, cardiopulmonary function, and balance with EMS compared to a control group. A study by Chaney et al., (2024) showed that EMS significantly reduced anxiety, enhanced executive brain function and increased HR when compared to a control. Studies have shown differing effects of EMS on HR, with some studies showing an increase (Chaney et al., 2024; Lee et al., 2012), where others show no significant difference between EMS and control (Sawada et al., 2022; Fernández-Elías et al., 2022). Alvarez-Barrio et al. (2023) highlighted a difference in HR seen between whole body EMS and local EMS, with a significantly higher heart rate in the whole-body EMS condition than the control, however a lower heart rate in the local EMS condition than both the control and whole-body EMS. This difference in results between papers suggests that other factors are likely involved. Alvarez-Barrio et al. (2024) suggested that the placement of the electrodes on different parts of the body may alter the effect on HR. There are many discrepancies between the electrical impulses applied, with studies utilising different frequencies and impulse widths. Individuals also experience EMS impulses differently, an impulse that may stimulate the muscle of one individual may not cause a reaction in another, as differences such as the muscle size affect the resistance of the electrical signal (Blazevich et al., 2021), therefore the intensity of the impulse should be adapted to each individual. Filipovic et al., (2011) suggested that a frequency of ≥60 Hz and an impulse width 100μs was sufficient for increasing strength and power.

EMS has been shown by numerous studies to have advantageous strengthening effects on the body when combined with exercise, including increasing muscle mass, maximal strength, speed strength, power, and motor abilities such as sprinting and jumping (Kemmler et al., 2021; Filipovic, 2011). Importantly, EMS has been implicated in elevating muscular stress and creatine kinase activity, consequently intensifying DOMS (Teschler & Mooren, 2019). Although the exact mechanisms behind the phenomenon are still being investigated, it has been well established that higher muscular stress is linked to higher DOMS and greater strength gains (Clarkson, Nosaka & Braun, 1992; Schoenfeld, 2012). The theory behind this link is that a higher level of stress causes microscopic tears in the muscle tissue, which heightens the level of pain by increasing the sensitivity of the nociceptors. These microtears in the tissue facilitate muscle hypertrophy by increasing the recruitment of macrophages which clear cellular debris, secrete growth factors, and regulate the inflammatory response. The macrophages also activate muscle satellite cells which stimulate the remodelling of the muscle tissue (Teschler & Mooren, 2019; Minari & Santos, 2022). It is, however, important to note that particularly high levels of DOMS can also be detrimental if the level of damage exceeds the muscle's capacity to repair it (Schoenfeld & Contreras, 2013; Minari & Santos, 2022). It is recommended to ensure that enough recovery time is allowed for the muscles experiencing DOMS to recover before engaging in further strenuous activity with the affected muscles (Cheung, Hume & Maxwell, 2003).

While EMS is well known for its ability to enhance muscle activation and improve exercise outcomes, there is limited research investigating the combination of EMS and VR. Various studies, such as that by Auda et al. (2019) investigate the use of EMS as haptics to increase the level of immersion in VR, however do not explore the physiological or psychological benefits. Lopes et al. (2017) investigated the use of EMS in VR to provide haptic feedback for walls and heavy objects by implementing a force in the opposing muscles, replicating the counter-force of an object. Participants found that the EMS made the environment more realistic, suggesting that EMS increases the immersion of a virtual experience. Research by Galofaro et al. (2022) also supported this conclusion, showing that the physiological responses to a virtual task in VR with EMS were similar to a real, physical task. Both the real and VR with EMS tasks were significantly different to the virtual task without EMS. Lee et al. (2018) observed a significant improvement in gross distal upper extremity function in stroke patients from functional electrical stimulation combined with VR, when compared to without VR. One suggested reason for this difference is that VR games help to sustain the motor intention, and the immersive feedback from VR augments therapeutic effects. Norouzi-Gheidari et al. (2021) also found that a combination of VR and EMS was beneficial for upper extremity stroke recovery. Lier et al. (2020) observed how active VR, where the user could interact with the environment, decreased the pain felt from EMS. An interesting effect of age was also seen, with older participants experiencing higher levels of pain attenuation. This hypoalgesic effect of VR is supported by various other studies (Lier et al., 2023), not only for physical pain, but mental pain as well (Smith et al., 2020). It is theorised that the immersive stimuli of VR distracts and diverts attention away from any physical and mental pain, the most widely accepted model for this is the gate control theory of attention (Theingi et al., 2022), first proposed by Melzack & Wall (1965). A higher level of immersion is linked to a higher level of distraction and therefore a higher level of pain reduction (Tong et al., 2016; Theingi et al., 2022).

The hypoalgesic effects of exercise have been well documented, various studies have shown how exercise induces an increase in pain tolerance, through testing the pressure sensitivity of the muscles (Naugle, Fillingim & Riley, 2012). However, there is a lack of research investigating the effect of EMS or exercise in VR or on pressure sensitivity. The present study sought to explore the effects of exercise in VR using EMS on the pressure sensitivity to provide new insight on the subject.

The integration of gamification into the Valkyrie EIR experience is theorised to play a crucial role in fostering participant engagement and establishing the framework for sustained long-term participation. The efficacy of the synergy between immersive VR and gamification for promoting enhanced participation and engagement, has been demonstrated by Hoolahan (2020). Additionally, a comprehensive review conducted by Nor, Sunar, and Kapi (2020) highlighted the combined impact of VR and gamification, showcasing positive effects on participant enjoyment and performance. Recognized for its capacity to make exercise more engaging, enjoyable, and goal-oriented (Eynon et al., 2019), gamification not only transforms the exercise experience but also shapes participants' perceptions and behaviours toward participation and engagement in the task (Deterding et al., 2011). As participants derive a sense of achievement through scoring and interactive gameplay, the intrinsic motivational aspects associated with gamification elements, will likely contribute to sustained participation in VR-based exercise programs that integrate gamification, such as Valkyrie EIR.

Methods

Participant Recruitment

31 healthy participants (17 male and 14 female) between the ages of 18-54 were recruited to participate in the present study. Inclusion criteria for the study ensured that participants did not suffer from any medical condition that could affect or be affected by exercise, electrical muscle stimulation or use of VR; were not pregnant; had any implanted electronic device; or suspected any underlying medical condition.

Before engaging with the study, participants were presented with an information sheet detailing the protocol and data that would be gathered throughout the study, as well as information about how data would be handled. It highlighted that participants may drop out of the study at any time, for any reason, with no repercussions. Participants were given adequate time to consider their participation and what that would require. A total of 26 participants (15 male and 11 female; mean age = 32.9) completed the study, with 5 participants dropping out after the first session.

Data Collection Protocol

Participants took part in two research sessions, each at least 3 days apart. A within-subject design was used. Participants were randomly assigned which condition they would participate in first - half of the participants completed the control condition first and the EMS condition second, and the other half the reverse.

Participants were asked to refrain from strenuous exercise for 48 hours before and 24 hours after each session (to control for the effect of DOMS from other physical activity) as well as refrain from the use of stimulants, such as caffeine, for at least 2 hours before each session (to control for external effects on HR). Upon arrival at the research facility for the first time, participants were required to complete an informed consent form.

Pressure sensitivity readings were taken using an algometer for the left and right biceps and triceps. This involved marking a spot on the belly of each muscle, then with the participant standing, with their arm against a wall for stability, the algometer was placed upon each spot in turn and pushed into the muscle. The pushing was stopped and measurement taken when the participant verbalised that they felt pain. Measurements were recorded digitally.

Each participant was then fitted with a Polar H10 chest strap HR monitor and asked to sit down in a comfortable position and relax for the first 5 minutes of the session - this allowed for participants' HR to settle to a resting rate. Once the participant was seated, the HR monitor started recording data and remained recording throughout the session. The timer on the HR monitor application (Polar Flow) was used to record key times and make notes of any issues throughout the session.

After 5 minutes of resting and acclimatising to the environment, two short online questionnaires were completed regarding the participant’s demographics and current mood. These questionnaires are shown in Appendix A.

The Valkyrie EIR system consisted of an Oculus Quest 2 VR headset, a VR exergame (EIR Training - Valkyrie Industries Ltd, 2022), as well as two Valkyrie EIR armbands, which were attached to the left and right biceps and triceps during the EMS condition. The Valkyrie EIR armbands consisted of two wireless EMS devices with symmetric biphasic pulsed signal at 100hz frequency and 100μs impulse width - which aligns with the suggestions by Filipovic et al., (2011) for increasing muscular strength and power. The participants were led through a tutorial for how to use the equipment and software, as well as a calibration of the Valkyrie system if doing the EMS condition. During the calibration, the participants each chose their preferred intensity of EMS (EMSlvl) on a scale of 1-11. They were asked to choose a level that activated their muscles but which they were also comfortable with. The levels 1-11 corresponded with a voltage of between 20-100V peak to peak. The intensity of the electrical stimulation chosen by each participant was recorded digitally.

Once the tutorial and calibration had been completed, participants began a 15 minute Valkyrie class, which involved high-intensity interval training. A 90 second warm up was included before a main workout involving 45 seconds of exercise then a 15 second rest, which repeated for the remaining time. Detailed workout is given in the Appendix C. The exercises consisted of alternating virtual dumbbell and punching exercises. In the EMS condition, participants were subjected to EMS whilst they were grabbing the virtual dumbbell and when punching virtual bubbles. The time that the participant began the class was recorded digitally, to be able to isolate the HR data during play. Any relevant notes from during the class, as well as the start and end time of the class were recorded.

