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Exercise in Virtual Reality With a Muscular Avatar Influences Performance on a Weightlifting Exercise

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Abstract

Virtual Reality (VR) technology can be used to influence performance on endurance exercises. In this study, we focused on manipulating perception of own-body strength by exercising in VR as a muscular avatar. In this repeated-measure study, twenty-nine participants performed biceps curl exercise in a maximum repetitions protocol, up to exhaustion. The exercise was done either in VR as a muscular avatar, or without VR, in front of the mirror. Dependent variables were the number of exercise repetitions and self-reported exertion. We also controlled blood glucose level, perceived weight of the barbell and level of embodiment. Participants performed significantly more biceps curl repetitions in the VR condition ($Z = -2.05$, $p < .05$) with an effect size of $d = 0.36$. The self-reported effort did not differ significantly between conditions. The results of this study may have an applied significance since number of exercise repetitions is an ecologically valid measure, directly relevant to real training protocols.

Keywords: Virtual reality; exercise; embodiment; resistance training; Proteus effect

Introduction

Research conducted in the past two decades has shown that virtual reality (VR) technology may be an effective tool in physical rehabilitation, exercise, and pain therapy (Howard, 2017; Jones et al., 2016; Kim & Biocca, 2018; Tashjian et al., 2017). VR may make physical activity more attractive for some users, since some of the VR apps may involve gamification of the exercises (Kim & Biocca, 2018; Mouatt et al., 2019; Zeng et al., 2017). It may distract attention from exercise-related pain, thus allowing participants to accept higher exercise loads (Matsangidou et al., 2017; Matsangidou et al., 2019; Wender et al., 2019). It may also provide altered visual feedback regarding certain exercise parameters (e.g., range of motion), thus manipulating the perceived difficulty level of a given activity (Debarba et al., 2018). An altered visual feedback strategy was used effectively in diminishing kinesiphobia and increasing mobility in patients with chronic back or neck pain (K. B. Chen et al., 2014; K. B. Chen et al., 2017; Debarba et al., 2018).

However, manipulating the perceived range of motion is not the only way to alter visual feedback regarding the exercise difficulty. Other visual cues may be used, as in Matsangidou et al. (2017) or Matsangidou et al. (2019), who manipulated visual information about the size of the weights to be lifted. In both studies, participants were performing a weightlifting exercise (a bicep curl), and time to exhaustion was significantly longer when visual cues understated the real weight of the dumbbell. The altered visual information used in those two studies also led to diminished effort and decreased intensity of exercise-related pain.

Apart from surrounding the user by a simulated environment, VR technology can be used to manipulate representations of the bodily self. Synchronous multisensory stimulation, together with the first-person

perspective over a virtual body, can create a strong feeling of embodiment. This phenomenon is called *body ownership illusion* (BOI) and is evoked by either visuo-tactile or visuomotor synchronies—that is, a virtual avatar being touched or making identical movements as the participant. After BOI is elicited, it can influence the multimodal perceptual process (i.e., how information from multiple sensory modalities is integrated).

Processes related to own body perception share many similarities with general principles of multisensory integration (See Ehrsson, 2020 for a recent review).

Multisensory integration is a study of how information from several sensory modalities is combined by the nervous system, and how sensory modalities interact in perception influencing each other (Stein et al., 2009).

The sense of body ownership emerges from integrating several sensory inputs, and the constructed perception of own body reciprocally influences the process of sensory integration itself. For example, under the influence of BOI asynchronous or incongruent visuo-tactile stimuli may be perceived as correct. Participants may experience touch as originating from virtual object in contact with the avatar's body even if visual and tactile stimuli are not synchronized in time (Maselli & Slater, 2013).

While several studies have investigated underlying neuronal mechanisms of this phenomenon (Ehrsson, 2020), there is also growing evidence that embodying certain body types—such as that of a person with a different skin color, a child, or a giant—can influence participants' behaviors and attitudes (Abtahi et al., 2019; Kiltner et al., 2012; Slater & Sanchez-Vives, 2014).

Theoretical models proposed to explain BOI are mainly constructed within the framework of predictive coding, and refer to the Bayesian integration of information from multiple sensory inputs (Kiltner et al., 2013, 2015).

