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Technical Note

Muscle Activity During Immersive Virtual Reality Exergaming Incorporating an Adaptive Cable Resistance System

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ABSTRACT

International Journal of Exercise Science 15(7): 261-275, 2022. The purpose of this exploratory study was to characterize muscle activation via surface electromyography (sEMG), user-perceived exertion, and enjoyment during a 30-minute session of immersive virtual reality (IVR) cable resistance exergaming. Ten healthy, college-aged males completed a signature 30-minute exergaming session using an IVR adaptive cable resistance system that incorporated six traditional compound exercises. Muscle activation (sEMG) was captured during the session with a wearable sEMG system. Rated of Perceived Exertion (RPE) and Physical Activity Enjoyment Scale (PACES) were recorded following the session. Pectoralis major showed the highest activation during chest press, deltoids showed the highest activation on overhead press, latissimus dorsi showed the highest activation during lat pulldown and row exercises, hamstrings were the most activated muscles during Romanian deadlift, and glutes showed the highest activity during squats. RPE and PACES mean scores were 14 (1) and 4.27 (0.38), respectively. IVR exergaming with resistance cable training provides an enjoyable experience and distracts practitioners from exertion while exercising at a high intensity. Results from this study suggest similar muscle activation responses compared to traditional resistance exercises as demonstrated with prior evidence. This novel form of exercise might have important repercussions for improving health outcomes among those who find it challenging to adhere to and enjoy exercise routines, as well as with little knowledge on how to progress in their resistance training. Further investigations are needed to explore long-term adaptations and to assess if IVR exergaming has additional benefits compared to traditional resistance training.

KEY WORDS: Gamification, resistance training, adaptive resistance, AI resistance, exercise, electromyography

INTRODUCTION

Physical activity has shown beneficial effects on 23 diseases or health conditions, including reduced risks of cardiovascular diseases, reduced risks and improved outcomes for a variety of cancers, improved immune function, enhanced cognition and memory, improvements in mental health, higher overall quality of life, and promotion of healthy aging (47). However, trends in physical inactivity continue to persist, even though leading organizations have increased efforts in bringing attention to this foremost issue (8, 24, 64). Due to the underappreciated toll physical inactivity takes on health and quality of life, it is essential to explore systems that might encourage those who still refuse to include physical activity into their everyday life (34). Although lack of time is commonly reported as a barrier towards physical activity (6, 9, 25, 29), a recent survey from the CDC reported that Americans have more than 5 hours of free time per day, making this barrier unconvincing (57). Lack of motivation and enjoyment, however, appears to be a more plausible reason, where gamifying physical activity might be a solution for certain populations (14, 48).

One attempt to make exercise more enjoyable is "exergaming," a term used to describe the integration of video gameplay into exercise training (4, 54). While exergaming was introduced early in the 1980s, it has reemerged due to the recent development and application of immersive virtual reality (IVR) technology which employs body sensors and head-mounted displays to create three-dimensional environments (59). This novel form of exercise has surpassed the ability of traditional screen-based exergaming to elicit motivation, compliance, and training outcomes (3, 11, 13, 35, 36, 42, 51, 65). Although these platforms have been classified as light/moderate intensity exercises, they have yet to integrate resistance exercise (51, 61). According to the American College of Sports Medicine (ACSM), resistance exercise is important for developing and maintaining musculoskeletal and neuromotor performance (21), which has a direct impact on overall health including functional independence, cognitive abilities, and self-esteem (63).

A recent investigation from our laboratory assessed an IVR device that integrated cable resistance training and found not only a substantial metabolic demand that meets the ACSM vigorous exercise requirements (27, 46) but high ratings of enjoyment that seemed to distract users from perceived exertion (27). The masking effect on perceived effort can be an inflection point for training, as vigorous or heavy resistance training is often avoided in a wide range of populations due to the uncomfortable feelings of intense exertion (23, 38, 40, 56). In addition, it has the potential of improving rehabilitation protocols, as IVR also distracts patients from perceived pain (26, 55). To the best of our knowledge, there are no studies assessing the musculoskeletal implications of these novel adaptive resistance devices. Obtaining a more comprehensive understanding of how this system works through examining the muscle activation profiles can guide future comparisons with traditional resistance exercises. Therefore, the purpose of this study was to characterize muscle activation via surface electromyography (sEMG), and evaluate perceived exertion and enjoyment during a 30-minute session of IVR cable resistance exergaming.

METHODS

Participants

Ten college-aged males (aged 20 - 26 years) were recruited from the University of California, Los Angeles (UCLA) campus through word of mouth. Inclusion criteria included apparently healthy and physically active participants that have engaged in resistance training exercise at least twice weekly for the past three months, while exclusion criteria included the presence of musculoskeletal, cardiovascular, pulmonary, metabolic, or other disorders that would preclude moderate-to-high intensity exercise participation and testing. Due to the non-existence of surface EMG-upper body compression garments for females, the primary outcome variable, only male participants were included. All participants provided written informed consent at the beginning of the study. This research was approved by the UCLA Institutional Review Board and carried out fully in accordance with the ethical standards of the Helsinki Declaration. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (44).