Once the class had finished, participants were then immediately asked to complete a short online questionnaire including their rate of perceived exertion (RPE) during play using Borg's RPE scale from 6-20 (Borg, 1998), and another questionnaire about their current mood. Each participant's in game score for the Valkyrie class was recorded. The score is based on many different aspects of gameplay, including the number of repetitions, speed and accuracy when performing exercises (i.e. the faster and more accurately the user does the exercise, the higher the score they will get). Pressure sensitivity readings were, again, taken using an algometer for the left and right biceps and triceps, and recorded digitally. Next, the participant was asked to complete a short questionnaire regarding their experience. This utilised questions with a Likert scale from 1-7 (completely disagree to completely agree) and included open comment sections.

Participants were then asked to complete a final questionnaire 24 hours after the data collection session, this included questions related to any DOMS experienced after the Valkyrie class. This involved three scores given for pain felt during flexion and extension (movement), physical palpation and active contraction of both biceps and triceps.

Participants then returned for the second session after a break of at least 3 days, and the protocol was repeated for the other condition (control or EMS).

Data Analysis

Analysis was carried out using r programming language in RStudio (version 2023.09.0). Data was formatted in Google Sheets before importing into RStudio. Outliers were removed from the analysis for each subset of data. Exclusion criteria included parts of the HR data that suddenly spiked below 45bpm (likely due to a brief disconnection between the application and the device). HR data was completely removed if there were many of these spikes. Paired data was also removed if the participant was missing one of either the control or EMS data points.

The difference between the pressure sensitivity at the beginning and end of each session was calculated, as well as the difference between mood before and after play. Averages and standard deviations were calculated for the answers to the questionnaire regarding experience and paired t-tests were used to compare responses between conditions. These results were also analysed with a more qualitative approach alongside the comments given. Before comparing data, Shapiro-Wilk normality testing was carried out on each subset of data. This included: average HR during play (HRavg), maximum HR reached during play (HRmax), RPE, difference in pressure sensitivity for each bicep and tricep, EMSlvl, mood before play (bMood) and mood after play (aMood) as well as self-assessed DOMS scores (movement, palpation & contraction).

Data that followed a normal distribution were compared between conditions (control vs EMS), individually using paired t-tests. The HRmax, mood and DOMS data did not follow a normal distribution, therefore individual comparisons including these data employed Wilcoxon Signed Rank tests. Spearman's Rank Correlations were also used to explore the relationships between data.

To accommodate the non-normal nature of the HRmax and DOMS data, Restricted Maximum Likelihood (REML) linear mixed models were employed to explore interactions between variables and assess their combined effects. For optimal model performance, the variables were all scaled before integration into the REML analysis. This scaling step was essential to ensure that all variables were on a comparable scale, preventing potential biases arising from disparate units or magnitudes. Due to the small scale of variables after scaling, variables with coefficients between 0.1-0.3 were considered to have a small effect, between 0.3-0.5 were considered a moderate effect, above 0.5 was considered a large effect. The combined effects of the condition (control or EMS) and score on HRmax and HRavg were examined. Finally, the effect of the condition, score and duration (time between play and completing the DOMS self-assessment) on DOMS (including movement, palpation & active contraction) was investigated. This approach allowed for in-depth exploration of the interactions between the various factors, providing essential insights for drawing meaningful conclusions.

Results

Demographics

Of the 26 participants that completed the study, 11 (57.7%) were male and 15 (42.3%) were female. One participant did not answer the demographics questionnaire, the following results are based on the data for the remaining participants. The mean age was 32.9 with a standard deviation of 8.2. 12% had never used VR before, 72% had used VR once or twice before and 16% owned a VR headset. 12% exercised everyday, 20% exercised 4-6 times per week, 44% exercised 2-3 times per week, 12% exercised once a week and 12% exercised occasionally.

Participant Experience

Condition Preference

When asked to compare the EMS and control conditions, 23 participants (88.5%) stated that they preferred the EMS condition, with 2 participants (7.7%) preferring the control condition and 1 participant (3.8%) unsure. Many participants stated that they preferred the EMS condition due to the added immersion, challenge and intensity that it provided. Participant comments, including those regarding the reasoning behind their condition preferences are included in Appendix B. 100% of participants answered that they would prefer to complete a class with EMS if it was proven to have increased health benefits.

Enjoyment and Engagement

A Likert scale of 1-7 (completely disagree to completely agree) was used for the following questions. Overall, participants gave an average score of 6.4 for both the control (sd = 0.9) and EMS condition (sd = 2.2), when prompted with the question “I enjoyed doing the class”. Various comments such as “I really enjoyed it.” supported this. For the opposite, “I disliked this class”, although participants did not dislike the class in either condition, there was a significant difference between conditions ($t(24) = 2.753$, $p = 0.011$) with participants showing more dislike for the EMS condition (mean = 1.5, sd = 0.9) compared to the control (mean = 1.2, sd = 0.7). Participants also found the class fun, which was slightly higher for the EMS condition, but not significantly (mean = 6.2, sd = 0.8) and EMS (mean = 6.4, sd = 1.1) conditions. These statistics were supported by comments such as, “It was fun and the instructer was great! I liked the visuals around me too” and “I loved the setup, the graphics, really cool. I enjoyed dancing to the music”.

Responding to the question "I found the class difficult", participants seemed to find the classes somewhat difficult, with no significant difference between conditions, however a slightly higher average in the control (mean = 4.1, sd = 1.2) than the EMS (mean = 3.8, sd = 1.5). One participant commented on exercises they found difficult "Some of the balancing bits I found difficult" and "I found the arm push out exercise hard because I didn't realise I was supposed to be twisting my arm". Participants did not find the control condition painful, however the EMS condition was found to be somewhat painful, with a significant difference between the EMS (mean 3.1, sd = 1.7) and control (mean = 2.1, sd = 1.1). Although participants found the EMS condition somewhat painful, there were no negative comments about this. One participant commented "Once I got used to the pulses it was fine… I think there is definitely an adaptation period and also learning to see what pulse intensity you need to use". Many participants highlighted that they liked the sensation of the EMS, with comments such as "I liked the feelings in my muscles", "I felt more connected to my body" and "I quite like the sensation of the ems".

Participants were asked to rate their agreement with the statement "I engaged fully with the class."). Overall, participants reported a strong sense of engagement, with no significant difference found between the control (mean = 6.2, sd = 1.1) and EMS (mean = 6.3, sd = 1.1) conditions. Similarly, responses to the statement "I put a lot of effort into the class" indicated that participants perceived a substantial investment of effort during the sessions, with slightly, but not significantly, higher effort in the EMS (mean = 5.9, sd = 0.9) compared to the control (mean = 5.8, sd = 1.1). Some participants commented on how they felt more engaged in the EMS condition highlighting that "EMS felt more novel and engaging." and that the EMS condition was a "More engaging experience, more intense of a workout".

On average, participants noted that they "would choose to take part in these classes again", with similar answers given for both control (mean = 6.2, sd = 1) and EMS (mean = 6.2, sd = 1.1) conditions. Mixed answers were given for whether participants would choose to spend money on these classes, with a slight, but not significant, difference between control (mean = 4.6, sd = 1.7) and EMS (mean = 4.4, sd = 1.8) conditions. Figure 1 depicts the answers to these questions.

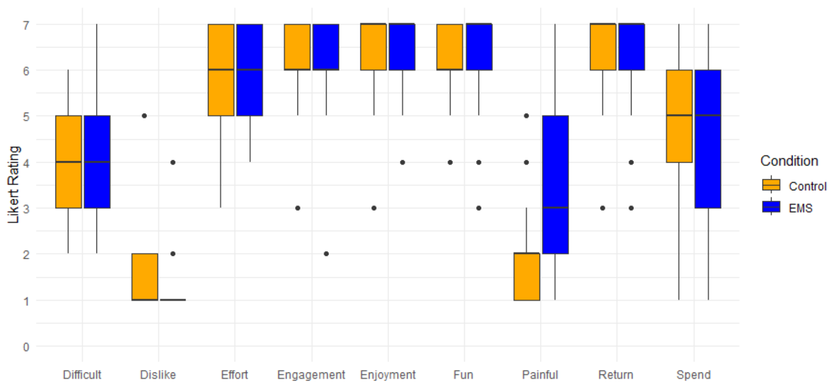

Figure 1.

Box Plot of Likert Scaled Questions

In the comments, 5 participants highlighted issues with sweating in the headset "The bigest problem for me was sweating under the VR halmet (maybe some fabric under the halmet might help?)". A few participants also mentioned some technical issues with the class, such as "my height glitched in one of the classes", and "Sometimes grabbing things is not working entirely". One comment mentioned "Comfortable EMS devises, very light and well attached (adhesive)".

Participants gave an overall rating on a scale of 1-10 for the class, with a slight, but non-significant difference between the control (mean = 7.9, sd = 1.4) and EMS (mean = 8.2, sd = 1.3) conditions. Participant comments, including those regarding reasoning behind their answers to these questions are included in Appendix A. Figure 2 depicts the overall ratings given by participants, with regards to control and EMS condition.