Predictive coding models assume, that the brain needs to infer the hidden causes of sensory signals. This inference is done by forming predictions about the upcoming sensory information, and subsequently verifying those predictions with the actual sensory signals (J. B. Hutchinson & Barrett, 2019). Because sensory signals may vary in reliability and precision it was proposed that brain employs a form of Bayesian inference while updating beliefs about hidden causes of sensory signal. Such computational models were successfully used to explain various phenomena in multisensory perception, and perception of own body (Kiltner et al., 2015).

Several studies on BOI investigated visuomotor and visuotactile integration, and resolution of sensory conflicts between these modalities (Costantini & Haggard, 2007; Ijsselstein et al., 2006; Tsakiris & Haggard, 2005). For example, Maselli and Slater (2013) compared the strength of the BOI in visuomotor versus visuotactile conditions, and have found that visuomotor synchronies elicit stronger BOI. Other studies established that the sufficient conditions for creating BOI are the first-person perspective over an avatar and realistic skin tone on the virtual body (Slater et al., 2009).

Cognitive and behavioural change in users due to their avatar appearance is known as the Proteus effect (Yee & Bailenson, 2007). One possible explanation is self-perception theory, where participants evaluate themselves from an imagined third-person perspective and behave according to this evaluation. As an example, participants who used attractive avatars were walking closer to their virtual confederate and disclosing more information (behaviours interpreted as self-confidence), in comparison with participants who used unattractive virtual bodies (Yee & Bailenson, 2007). According to Peña (2011), the Proteus effect can be explained by automatic priming processes. The virtual body activates concepts relevant to the attributes of one's avatar, and these activated concepts influence one's cognitions and behaviors (Peña et al., 2009). The Proteus effect was observed in studies using physical activity outcomes (Peña et al., 2016; Peña & Kim, 2014) where participants operating normal weight virtual bodies were more physically active compared to those who operated obese avatars.

Proteus effects were also observed in the context of pro-social and anti-social behaviors (Yoon & Vargas, 2014), product perception and purchasing behaviors (Yoo et al., 2015), and physical actions, like walking speed (Reinhard et al., 2020).

Fox & Bailenson (2009) also demonstrated that the change in one's avatar's body affected their physical activities, although this study was based on social cognitive theory. Other published research suggests that identification with the avatar may influence player motivation in physically immersive video games (Li & Lwin, 2016).

There is also published evidence linking embodiment illusions of a virtual limb to diminished pain perception and increased pain threshold on that limb (Hänsel et al., 2011; Martini et al., 2014; Romano et al., 2016). Therefore, based on BOI and Proteus effect literature, we hypothesized that embodying a muscular and resilient looking virtual avatar would improve performance during a weightlifting exercise.

It is also possible, that embodiment of a muscular body would lead to a change in perceived effort during the exercise. Several studies established a relationship between self-efficacy and perception of effort. This relationship is reciprocal. The exercise which is perceived as effortful can increase post-exercise self-efficacy. And in turn, higher pre-exercise self-efficacy may lead to lower ratings of perceived physical exertion (Rudolph & McAuley, 1996). Influence of self-efficacy on perceived effort was documented during isometric muscle exercises, and increasing participant's self-efficacy has led to lower perceived effort (J. C. Hutchinson et al., 2008). In a recently published study using a muscular avatar has led to lower perceived exertion during an isometric force task (Kocur et al., 2020).

In summary, results of published studies suggest that exercising in VR, while embodied as a muscular avatar may lead to a better performance. Such performance improvement could be driven by changes in perceived self-efficacy and effort. It may also be caused by phenomena related to Proteus effect, or VR based distraction from pain.

In this study participants were performing bicep curls in a maximum repetition protocol (i.e., up to exhaustion). They were doing it either in the VR embodiment condition or without VR (i.e., watching themselves in the mirror). We tested the following two hypotheses in a repeated-measures experimental design:

H1: Participants will perform more bicep curl repetitions when they are embodied in a muscular virtual avatar through VR than when they are seeing themselves in a mirror

H2: Self-reported ratings of perceived physical exertion will be lower after exercising in the VR as a muscular avatar, compared to the non-VR condition where participants train in front of a mirror.

Methods

The independent variable was VR embodiment, which was manipulated on two levels (VR muscular avatar vs. non-VR control). The dependent variables were the number of bicep curl repetitions and self-reported exertion. The control variables were glucose level in the blood, perceived weight of the barbell, and the level of BOI over the virtual body.