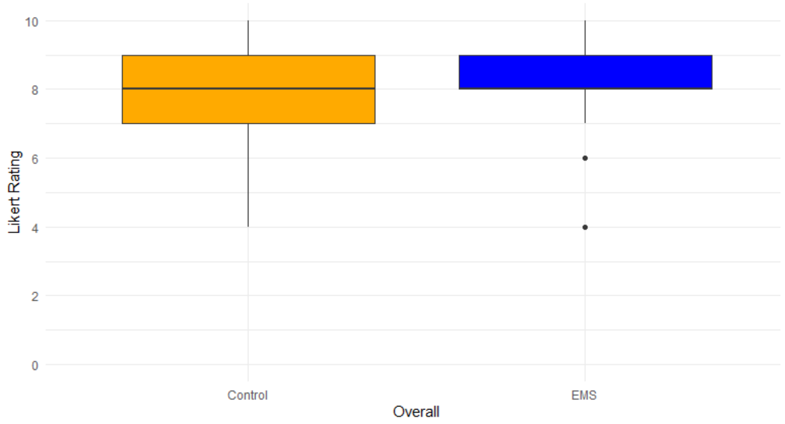

Figure 2.

Overall Ratings Given by Participants

Mood

A Shapiro-Wilk test showed all the mood data to follow a non-normal distribution. A Wilcoxon Signed Rank test was conducted to compare the difference in mood change between conditions, which showed no significant difference between the EMS and control conditions (V = 80.5, p = 0.865) with a mean difference of 0.04. A Wilcoxon Signed Rank test compared mood before and after play for both conditions and found a significant increase in mood (V = 171.5, p = 0.005) after play compared to before, with a mean difference of 0.62. These results suggest that participants' mood increased after play, with no difference between conditions. Figure 3 depicts participants' mood before and after, with regards to control and EMS condition.

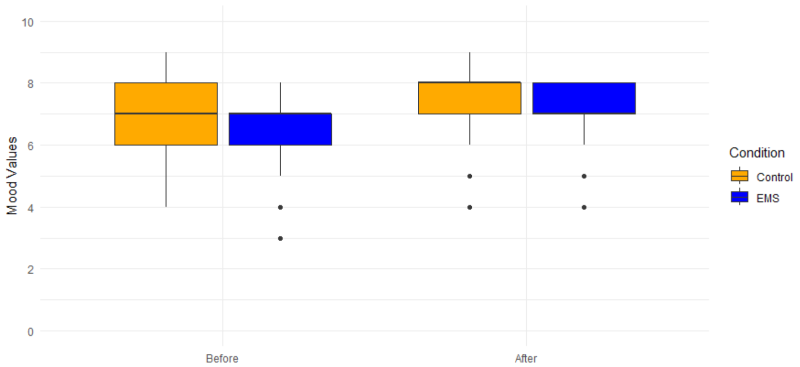

Figure 3.

Box Plot of Mood Before and After Play, with Regards to Condition

RPE

A paired t-test highlighted a significant difference in RPE between conditions (t(20) = -2.203, p = 0.039). Participants reported a higher perceived exertion during the EMS condition. Figure 4 shows the differences in RPE between the control and EMS conditions.

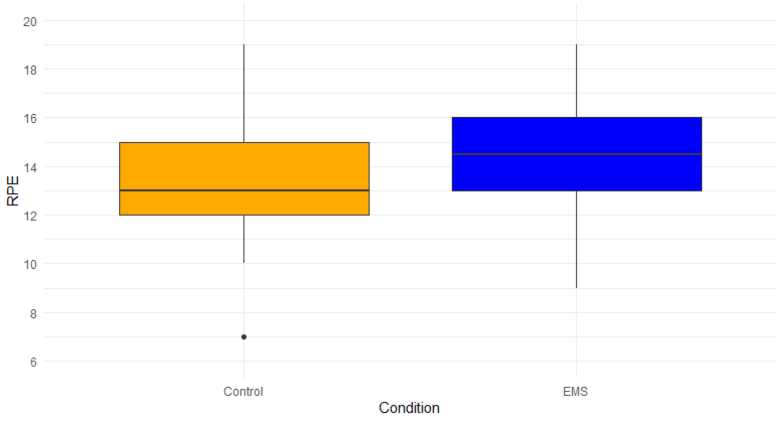

Figure 4.

Box Plot of RPE Differences Between Conditions

Comparisons Between Conditions

Pressure Sensitivity

No significant difference was observed between pressure sensitivity before and after the class in either condition, or for pressure sensitivity between conditions.

DOMS

A Shapiro-Wilk test revealed a non-normal distribution for all assessment types. Wilcoxon Signed Rank tests were employed to compare DOMS between conditions. A significant difference was observed between conditions for DOMS assessed by movement (V = 12, p = 0.006), palpation (V = 7.5, p = 0.001) and active contraction (V = 6.5, p = 0.001). This highlighted that there were higher scores for DOMS in the EMS condition compared to the control condition, with a mean difference of 1.947 for movement, 3.263 for palpation and 2.474 for active contraction.

Figure 5 shows the differences in self-assessed pain ratings, as assessed by movement, palpation and active contraction, for the biceps and triceps between the control and EMS conditions.

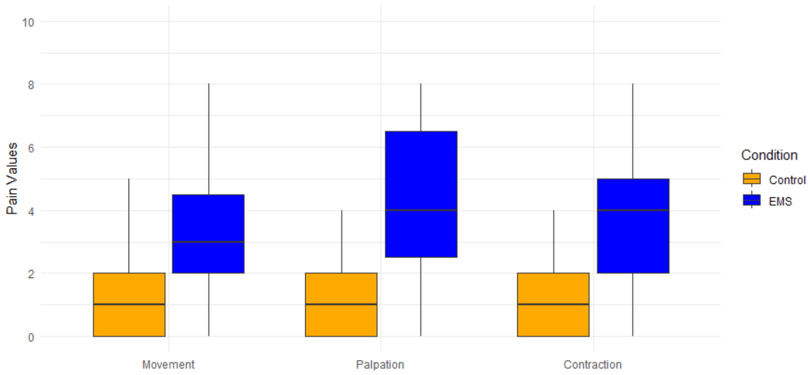

Figure 5.

Box Plot of DOMS Differences Between Conditions

HR

Shapiro-Wilk normality testing highlighted the non-normal distribution of the HRmax data for the EMS condition (p = 0.004), therefore a Wilcoxon signed-rank test was used to compare the HRmax data between conditions. This showed no statistically significant difference in HRmax between conditions (V = 114, p = 0.697), with a mean difference of 3.3 BPM (Control: mean = 163.2, sd =

22.4; EMS: mean = 166.5, sd = 20). A paired t-test was used to compare HRavg between conditions, which also showed no significant difference in HRavg between conditions (t(21) = -0.887, p= 0.385), with a mean difference of 2.2 BPM (Control: mean = 135.5, sd = 20.7; EMS: mean = 137.7, sd = 25.7).

RPE

Shapiro-Wilk normality testing showed a normal distribution of the RPE data for the control (p = 0.3) and EMS conditions (p = 0.127), therefore a paired t-test was used to compare the HRmax data between conditions. This showed a significant difference in RPE between conditions (t(25) = -2.703, p= 0.012), with a mean difference of -1.12 (Control: mean = 13.4, sd = 2.4; EMS: mean = 14.5, sd = 2.2).

Correlation Between RPE and HR

Spearman's Rank Correlation was used to assess the relationship between RPE and HR. It is important to note that due to tied ranks in the data, the exact p-value could not be computed, however the significance is still valid due to the robustness of the Spearman's Rank Correlation to ties.

A non-significant weak, positive correlation was observed for both the EMS (rho = 0.241, p = 0.306) and control (rho = 0.346, p = 0.135) conditions between RPE and HRavg. However, when both conditions were considered together, the correlation became significant (rho = 0.314, p = 0.049), suggesting that generally, higher RPE was associated with increased HRavg. Figure 6 shows the correlation between RPE and HRavg.

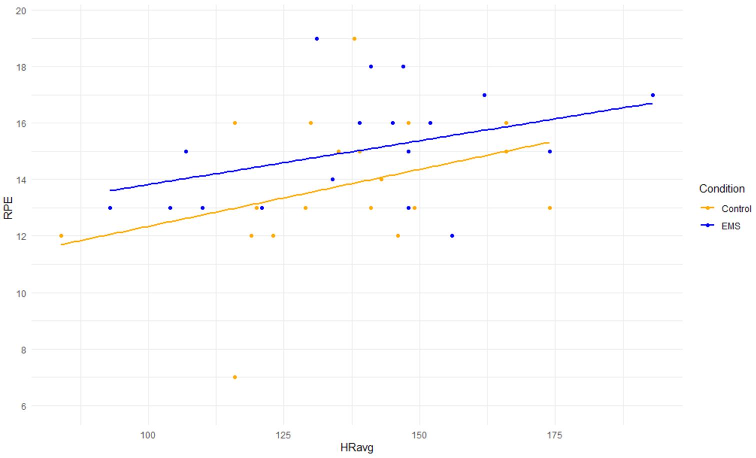

Figure 6.

Correlation Between RPE and HRavg

A non-significant, positive correlation was observed between RPE and HRmax, with a weak correlation for the EMS condition (rho = 0.229, p = 0.331) and a very weak correlation for the control (rho = 0.179, p = 0.451). Figure 7 shows the correlation between RPE and HRavg.

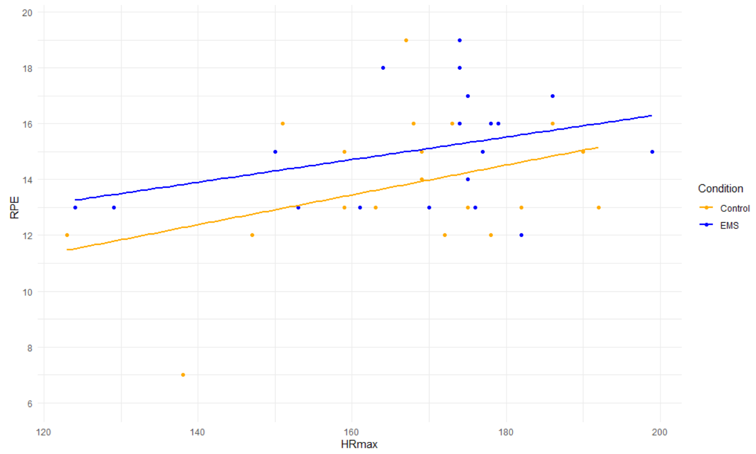

Figure 7.

Correlation Between RPE and HRmax

Correlation Between Score and HR

Examining the correlation between participant's scores and HR metrics using a showed a notable relationship between score and HR. A significant, positive correlation between score and HRmax was observed, with a very strong correlation for the EMS condition (rho = 0.722, $p < 0.001$) and a strong correlation for the control (rho = 0.643, $p = 0.002$), indicating that maximal HRs are closely aligned with the score gained.

A significant, strong, positive correlation between score and HRavg for both the EMS (rho = 0.63, $p = 0.003$) and control (rho = 0.698, $p < 0.001$) conditions, also indicated that higher scores were associated with increased HRavg.

It is important to note that due to tied ranks in the data, the exact p-value could not be computed, however the significance is still valid due to the robustness of the Spearman's Rank Correlation to ties. Figures 8 and 9 show the correlation between score and HR.

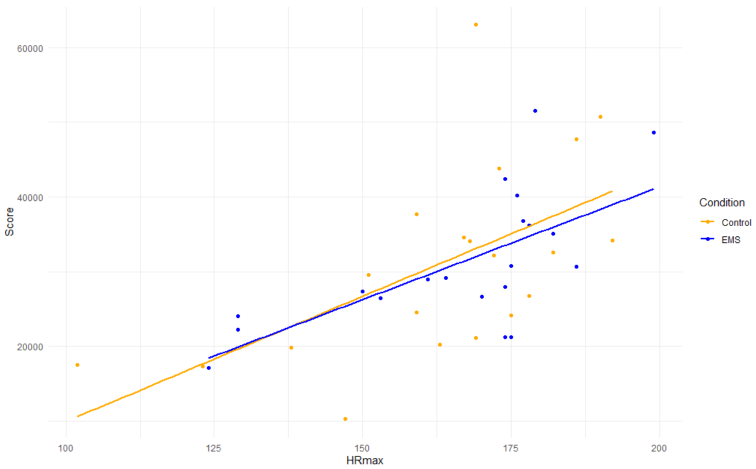

Figure 8.

Correlation Between Score and HRmax

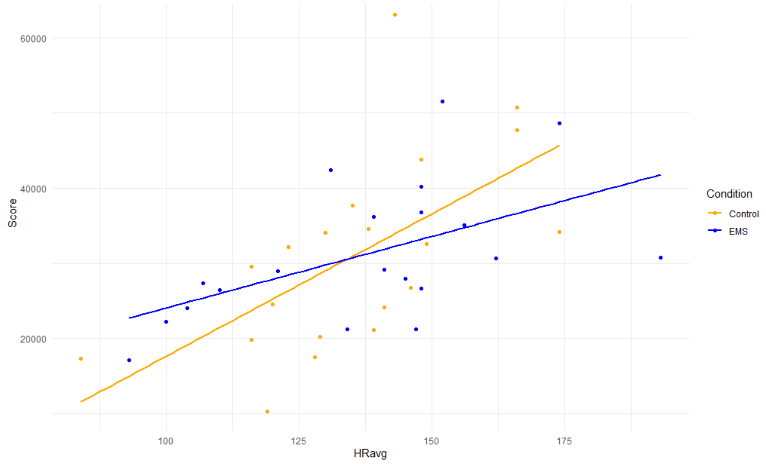

Figure 9.

Correlation Between Score and HRavg

Correlation Between Score and Effort

Spearman's Rank Correlation was used to assess the relationship between score and effort. A very weak, non-significant positive correlation was observed between score and effort in the EMS condition (rho = 0.13, p = 0.595). However a significant, strong, positive correlation was seen for the control condition (rho = 0.684, p = 0.001). It is important to note that due to tied ranks in the data, the exact p-value could not be computed, however the significance is still valid due to the robustness of the Spearman's Rank Correlation to ties. Figure 10 shows the correlation between score and effort for each condition.

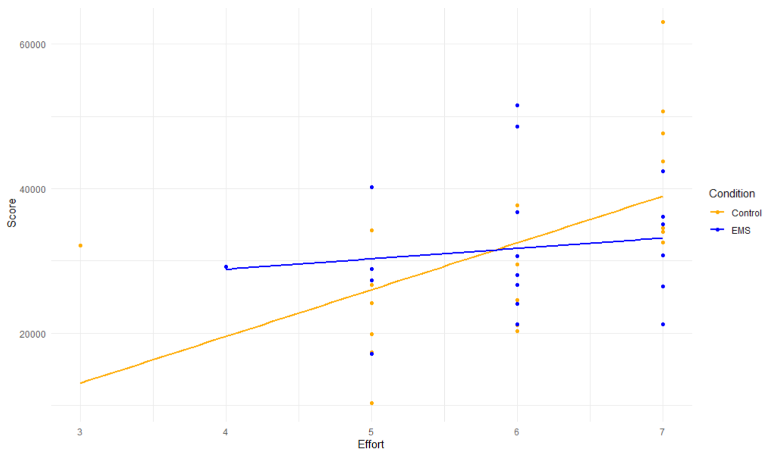

Figure 10.

Correlation Between Score and Effort

Correlation Between RPE and Effort

Spearman's Rank Correlation was used to assess the relationship between RPE and effort. A very strong, significant positive correlation was observed between RPE and effort in the control condition (rho = 0.791, p < 0.001). However a very weak, non-significant, positive correlation was seen for the EMS condition (rho = 0.207, p = 0.396). It is important to note that due to tied ranks in the data, the exact p-value could not be computed, however the significance is still valid due to the robustness of the Spearman's Rank Correlation to ties. Figure 11 shows the correlation between score and effort for each condition.

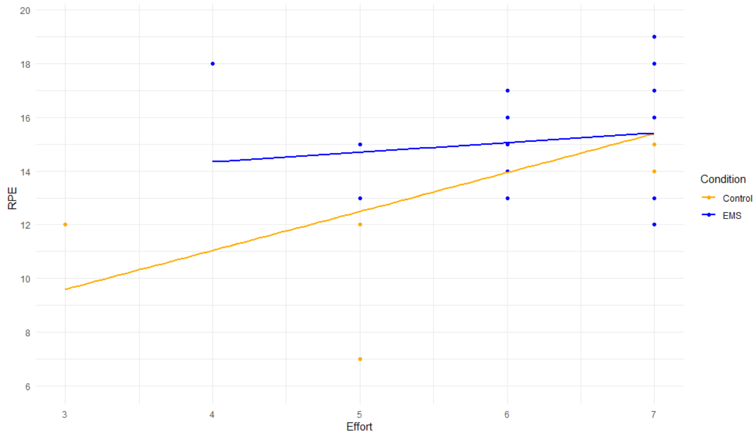

Figure 11.

Correlation Between RPE and Effort

Correlation Between EMSlvl and DOMS

No correlation was found between EMSlvl and DOMS for any of the types of self-assessment.

Multivariate Interactions of Variables

Interactions of Variables Affecting HR

The combined impact of EMS and participant score on HR metrics uncovered a small effect of condition (ConditionEMS = 0.152) and a moderate effect of score (Score = 0.415) on HRmax, with the EMS condition and a higher score both leading to a greater HRmax. A small interaction effect (ConditionEMS:HRmax = 0.115) was also observed. The HRavg model revealed no to little effect of condition (ConditionEMS = 0.088), and a moderate effect of the score (Score = 0.329), along with a small interaction effect (ConditionEMS:Score = 0.252).

Interaction of Variables Affecting DOMS

The interactions between condition, HRmax and the duration between the class and DOMS self-assessment on the effect on DOMS assessed by flexion and extension, palpation and active contraction.

Flexion and Extension of Biceps and Triceps

A large positive effect was observed for the condition (ConditionEMS = 0.9), showing higher pain induced by flexion and extension of the biceps and triceps (movement DOMS) in the EMS condition compared to the control. A small effect was observed for the HRmax, with higher movement DOMS from a higher HRmax (HRmax = 0.178). The duration coefficient shows no to little effect of the duration (Duration = 0.055). There was a moderate positive interaction effect between the EMS condition and HRmax (ConditionEMS:HRmax = 0.441) and a small positive interaction effect between HRmax and duration (HRmax:Duration = 0.165). No to little interaction effect was found between the EMS condition and duration (ConditionEMS:Duration = -0.053). A large positive interaction effect was seen between all three variables (ConditionEMS:HRmax:Duration = 0.969).