Blood glucose was measured in both experimental conditions in order to control for variation in baseline glucose level before exercise. This is an important variable to monitor because a higher level of blood glucose is related to better performance on endurance muscle exercises (Wilber & Moffatt, 1992) and variation in blood glucose level might have been observed because of meal consumption or physical activity before the study.

Perceived barbell weight was monitored in order to rule out the occurrence of size-weight illusion. People tend to underestimate the weight of larger objects, compared with smaller objects of the same mass (Heineken & Schulte, 2007). On the other hand, people may misperceive distances and sizes of objects in VR (Maruhn et al., 2019). Size underestimation is less pronounced but still present with the type of VR equipment used in this study (Kelly et al., 2017). Therefore, the barbell and weights might seem to differ in size between the VR and non-VR conditions, and although this should not influence performance (Luebbers et al., 2017), it could influence self-reported effort (Burgess & Jones, 1997).

Participants

A convenience sample of 38 students from Wroclaw University was recruited for the study, with an age range of 20 to 30 years old. Persons with any functional and/or medical problems with the muscles or joints were excluded, as well as people who had a history of accident-related soft tissue damage or other medical conditions that could have potentially been worsened by participating in exercise during the experimental procedure. Additionally, people who regularly train in weightlifting or practiced other forms of strength training were excluded from participation.

In previously published research on VR and endurance bicep exercises (Matsangidou et al., 2019) VR have been shown to have a large effect size, compared with a non-VR control group ($d = 0.86$ for time-to-exhaustion measure; computed from data available in their publication). Therefore, we conducted an a priori power analysis to determine the sample size necessary to detect a large effect size ($d = 0.8$), with Wilcoxon signed-rank test (matched pairs), two-tailed, $\alpha = .05$, and power = .95. The analysis was conducted using G*Power Version 3.1.9.2, and the resultant necessary sample size was 24. Substantial participant attrition was expected; therefore, a larger initial sample was recruited. The data was collected between May and July, 2019.

From the initial sample of 38 participants, nine people were excluded from the analysis at a later stage. Thus, the final sample used in the statistical analysis was comprised of 29 individuals (17 males, 12 females). Two participants were excluded because of infection during the day of measurement, two participants were excluded because of VR application failure during the experiment, and two others were excluded because they initiated regular strength training during the time between measurement sessions. Finally, three participants were excluded because of improper execution of the exercise, despite repeated instructions given by the experimenter. The age of the analysed sample was $M = 24.1$, $SD = 2.03$.

Materials

The study took place in a lab room at the Institute of Psychology at the University of Wroclaw. The lab room was equipped with a large-sized two-way mirror (220 × 80 cm) to prevent the participant from seeing other parts of the room. The VR application was run on a desktop computer (Intel i7, 8 GB RAM, Nvidia GTX 1070 GeForce) and a room-scale VR system (HTC Vive, resolution 1080 × 1200 per eye, 90 Hz refresh rate, 110 deg FOV). The VR system has 6DOF, which means it offers both rotational and positional tracking. The system was equipped with two controllers, which were mounted on a barbell, allowing for translation of physical movements of the barbell onto a virtual barbell used in the VR application (see Figures 1 and 2 in the Procedure section).

Software

The VR application was programmed in Unity3d, and the avatar was created in Adobe Fuse (Mixamo). The virtual scene consisted of a muscular character standing in a gym in front of a large virtual mirror. The avatar was holding a virtual barbell, which was synchronized with a physical barbell. Participants were seeing the avatar's body from the first-person perspective and were able to move the barbell, look around, and lean forward or backward. Additionally, walking in the virtual space was disabled.

Training Equipment

A barbell was used in the study. The barbell weight was 7 kg, and two plates (1,250 g each) were loaded onto the barbell. The total mass of the barbell with plates was 9.5 kg. Two VR controllers from the Vive system were attached to the sides of the barbell in both the control and VR conditions.

Measures and Questionnaires

Blood glucose level was measured using the AccuCheck Proforma "Nano" device, equipped with a finger prick.

The Borg rating scale of perceived exertion was used to measure self-reported effort related to the exercise (Borg, 1982; Day et al., 2004). This scale is highly correlated with participant pulse rate and other physiological measures of exertion (M. J. Chen et al., 2002).