Palpation of Biceps and Triceps

A large positive effect was observed for the condition (ConditionEMS = 0.991) showing higher pain induced by palpation of the biceps and triceps (palpation DOMS) in the EMS condition compared to the control. A small negative effect was seen for HRmax (HRmax = -0.148), suggesting that a lower HR max slightly increased palpation DOMS when considered alongside condition and duration. A large negative effect was seen for duration (Duration = -0.591), suggesting lower palpation DOMS from a longer duration between participation and DOMS self-assessment. There was a large positive interaction effect between the EMS condition and HRmax (ConditionEMS:HRmax = 0.778), a moderate positive interaction effect between the EMS condition and duration (ConditionEMS:Duration = 0.396) and a small negative interaction effect between HRmax and duration (HRmax:Duration = -0.104). A large positive interaction effect was seen between all three variables (ConditionEMS:HRmax:Duration = 1.487).

Active Contraction of Biceps and Triceps

A large positive effect was observed for the condition (ConditionEMS = 1.139) showing higher pain induced by active contraction of the biceps and triceps (contraction DOMS) in the EMS condition compared to the control. A small negative effect was seen for HRmax (HRmax = -0.109), suggesting that a lower HRmax slightly increased contraction DOMS when considered alongside condition and duration. A moderate negative effect was seen for duration (Duration = -0.359), suggesting lower contraction DOMS from a longer duration between participation and DOMS self-assessment. There was a moderate positive interaction effect between the EMS condition and HRmax (ConditionEMS:HRmax = 0.482), as well as a large positive effect between the EMS condition and duration (HRmax:Duration = 0.566). No to little interaction effect was seen between HRmax and duration (HRmax:Duration = 0.068). A large positive interaction effect was seen between all three variables (ConditionEMS:HRmax:Duration = 0.535).

Discussion

The present study not only tested one main hypothesis but also undertook a comprehensive exploration of the effects of Valkyrie EIR on various physiological and psychological aspects. The hypothesis, predicting that the EMS condition would lead to a higher HR and increased levels of DOMS compared to the control condition, was supported - the null hypothesis was rejected in favour of the alternative.

Independent Differences

HR, RPE, pressure sensitivity and DOMS were individually compared between conditions. RPE scores were found to be significantly higher in the EMS condition, highlighting how participants felt that they exerted themselves more in the EMS condition compared to the control. Higher RPE is associated with higher HR (Williams, 2017), however, when examining HR in isolation, without accounting for other variables, no statistically significant difference between conditions emerged. This could potentially indicate support for research that observed no increase in HR from local EMS (Sawada et al., 2022; Alvarez-Barrio et al., 2024). The RPE serves as a subjective gauge of physical effort, as highlighted in the correlation seen between effort and RPE in the control condition, while HR offers an objective physiological indicator of the body's response to exercise intensity (Flairty & Scheadler, 2020). This could, in part, be linked to the effect the VR has on RPE, as observed by Hoolahan (2020). This, as well as the non-significance of the difference in HR between conditions, highlights the potential for interplay with other factors. This is supported by its strong, positive correlation with the score, emphasising the necessity for a more nuanced exploration of the relationship, particularly considering the influence of specific exercise modalities, as well as other factors that may come into play (Hetzler et al., 1991). Further exploration into the complexities of the interplay of variables is important for a comprehensive understanding of participants' subjective and physiological responses to each condition.

When considered independently, no significant difference was found between conditions for the pressure sensitivity of any of the muscles involved. Also, pressure sensitivity was not significantly different after any of the classes compared to before, for any of the muscles involved.

Self-assessed DOMS scores were found to be higher in the EMS condition for all three forms of assessment (movement, palpation and active contraction). These results suggest that the EMS condition induced a higher intensity of exercise, which is associated with a higher perception of muscular soreness (Cheung, Hume & Maxwell, 2003). This aligns with the principle of muscle adaptation, where higher levels of DOMS are indicative of increased mechanical stress and microtrauma to muscle fibres, ultimately contributing to muscle hypertrophy and strength gains (Teschler & Mooren, 2019). The heightened DOMS experienced in the EMS condition implies a more intense and demanding muscular effort, leading to greater improvements in muscle strength and endurance over time (Minari & Thomatieli-Santos, 2022; Kemmler et al., 2021). These findings suggest a potential for enhanced muscular adaptation and performance benefits from the EMS condition, and builds upon similar findings from previous research which did not include the use of VR (Kemmler et al., 2021). Further research is needed to explore the long-term effects of increased DOMS from exercise with EMS in VR to better support this conclusion.

Multivariate Interactions of Variables

The application of mixed-effects models revealed intriguing insights into the interplay of variables influencing the physiological and perceptual responses during the Valkyrie EIR sessions. Although no significant differences were found for HR when considered independently, the REML mixed model provides a more accurate representation of the underlying patterns, highlighting the nuanced relationship between variables such as the condition, score and HR to show their effects when considered together.

Effects on HR

When exploring the interaction of score and condition, both emerged as significant contributors to an increase in both HRavg and HRmax during gameplay. Both the EMS condition and a higher score induced a higher HRmax and HRavg when compared to the control. A small interaction effect was found between the condition and the score, suggesting that the combined influence of EMS condition and score resulted in a slightly amplified effect on HRmax and HRavg beyond the sum of their individual effects.

It is evident that the intensity of Valkyrie EIR sessions is influenced by a combination of the participants' performance scores and the condition. The score is based on many different aspects of gameplay, including the number of repetitions, speed and accuracy when performing exercises. These aspects are inherently linked to intensity and align with the correlation between score and effort in the control condition. Notably, participants reported differences in their RPE levels between conditions, suggesting that the EMS not only impacts physiological responses, such as heart rate, but also affects participants' subjective experiences of effort and exertion, which is further supported by the significant correlation between RPE and effort in the control condition, which was absent in the EMS condition. The interaction effect seen in these results implies that as participants' scores improved, the impact of the EMS condition on heart rate responses became more pronounced. This interaction highlights the importance of considering both performance and condition together when evaluating the overall intensity of the training sessions. This underscores the intricate interplay between participants' perceived effort and exertion, the scoring mechanism, and physiological responses, emphasising the multifaceted nature of the observed outcomes.

Effects on DOMS

When considering the combined effects of condition, HRmax and duration between participation and DOMS assessment together on the perceived severity of DOMS, the condition had a large effect on all three assessments of DOMS. The results indicate that the use of EMS substantially increases DOMS, as self-assessed through movement, palpation and active contraction of the biceps and triceps, in comparison to the control. This supports the previous conclusion that the increased DOMS in the EMS condition relates to higher muscular stress, leading to greater improvements in muscle strength and endurance over time (Minari & Thomatieli-Santos, 2022; Kemmler et al., 2021). HRmax appeared to have a small positive effect on movement DOMS, but a small negative effect on palpation and contraction DOMS. Indicating an increase in movement DOMS but a decrease in palpation and contraction DOMS with a higher HRmax. These negative effects could reflect a small protective effect of cardiovascular exercise against DOMS, due to the increased blood flow increasing the rate of muscular repair (Tufano et al., 2012). Duration between participation and assessment appeared to have no to little effect on DOMS assessed by movement, however a moderate negative effect on the palpation and contraction assessments of DOMS, indicating that DOMS decreased with a longer duration between participation and assessment. The discrepancy in the positive effects of HR and duration in the movement self-assessment of DOMS could be due to differences in the assessments through different modalities - movement was a less intrusive measure than palpation or active contraction which induced lower scores of perceived pain. Further research should further explore the interdependencies of these variables and their implications.

Moderate to large positive interaction effects were found between all three variables - condition, HRmax and duration. These results suggest a synergistic impact, with the combined effect of these variables amplifying the observed increase in DOMS.

Participant Preferences

88.5% of participants stated that they preferred the EMS condition over the control condition. The reasons given for this were due to the increased immersion, challenge and intensity of the session. Several participants highlighted how the sensation of the EMS resembled the experience of lifting weights at the gym - with many also highlighting that they liked the sensation of the EMS. These findings align with previous research by Lopes et al. (2017) and Galofaro et al. (2022), which substantiated that EMS contributes to a more realistic VR experience. A more realistic experience is associated with a higher level of immersion in the virtual world - a factor that has been linked to a reduction in the perception of physical and mental pain (Tong et al., 2016; Theingi et al., 2022). This reduction in pain due to the immersion of modern VR headset is theorised to be linked to the lower perception of exertion felt whilst in VR in comparison to the actual exertion (Hoolahan, 2020). The potential implication of using EMS and VR to intensify workouts while simultaneously reducing the perceived level of exertion and pain experienced, holds promise for both fitness and healthcare applications. This theory warrants further in-depth research to investigate.

Two participants mentioned a novelty aspect of the EMS condition, which suggests that novelty may be a potential factor in the enjoyment of the EMS condition. It is recommended that future studies should investigate this novelty aspect over a long-term period, to provide a more in-depth understanding.

Overall, participants enjoyed the class and found it fun, giving an overall average score of 8.1 out of 10. Participants would generally choose to take part in the class again. The enjoyment of the classes likely contributed to the significant increase in mood after participation. Enjoyment is inherently linked with increased participation and engagement in the task, due to its intrinsic motivational aspect (Teixeira et al., 2012). Low participation in physical activity, particularly strengthening exercises, has been a well documented problem for many years (National Statistics, 2023).