Perceived mass of the curl bar was measured with a question: "How heavy in your opinion was the curl bar?" The question was asked after completion of exercise repetitions.

BOI was measured in the VR condition with a single question: "Did you experience the virtual body as if it was your body?" This question was anchored to a 10-point Likert scale (1 = *not at all*, 10 = *completely*).

Although most studies use multiple-item questionnaires to assess BOI after the VR immersion, we decided to use a single-item oral measure. Phenomena induced by VR immersion may be quickly lost after removing the goggles, and such temporal dynamics are considered problematic for measurement of the related phenomenon of presence in VR (Oberdörfer et al., 2018). For this reason, several studies used single-item measures of presence in a virtual environment (Bouchard et al., 2004; Bouchard et al., 2008; Freeman et al., 1999; Oberdörfer et al., 2018). Such measures are less intrusive, and they have been validated in terms of content validity, face validity, test-retest reliability, convergent and divergent validity, as well as sensitivity (Bouchard et al., 2004).

In a recent review focusing on methodology of RHI (Riemer et al., 2019) the authors conclude that there is a large variation across studies in questionnaire items measuring BOI. However, an item directly targeting body ownership was used in most published studies. Therefore, such an item was chosen as a single-question measure used in this study.

Procedure

In this repeated-measures study, each participant visited the lab twice within an interval between 3 and 5 weeks from the initial measurement time. This is enough time to allow for complete regeneration of the muscle fibers activated during exercise at the first measurement time (Allbrook, 1981). The specific length of the interval for each participant was scheduling related. The order of conditions was counterbalanced. In both VR and non-VR conditions participants performed the exercise up to exhaustion.

Repetitions to fatigue is considered a safe procedure used in endurance training and in evaluation of one's strength (Mayhew et al., 2008). It can be used to calculate one's repetition maximum—which is a commonly used predictor of muscular strength.

The procedure was used together with several common resistance training exercises (García-López et al., 2007; Hutchins & Gearhart, 2010; Kravitz et al., 2003; Schlumberger et al., 2001). Several studies used repetitions to fatigue procedure specifically with a biceps curl exercise (Eston & Evans, 2009; Hutchins & Gearhart, 2010). While many variants of the procedure exist, all of them are based on performing a given exercise as many times as possible, using submaximal weight load.

Biceps curl can be performed in a standing body position using a barbell, and such exercise method was used in a study by Eston and Evans (2009).

Participants were informed about the possible consequences of maximum repetition exercises (i.e., sore muscles and pain lasting up to several days). They were also informed about possible discomfort related to the glucose measurement procedure, as well as the possibility to withdraw from participation at any moment. The study was approved by a local ethics committee. Participants were first screened for alcohol and/or psychoactive substance use in the previous 2 days and for any infections in the previous week. Then, blood glucose level was measured using the AccuCheck device.

After the measurement, the participants underwent 4 minutes of standardized warm-up exercises. The purpose of the warm-up exercise was to prepare the muscles for weightlifting and minimize risk for injury. After the warm-up, participants were instructed on how to hold the barbell correctly, assume correct body posture for the

exercise, and perform the bicep arm curl movement. Subsequently, participants performed five test repetitions of the bicep curl in order to verify their ability to do the exercise correctly. The sessions lasted up to one hour.