Although there was more of a mixed response, with an average of 4.5 (on a scale of 1-7 from completely disagree to completely agree) to the question “I would spend money on this class”, this still favoured that the participants would, more often than not, spend money on the class. One participant highlighted the complexity of purchasing the EMS equipment, particularly the requirement for a VR headset, which they did not possess. The ambiguity surrounding whether participants needed both the EMS and VR equipment or could participate by paying without purchasing the equipment may have contributed to disparities in responses. Notably, the lack of further comments on this matter raises questions about the clarity of the question and therefore the validity of the results for this question.

Limitations

It is important to acknowledge the limitations of the present study. The small sample size may limit the generalisability of these results to a wider population. The study experienced dropouts, introducing the potential for selection bias. The reliance on self-reported measures for pressure sensitivity, DOMS and participant experience introduces subjectivity, and the possibility of social desirability bias should be considered.

Despite these limitations, the study offers valuable insights into the complex dynamics of combining VR, gamification, and EMS in an exercise setting. Addressing these limitations in future research will contribute to a better understanding of the broader implications of these technologies in promoting exercise performance and engagement.

Conclusion

In conclusion, the findings of the present study offer valuable insights into the complex dynamics of participant mood, preferences, and physiological responses to Valkyrie EIR system with and without EMS. Multivariate analyses highlighted intricate interactions among variables shaping the physiological responses to Valkyrie EIR. It was evident that the EMS heightened exercise intensity. This increase in intensity manifested in elevated HR, higher RPE and enhanced DOMS. Notably, the large positive effect of the EMS condition on DOMS, in contrast to the control, implies benefits for muscle adaptation and performance when using Valkyrie EIR with EMS, aligning with prior research in the field. The in-game score emerged as an interlinking variable, which was tied to factors such as the speed and repetition count of exercises, affecting participants’ HR, as well as correlating with participant effort; connecting the physiological and psychological aspects of the study.

Participants' enjoyment and overall positive experience was reflected in the average overall score of 8.1 out of 10, with this enjoyment contributing to the potential long-term success of such exercise programs. This is also supported by the significant increase in mood experienced by participants, regardless of the inclusion of EMS. Notably, the participants' preference for the EMS condition, reported by 88.5% of participants, highlights the significance of immersion, challenge, and intensity in shaping positive exercise experiences. A potential novelty factor, identified by some participants, warrants further exploration in future studies to obtain a deeper understanding of its impact on long-term engagement.

In summary, the integration of gamification, immersive VR, and EMS in the Valkyrie EIR system creates a holistic exercise environment that not only addresses the problems of engagement in exercise, but also offers a multifaceted approach to optimising exercise experience and the benefits it can provide. Future studies should delve deeper into the long-term effects of EMS training using the Valkyrie EIR system, and further explore the complexities of the interplay between psychological and physiological variables. This research contributes to the ongoing efforts to enhance exercise engagement and provides a foundation for refining VR-based exercise programs for improved participant outcomes.

Conflict of Interest

The authors declare a potential conflict of interest associated with the funding and conduct of this study. VR Healthy was contracted and financially compensated by Valkyrie Industries for the data analysis and composition of this research. Additionally, Valkyrie Industries, the developers of the software and hardware investigated in the present study, was responsible for data collection for this study. This involves a potential conflict of interest which could influence the gathering of data as well as the interpretation and reporting of study results.

It is important to note that steps were taken to reduce potential bias and the authors have made efforts to present the findings transparently. This study underwent a rigorous review process to ensure scientific integrity, and all data analysis and interpretation were conducted with impartiality. The authors are committed to transparent reporting and acknowledge these potential conflicts to maintain the credibility and trustworthiness of the research.

The authors affirm that this conflict of interest did not compromise the validity of the study and remain dedicated to the principles of unbiased scientific inquiry.

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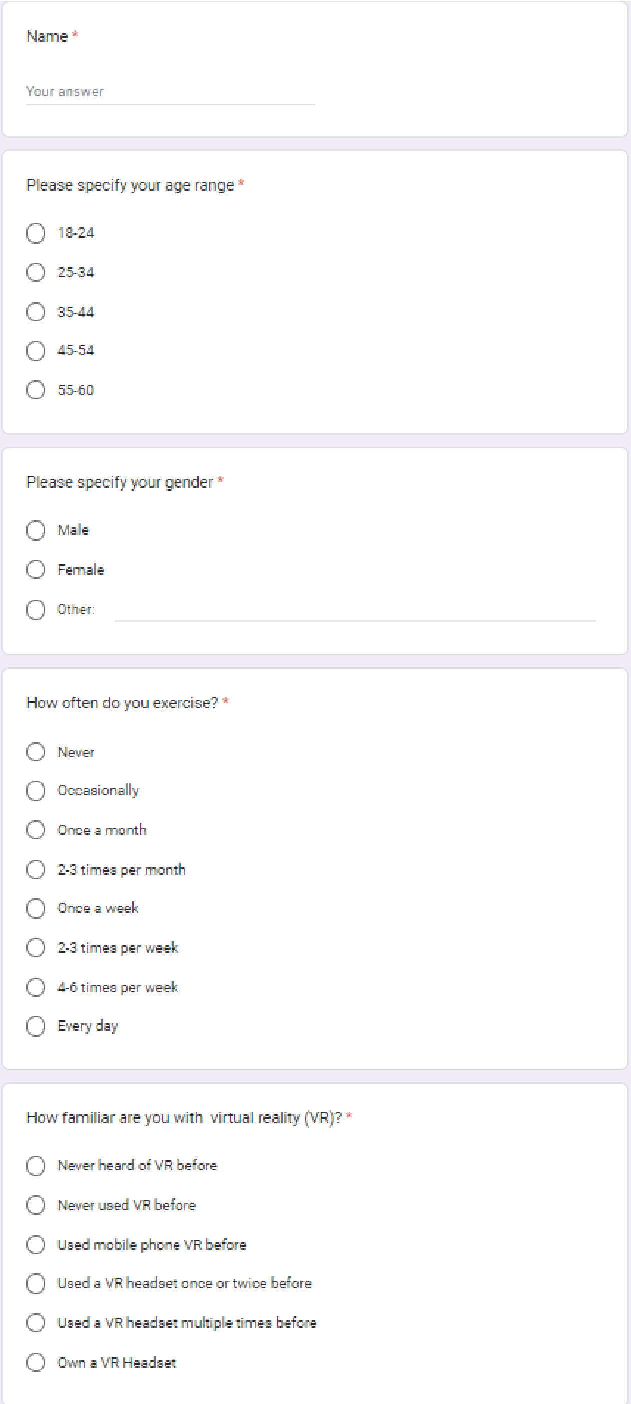
Appendix A

Questionnaires



Name *

Your answer

Please specify your age range *

- 18-24
- 25-34
- 35-44
- 45-54
- 55-60

Please specify your gender *

- Male
- Female
- Other:

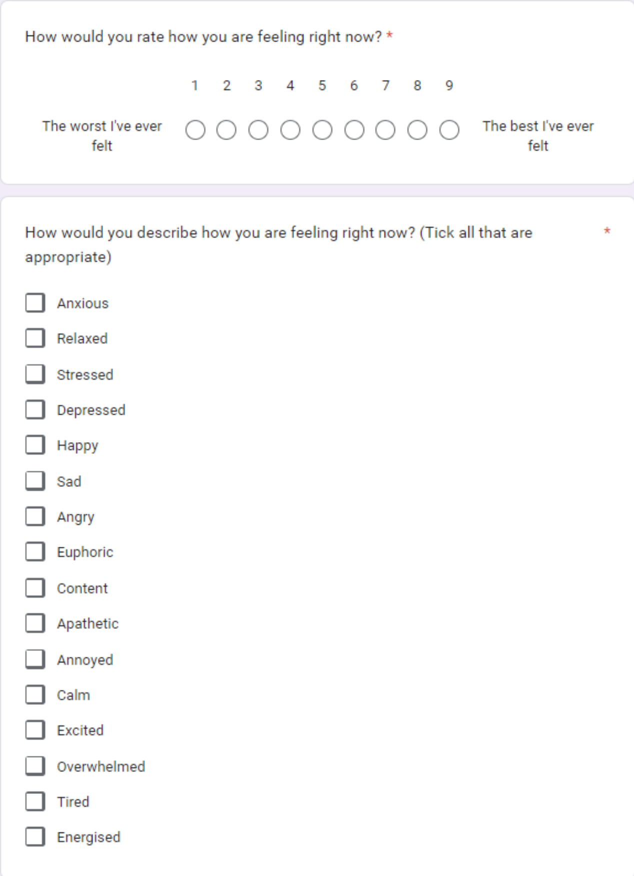
How often do you exercise? *

- Never
- Occasionally
- Once a month
- 2-3 times per month
- Once a week
- 2-3 times per week
- 4-6 times per week
- Every day

How familiar are you with virtual reality (VR)? *

- Never heard of VR before
- Never used VR before
- Used mobile phone VR before
- Used a VR headset once or twice before
- Used a VR headset multiple times before
- Own a VR Headset

Figure A1
Demographics Questionnaire



How would you rate how you are feeling right now? *

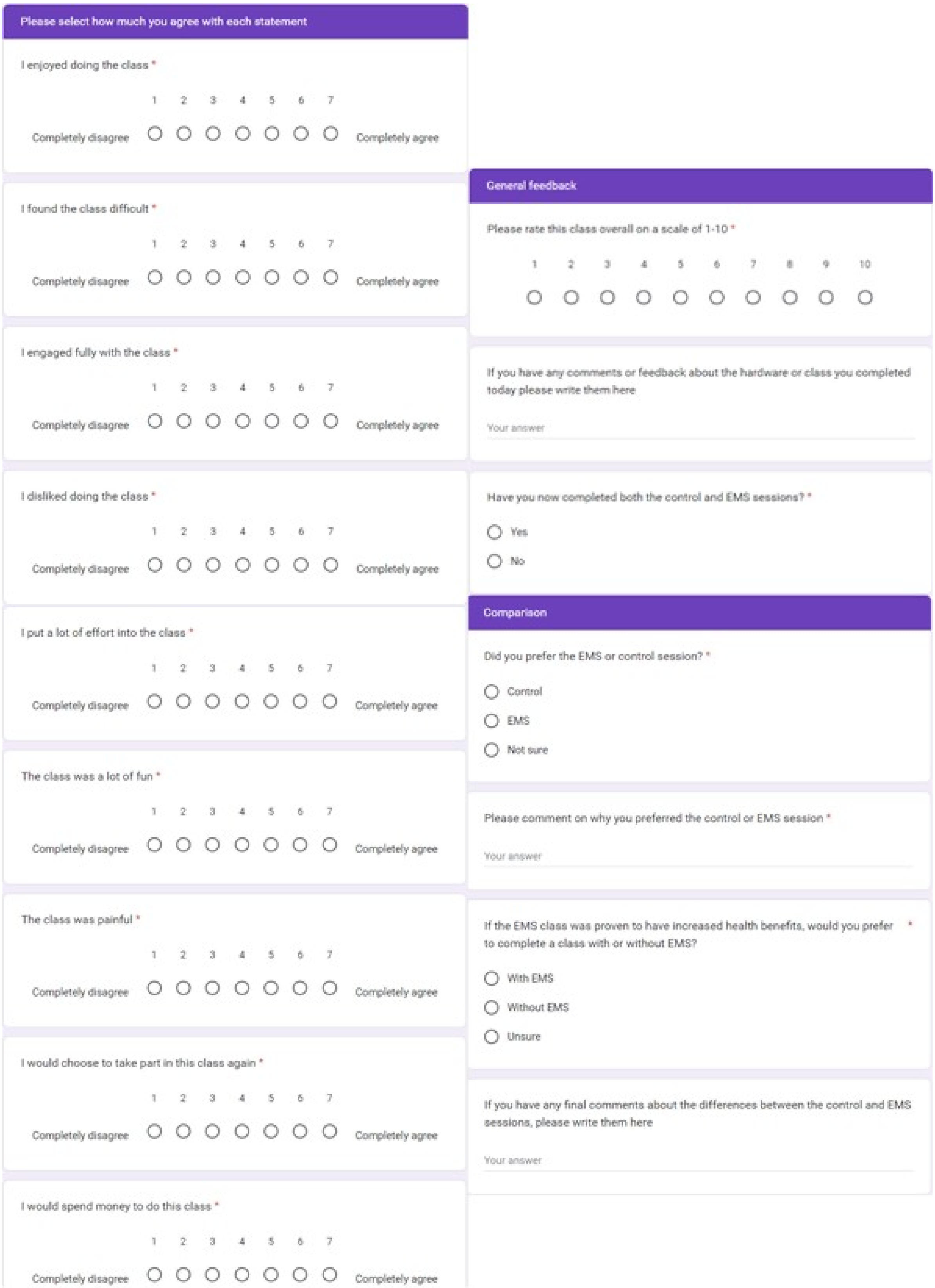
	1	2	3	4	5	6	7	8	9	
The worst I've ever felt	○	○	○	○	○	○	○	○	○	The best I've ever felt

How would you describe how you are feeling right now? (Tick all that are appropriate) *

- ☐ Anxious
- ☐ Relaxed
- ☐ Stressed
- ☐ Depressed
- ☐ Happy
- ☐ Sad
- ☐ Angry
- ☐ Euphoric
- ☐ Content
- ☐ Apathetic
- ☐ Annoyed
- ☐ Calm
- ☐ Excited
- ☐ Overwhelmed
- ☐ Tired
- ☐ Energised

Figure A2

Mood questionnaire



Please select how much you agree with each statement

I enjoyed doing the class *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I found the class difficult *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I engaged fully with the class *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I disliked doing the class *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I put a lot of effort into the class *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

The class was a lot of fun *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

The class was painful *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I would choose to take part in this class again *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

I would spend money to do this class *

1 2 3 4 5 6 7

Completely disagree ○ ○ ○ ○ ○ ○ ○ Completely agree

General feedback

Please rate this class overall on a scale of 1-10 *

1 2 3 4 5 6 7 8 9 10

○ ○ ○ ○ ○ ○ ○ ○ ○ ○

If you have any comments or feedback about the hardware or class you completed today please write them here

Your answer

Have you now completed both the control and EMS sessions? *

○ Yes

○ No

Comparison

Did you prefer the EMS or control session? *

○ Control

○ EMS

○ Not sure

Please comment on why you preferred the control or EMS session *

Your answer

If the EMS class was proven to have increased health benefits, would you prefer to complete a class with or without EMS? *

○ With EMS

○ Without EMS

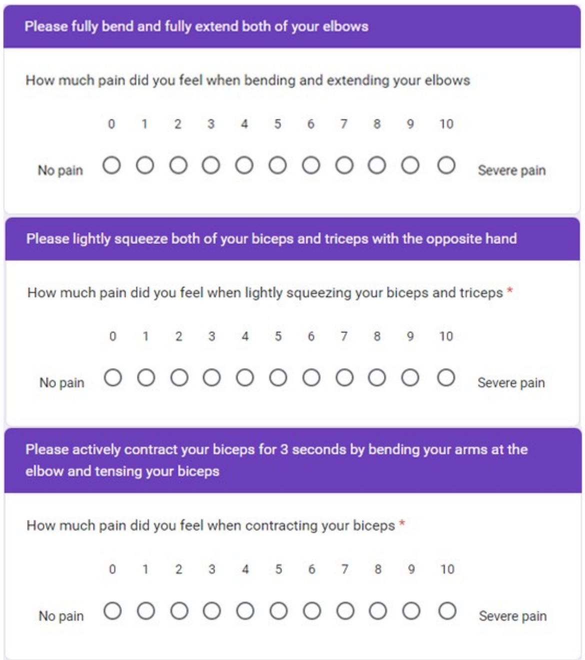
○ Unsure

If you have any final comments about the differences between the control and EMS sessions, please write them here

Your answer

Figure A3

Participant Experience Questionnaire



Please fully bend and fully extend both of your elbows

How much pain did you feel when bending and extending your elbows

	0	1	2	3	4	5	6	7	8	9	10	
No pain	○	○	○	○	○	○	○	○	○	○	○	Severe pain

Please lightly squeeze both of your biceps and triceps with the opposite hand

How much pain did you feel when lightly squeezing your biceps and triceps *

	0	1	2	3	4	5	6	7	8	9	10	
No pain	○	○	○	○	○	○	○	○	○	○	○	Severe pain

Please actively contract your biceps for 3 seconds by bending your arms at the elbow and tensing your biceps

How much pain did you feel when contracting your biceps *

	0	1	2	3	4	5	6	7	8	9	10	
No pain	○	○	○	○	○	○	○	○	○	○	○	Severe pain

Figure A4.

Muscular Soreness Questionnaire

Appendix B

Participant Comments

This appendix contains comments from participants regarding their experience. Spelling and grammatical errors have not been corrected to present the comments as they were given by participants.

Table B1

Participant Comments Regarding their Experience for each Session

Participant	If you have any comments or feedback about the hardware or class you completed today please write them here (control)	If you have any comments or feedback about the hardware or class you completed today please write them here (EMS)
1	Same as last time, i would love to be able to check whether my movements are done correctly. Otherwise, i like the fact that althought the EMS is focused on the arms, the session is comprehensive and my whole body has exercised.	It gets a bit foggy with the sweat but i guess sweat is expected from an intense training. It would be great to know whether i'm doing the movement as expected by the trainer.
2	the slow punches felt a little high, would be nice to calibrate it for shoulder length pre-class	the class was great would be nice of the video corresponded exactly to the workout.
3	This was a general cardio class. If I did it again I would probably go for range of movement rather than speed which would have made the exercise more intense	Found more benefit using the EMC configuration
4	-	Although it was good fun with EMS - that part I definitely enjoyed - I was struggling with headache that first appeared in the tutorial. I started with Level 3, than went to Level 4 and back to see if it changes but the main correlate for me looks like to be the sound. After it hit me I had to remove the goggles, had a bit of rest and lowered the sound volume level, then it got better, I only encountered headache in the excersize no10. Particularly I might be affected by the sound of electricity. Whenever I was hearing it in the slow excersizes my headache was getting stronger