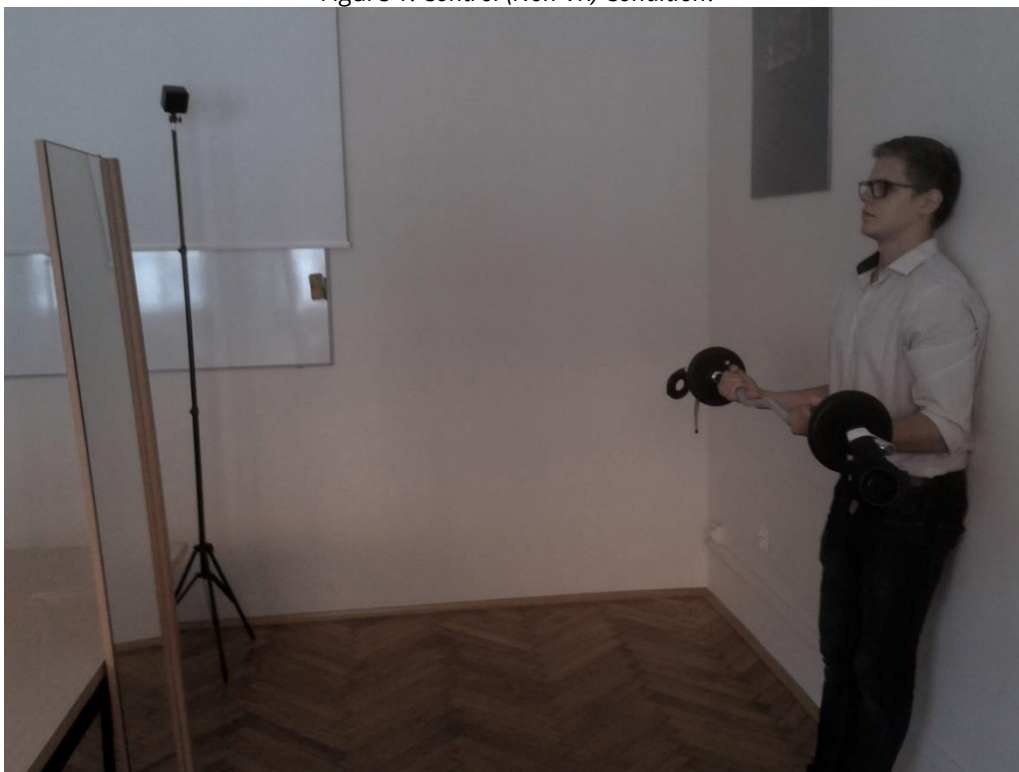
Non-VR (Control) Condition

After the introductory phase described above, participants assumed position in front of the mirror, with their buttocks and shoulder blades touching the wall to further ensure they would not lean back or forward, thus exercising other muscles groups, not the biceps (see Figure 1). Participants were instructed to perform as many correct repetitions of the biceps curl as possible, without moving their buttocks and shoulder blades away from the wall.

The experimenter counted the number of repetitions. In order for a repetition to be counted, the participant had to perform the entire range of movement (i.e., elbow joints fully extended in the starting position, bar held still for a second, and then full contraction of the bicep muscle; bar kept at shoulder level).

The exercise/measurement was stopped when participants declared that they could not perform another repetition, or if experimenter noted that three total repetitions (not necessarily subsequent repetitions) had been performed incorrectly. After stopping the exercise, participants filled in their Borg rating of perceived exertion, judged the perceived weight of the barbell, and performed a cool-down stretching procedure to minimize muscle soreness.

Figure 1. *Control (Non-VR) Condition.*



VR Condition

The procedure for the VR condition was very similar to the one described earlier. Participants were additionally told that the study's purpose was to investigate exercise and motor coordination in VR. No hints were given regarding the real focus of the study (i.e., embodiment of the virtual muscular body).

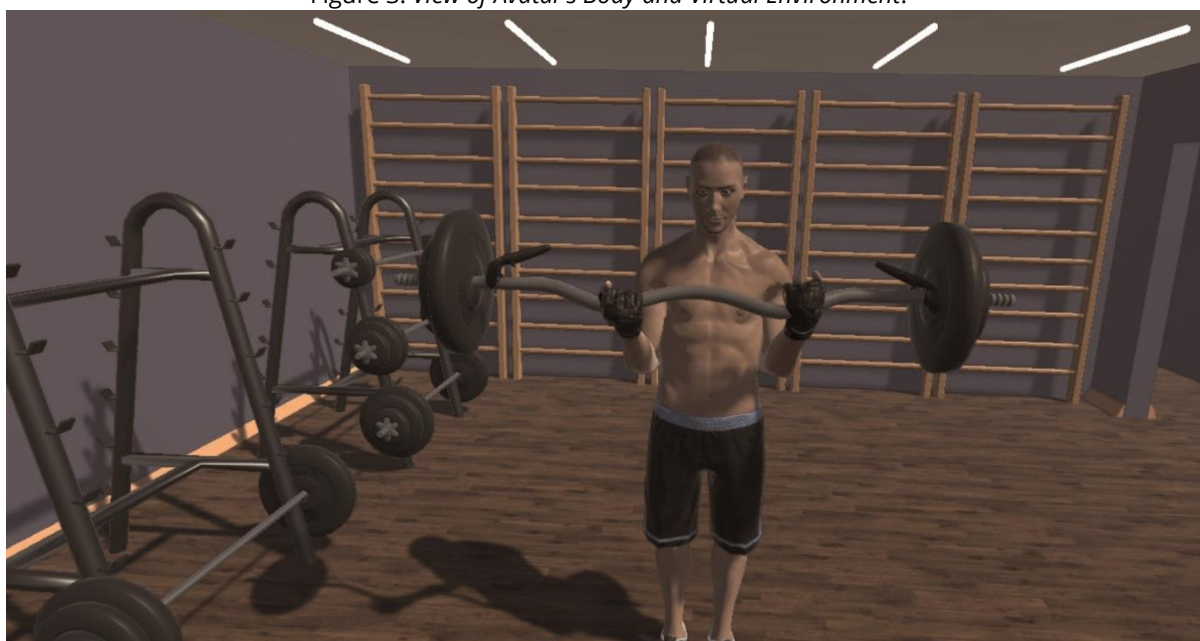
After instructions and warm-up, participants were immersed in VR, assumed correct body position near the wall, and saw the virtual body in front of a virtual mirror (see Figures 2 & 3). Then, they were given a physical barbell and performed bicep curl repetitions using the identical procedure as in the control condition. After finishing the

exercise and removing the Head Mounted Displays, participants completed their Borg rating, reported their perceived weight of the barbell, and assessed their perceived embodiment of the virtual body.

Figure 2. *VR Condition.*



Figure 3. *View of Avatar's Body and Virtual Environment.*



Statistical Analyses

Statistical analysis was performed using the R statistical programming language. Because the distributions of the dependent variables deviated significantly from normal, we used non-parametric statistics to conduct the hypothesis testing (Wilcoxon signed-rank test). P-values are reported without applying correction for multiple comparisons. A bootstrap method was used to compute effect sizes with 95% confidence intervals. This was done with the bootES package for R (Kirby & Gerlanc, 2013).

Results

Descriptive statistics for the dependent and control variables are presented in Table 1. H1 was confirmed: The number of bicep curl repetitions differed significantly between the VR and control conditions, $Z = -2.05$, $p < .05$. The unstandardized effect size was 3.5, 95% CI [-0.1, 6.9], which means that participants were performing on average 3.5 more bicep curls in the VR condition than in the control condition. Cohen's d was 0.36, 95% CI [-0.05, 0.7], which means that 64% of participants in the VR condition performed a higher number of bicep curls than the average for the control condition. Figure 4 shows the distribution of differences in the number of repetitions between the VR and control conditions (a negative value means the participant performed more bicep curls in the control condition).

H2 was not confirmed: There was no significant difference between the VR and control conditions for ratings on the Borg scale, $Z = -1.56$, $p > .05$. However, the direction of the difference was in agreement with H2, and the effect size was $d = 0.27$, 95% CI [-0.17, 0.73]. Borg scale results were not correlated with the number of exercise repetitions in the VR condition (Spearman's $r = .01$) or in the control condition ($r = -.13$).

Baseline blood glucose level was $M = 101.8$, $SD = 11.8$ in the VR condition, and $M = 106.7$, $SD = 12.1$ in the control condition. Baseline blood glucose levels did not differ significantly between conditions, $Z = 1.17$, $p > .05$. Thus, it is unlikely that the difference in bicep curl repetitions was a reflection of random factors like activity level that day or meals consumed before the exercise.

Reported level of virtual embodiment was: $M = 3.83$, $SD = 2.10$. Male participants reported higher BOI level than female participants ($M = 4.06$ for males, and $M = 3.5$ for females) although this difference was not statistically significant ($W = 90$, $p > .05$).