5	1. Not sure if there is adjustment for height but I feel some things were too high up 2. The table for dumbells was quite close to me, it felt scary 3. I sometimes bumped the controllers together 4. I really like Ivan doing the tutorial, it was sometimes annoying when he said something two times. He ended each tutorial looking to the side. 5. I loved the setup, the graphics, really cool. I enjoyed dancing to the music, perhaps you can choose your own music at the beginning of the tutorial. spotify integration? 6. When choosing the level of ems, even though I was in control group I almost felt the different levels because of the visual and sound cues. Not sure if intended or not. 7. I haven't done VR exercises before, this was super fun even without the device, it was engaging. 8. Sometimes grabbing things is not working entirely, I was trying to catch it a few times and once I lost a dumbell. Perhaps more practice in grabbing? Was I supposed to 'grab' with all 3 fingers or just the bottom one? 9. Super cool that there is speed meter which determines how many points I get. 10. When there is yellow plane it takes over the vision and I can't find other things. different colour? 11. The slow punches exercise was confusing, I didn't understand how to 'start'. I eventually started but still I have no idea how or if I would be able to repeat it. 12. Sometimes there were larger bubbles and I am not entirely sure what I was supposed to do with them. Go through them? Awesome [****]ing job. This was super fun. Well done!	1. I really like the spinning electrical towers that sync with your moves. they are not too much and super nice touch 2. I really like the way the teacher shows the next moves while you rest 3. The balance between exercise and rest was perfect for me 4. I felt the most ems during the slow punches, it was much much more than on other exercises and I enjoyed that. 5. I like the graphics, there are a lot of nice small touches. Perhaps even more 'easter eggs' or maybe they are already there 6. The bubbles for when I was supposed have hands 'above ears' were actually in front of me even if i moved forward in the floor circle 7. I really like the calibration, it seems to be intuitive, easy, etc
6	-	-
7	I had an issue finding the class as I wasn't aware the class menu could slide and I would personally prefer more slower exercises where I really work on the mind muscle connection, putting lots of tension on the muslces	I really enjoyed it. I done it on 11 and it definetly was a challenge but I knew what I was getting into and it definetly pushed nme
8	I really enjoyed universe in the background! I liked videos with coaches	-

	and their voices. The bigest problem for me was sweating under the VR halmet (maybe some fabric under the halmet might help?). Also I feel a bit dizzy right now (I usually feel dizzy after 45-60 mins in VR halmet).	
9	-	-
10	My dumbell has disappeared and did not re-appear; my height glitched in one of the classes; the alignment of circles to put hands into didn't work in one of the classes;	-
11	Some times the bubbles felt like they were slightly in the wrong place	-
12	I felt worried at points that I was going to run into/hit the "table" and it made me a bit nervous about doing the exercises quickly/to full extension. For some of the punching bits, my hands naturally want to curl around the controllers, i.e. compressing some of the buttons, but I was unsure whether this would affect gameplay (this is something I could have asked about ahead of time). As my face got sweaty, the head portion started to slip, again I could have really tightened this ahead of gameplay, so not a detractant. Some of the bubbles felt too short for my arm length, I think this is user error from calibration. Some of the balancing bits I found difficult with the requirement to stay inside the white circle, such as the arm slam when you rise onto your toes, I kept toppling over. I found the arm push out exercise hard because I didn't realise I was supposed to be twisting my arm as I pushed the dumbbell away from me and then couldn't figure out how to keep it in the bubbles/do it correctly with the indicators, haha.	Everything was great, I would love less squat-oriented activities if possible! or alternate squat forms.
13	-	Comfortable EMS devises, very light and well attached (adhesive)
14	I really enjoyed it, the headset can be a bit annoying becuase you sweat a lot and with the headset on your face it casues it to build up and drip down while you are playing	-
15	-	very good for cardio
16	It was fun and the instructer was great! I liked the visuals around me too.	Sometimes when I hit the bobbles, it didn't work and I didn't get points.
17	-	someting the visual was a bit not clear and needed headset adjustment.

		also i could still see some parts of real things in the roomm outside the visuals and it was a bit weird feeling. the excercise is very engaging and i loved it. getting feedback from the voice was encouraging. would be great if this feedback is more and more personalised as this is very encouraging. this handsats can be more comfortable somehow.
18	-	-
19	I sometimes hit the remotes together when punching the balls and sometimes I would lose the dumbells by accidentally losing the grip on the button.	With the EMS it was a new experience and interesting. I do a lot of sport and it was a bit shocking at first when you get the elecctric pulses, it makes you go a bit slower at first. When I was getting the pulse I could also feel it on my fingers and would make me reduce my grip, which was a bit awkward to hold the remotes. Once I got used to the pulses it was fine and I could concentrate more on the exercises and putting the intensity. I think there is definitely an adaptation period and also learning to see what pulse intensity you need to use.
20	Once sweat start to acumulate I have to celan the headset	sweat in the headset ...
21	-	-
22	-	i wasn't fully clear on whether i was hitting the targets right/well, and how to improve this (e.g. what was the maximum to score for a hit/move?). Visually the class could still be better/more exciting, eg. with more light effects, other (virtual participants) etc
23	-	-
24	In the later part of the class, I could only see one dumbbell so the excercises were incomplete and I did not have to put too much effort as I would have done if it was working. Also the interface was moving front and back so I had to keep changing my position which was inconvinient. This did not happen the first time around.	-
25	just need a bit of time to pick up dumbels before the timer starts	none
26	-	-

Table A2

Participant Comments Regarding the Differences Between Conditions

Participant	Please comment on why you preferred the control or EMS session	If you have any final comments about the differences between the control and EMS sessions, please write them here
1	the EMS adds a element of challenge in an already intense session, and the different levels of resistance can be used as goals to achieve and therefore incentivise competitive minds to use regurlarly the devise.	I guess without the devise the intensity of the training can be higher because your arms are lees tired. However with the EMS, and especially on the slow punchs, quick execution is not the priority as maintaining a right movement is way more difficult, so focus is more on executing the movement correctly, speed of that execution comes second
2	EMS felt more novel and engaging. although it was nice to take the control class and finding it easier	-
3	Felt more intense and felt more of a complete workout	Looking forward to the published product
4	I liked the feelings in my muscles - this was something new	-
5	1. The musce engagement was just a bit more. 2. It makes some of move much more realistic, in particular i liked the feeling of 'slow punches' - the movement and 'burn' reminded me of the gym 3. Novelty aspec 4. The feeling is pleasant in a way	-
6	I felt more connected to my body.	-
7	My muscles feel far more tired so I feel I have done a real work out which is a feeling I love	I really enjoyed it I do enjoy weighted exercises as opposed to calisthenics
8	EMS session is much more intesive. I feel muscles pain in my biceps (after control I didn't), and I like it. Also EMS feels more fancy rather then plain training in VR:)	-
9	EMS gave more resistance, felt like the muscles worked.	-
10	It was just more buzzing with energy!	-
11	Felt more like a work out	-

12	I felt like I could do more repsmore quickly and concentrate more on the correct motions without distraction. It felt more "natural" to me; I do a lot of bodyweight exercises in day-to-day life so might not be used to the weight training format.	-
13	The tingling senation and the feeling I got in the musles was the same as I would get while doing the gym, the first session was quite easy in comparison and I aslo get the greater feeling of satisfaction from the class	Other comments: Software -orientation pointers could be useful (white or blue?), some exercise balls could be bigger,the score at hit level could be alos bigger, gradient from red to yellow to green is very intuitive, I liked that. The fingers that were not used - was not sure what to do with them and that sat at the back of the mind during the exercise.
14	I quite like the sensation of the ems and I got tired a lot quicker	-
15	because its diffrent but for normal gym control	-
16	EMS feels like a real workout at a gym, with all the weights and equipment. Control session was fun, but only body weight wasn't enough :)	-
17	I preferred EMS because it brings more dificulty to the class. Its like when you have a bicycle with gears and you have put gear 1 and then with EMS you put gear 2 or 3. and with this you are able to put even more effort.	-
18	More engaging experience, more intense of a workout	-
19	I prefered the control version because I could go full out on the exercises, whereas with the EMS I needed a period of adaptation. I also don't know about how intense the pulses should be and how that affects your work out as much. I personally don't like having electric pulses down my body but if it helps to intensify the work out then I would change my opinion. I think tomorrow, after feeling the effects, I will be more able to determine whether it was worth it or not.	I think I made my comments on the above.
20	More unique and potnetially more efficiant to activate these muscles.	Would be good to have the EMS for the legs
21	a different sensation	-
22	It felt more immersive, I felt more exhausted afterwards	Personally, I'm on the threshold of whether I would pay for the EMS equipment. Firstly, I would need to own a VR headset (I currently do not), plus the price is then the question. BUT it would definitely be a

		piece of equipment that would make me interested in doing VR fitness sessions. I don't think I'd do them without the EMS.
23	I felt like i was going at my own pace and nothing was pushing me a certain way	-
24	The additional sensation and emersion	The session on EMS was more engaging due to simulation of actually lifting weights. There was a pump in my muscles after the EMS session which I did not feel after the Control session. I was mentally more engaged during the EMS session as compared to the Control one.
25	-	none
26	I like the electrical muscle stimulator- made the workout more challenging	-

Appendix C

Workout

The workout consisted of a 90 seconds warm up and a main workout. The warm up had 4 exercises of 15 seconds each, as listed below. The main workout consisted of 13 exercises of 45 seconds each, as listed below, with a 15 seconds rest in between each exercise

Warmup:

1. Arm swings
2. Arm rotations
3. Side punches
4. Squats

Main workout:

1. Jabs and hooks;
2. Dumbbell woodchops up and over
3. Hooks
4. Pause thruster with dumbbells
5. Overhead punches
6. Slow punch with dumbbells
7. Uppercuts
8. Rack reverse lunge with dumbbells
9. Snatch with dumbbells
10. Good morning curl with dumbbells
11. Lateral raises with dumbbells
12. Overhead punches
13. Slams with dumbbells

The walkthrough can be found in the following video:
https://www.youtube.com/watch?v=nhoZe2mZkmU