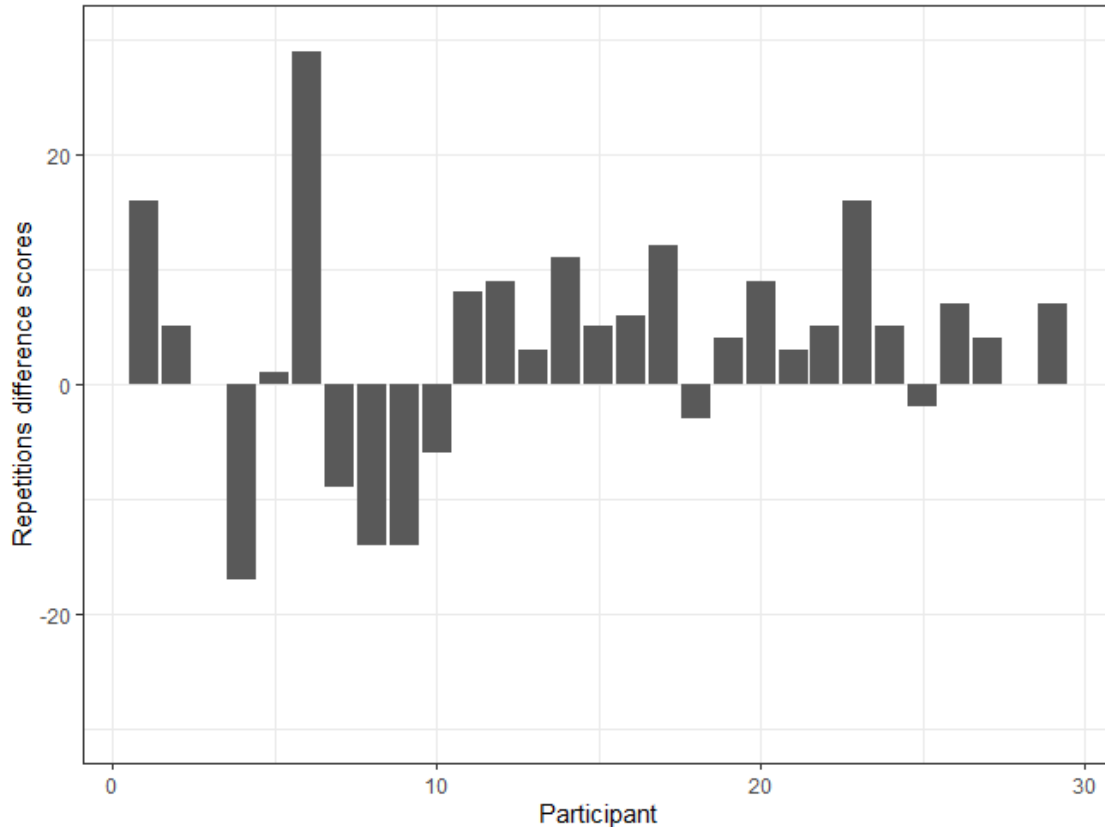
Correlation between exercise repetitions and BOI was not significant ($r = .16$). Similarly, correlation between Borg scale results and the BOI was not significant ($r = .17$).

The correlation between the simple effect size for each participant (the difference between VR and control in the number of repetitions) and BOI question responses was not significant ($r = .14$). This analysis was performed to test if changes in performance across experimental conditions are related to BOI. The term 'simple' or 'unstandardized' effect size is used to describe raw difference in scores between conditions. Simple effect sizes, because they are measured in meaningful units (in this case - exercise repetition numbers) are easier to interpret, and their use is often recommended (Baguley, 2009).

Similar analysis was performed for changes in perceived effort (Borg scale results) and BOI. The correlation between simple effect sizes on Borg scale and level of BOI was not significant ($r = .19$).

The perceived weight of the barbell did not differ significantly between the conditions, $Z = 1.24$, $p > .05$, which means that the difference in bicep curl repetitions could not be explained by the fact that the barbell seemed heavier in one condition compared to the other.

Figure 4. Differences in the Number of Repetitions Between VR and Control Conditions.



Note. Positive values mean participants made more repetitions in the VR condition.

Table 1. Repeated Measure Analysis Summary.

	VR	Control	Z
Number of repetitions	59.48 (35.12)	56.03 (32.62)	-2.05*
Borg's scale	13.83 (3.06)	14.14 (1.32)	-1.56
Perceived mass of the curl bar	10.56 (3.98)	11.586 (5.36)	1.24
Blood glucose	101.8 (11.8)	106.7 (12.1)	1.17

Note. * $p < .05$. VR and Control columns contain mean values and standard deviations (*SD* in parentheses).

Discussion

Participants did more bicep curl repetitions in the VR condition than the non-VR control condition. However, self-reported effort did not differ between the conditions, and there were no correlations with the embodiment question. There are several possible explanations for this pattern of results. First, exercise repetitions and perceived effort are interrelated. We would expect effort to increase together with the exercise load. However, in this study, participants did more bicep curls in the VR condition, but this was without a corresponding increase in perceived effort.

Contrary to our predictions, correlations between the BOI question and the dependent variables (perceived effort and number of repetitions) were not significant. While this may mean that the effect on the number of repetitions could be explained by other factors than BOI, certain limitations of the method we used to measure embodiment must also be taken into account. Despite arguments regarding single-item measurement of presence, the reliability and validity of single-item measurement of BOI have not yet been confirmed.

Therefore, body ownership results of this study should be treated as preliminary. The primary outcome variables were number of biceps curl repetitions and self-perceived effort.

Using a single item measure of BOI has several advantages, which were discussed in the Methods section. However, limitations of such measurement method also exist. Single item measure can assess only one specific aspect of a broader experience of embodiment – e.g., feelings of ownership over a virtual body.

Phenomenology of embodiment is more complex than just feeling of ownership. Longo et al. (2008) used a psychometric approach, and analysed structured introspective reports of rubber hand illusion (RHI) experiences. The authors found four major components of the experience - apart from embodiment, participants reported also experiences related to the loss of own hand, sensations of movement, and affective reactions. Embodiment component itself could be divided into three subcomponents – ownership, location and agency.

Although Longo et al. (2008) study was based on RHI, the concept of BOI is very closely related, and it is possible that aspects of embodiment other than ownership may influence participants' behavior during VR based exercising.

Lack of significant difference in self-perceived effort may also be explained by too small sample size. Referring to previously published studies, we conducted power analysis assuming a large effect size. Therefore, if the effect of experimental condition on self-perceived effort was smaller, it might have not been detected in this study.

With current design, we cannot exclude the possibility that VR by itself, and not the embodiment was responsible for the effect. It is possible that VR modality shifted participants' focus away from their body sensations and toward performing the movement. Such shift in attentional focus was shown to improve performance in weightlifting exercises (Neumann, 2019).

Also, perceived similarity of the avatar and the participant was not measured. The level of similarity might have affected outcome variables – for example by participants more strongly embodying an avatar perceived as similar.

There is substantial literature published on attention distraction from pain using VR technologies, both in experimental pain paradigms and various clinical populations (Hoffman et al., 2008; Jones et al., 2016; Malloy & Milling, 2010; Tashjian et al., 2017; Wender et al., 2019). However, in these studies, VR was used to shift attention away from painful contexts, while in our experiment, the virtual environment was reflecting the pain-inducing exercise, which makes the attention distraction explanation less likely.

Further research with more VR and no-VR conditions needs to be conducted in order to clarify the effect of VR modality. Such research programme should include studies testing presence or absence of a virtual body in the VR, and presence or absence of mirror-based feedback, both in VR and non-VR conditions. In order to get more precise data regarding the effect of a muscular virtual body, the embodiment of a slim/skinny avatar should be used as an "active control" condition. In such a design, only visual cues related to the strength of a virtual avatar would be manipulated (muscular-strong vs. skinny-weak), so the effect of experimental conditions, if observed, could be attributed to the virtual body and not the VR medium by itself.

However, even if the effect of this study was not driven by embodiment of muscular avatar, our results still hold practical value and point to the possibility of novel training protocols. Presumably, any virtual environment used for such training will include some form of virtual body and virtual weights, since visual feedback is crucial for the correct performance of free weight exercises. The results of our study show that such setup is not only feasible with real training protocols, but also holds the possibility of enhancing performance.

Lastly, in this study, we specifically focused on people who did not perform strength training regularly. In untrained persons, exercise protocols with lower weight but more repetitions lead to similar neuromuscular adaptations as protocols with higher weight and fewer repetitions (Chestnut & Docherty, 1999). Methods that increase the maximum number of exercise repetitions may be especially useful in the context of rehabilitation or training protocols designed for the elderly, considering that exercising with lower weight is safer (i.e., lower risk for accidents and decreased severity of accidents).

Conclusions

Results of this study show that VR can be effectively used together with free weight exercise protocols and increase performance in such exercises. We believe that the results of this study are useful from an applied perspective, given that free weight exercising is often recommended over machine-based weight lifting (Schick et al., 2010; Schwanbeck et al., 2009), and that the number of exercise repetitions is an ecologically valid measure, directly relevant to real training protocols.

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