Table 1. Basic demographic and anthropometric data

	Mean ± SD	Range
Age (y)	23 ± 2	20 - 26
Height (cm)	179.1 ± 6.3	170.2 - 188
Weight (Kg)	75.9 ± 8.4	63 - 95
Body fat (%)	11.0 ± 4	4.4 - 17.5

Protocol

The novel IVR exergaming system (Black Box VR, Boise, ID) consists of a servo-based electromagnetic dynamic resistance mechanism, a head-mounted display (HMD) (HTC Vive Pro, Taipei, Taiwan), an automated support pad, and a pair of resistance handles that automatically adjust up and down on articulating carriages to the correct exercise position based on participant's height. The HMD enables the synchronization between the user's actions and the IVR gameplay. The progression algorithm models adjust and prescribe the correct weight during the exercises for each user in-and-between sessions. According to the manufacturer, these adjustments are possible by integrating data such as rep length, time, power, weight, volume, and concentric and eccentric min/max, among others.

The IVR exergame is similar to traditional tower defense, a subgenre of strategy video games where the goal is to defend a player's territories or possessions by obstructing/eliminating the enemy attackers. The resistance exercises (i.e., lat pulldown, chest press, row, overhead press, stiff leg or Romanian deadlift, squat) are linked to in-game attacks and used for defensive and offensive actions (Figure 1). Players can select any of those exercises to perform but are encouraged to choose exercises of a certain category to have the most success in their counterattack. The element match-up aspect of this IVR exergame reduces the user's freedom of choice in selecting which exercises to perform and in what order. However, freedom of choice and individual gameplay strategy are still present and integral to this immersive exergaming experience.

Muscle activation was recorded using an sEMG system embedded into athletic compression garments (Athos, Redwood City, CA, USA) that captured data at 1kHz. A portable device acquired the sEMG signals that clips into the garment, processed, and paired to a mobile application on an iPad 8th generation (Apple, Cupertino, CA, USA) for presentation to the investigator. This novel technology has been previously compared to research-grade systems, and enables muscle activity recordings that have shown to be valid and not statistically different to the gold standard ($x^2 = 0.65$, $p = 0.42$; $r = 0.69 – 0.71$) and reliable (CV = 18.7 – 26.7%) without skin preparation (39). The sEMG compression garments were fit to each participant to ensure the electrodes embedded in the garments were directly on the surface of the skin of the following muscles: vastus medialis, vastus lateralis, biceps femoris, gluteus maximus, latissimus dorsi, pectoralis major, anterior and posterior deltoids, biceps brachii, and triceps brachii. Anthropometrics were recorded to determine the appropriate sEMG gear size, as well as for descriptive statistics. Hip and waist circumferences were measured with a tape measure (Nutriactiva, Minneapolis, MN, USA). Height was measured using a precision stadiometer (Seca, Hanover, MD, USA), and body mass and percentage body fat via a validated multi-frequency, multi-segmental bioelectrical impedance device (270; InBody Co., Seoul, South Korea) (16).

Two questionnaires were assessed post-exercise. The Borg 6 - 20 scale was used to measure the rate of perceived exertion (RPE) (5) and it has been previously correlated with heart rate (66). Enjoyment of the exergame was measured using the Physical Activity Enjoyment Scale (PACES). This questionnaire consists of 16 items scored on a scale from 1 (strongly disagree) to 5 (strongly agree) to determine the participant's level of physical activity enjoyment. A high overall mean score correlates with a high level of enjoyment. PACES results have shown acceptable internal consistency (32).

In the first visit to the lab, participants (*i*) observed an IVR exergaming familiarization session (a twelve-minute instructional video of the training session); (*ii*) were fitted with the HMD and wrist sensors, and (*iii*) were measured for standard anthropometric measurements. An initial habituation phase of fourteen successive 30-minute sessions, no more than three times weekly over five weeks, was implemented to control for the effects of exergaming expertise. This also enabled participants to practice the resistance exercises integrated within game strategy and acclimate to the virtual reality environment.

Following this habituation phase, participants were asked to come euhydrated, avoid heavy meals three hours before the session, and abstain from exhaustive activity 24 hours before testing. Upon arrival to the lab, participants were instrumented with the HMD, wrist-worn sensors, and sEMG compression garments. The sEMG compression garments were then individually calibrated to each participant to obtain the maximum isometric voluntary contraction (MVIC). Three attempts of five seconds were done for each muscle group. Since each muscle group was measured bilaterally, the side with the highest amplitude was used for real-time visualization on the app and posterior analysis. Following the successful calibration of the garments, the exercise session was initialized on the mobile application of the sEMG system simultaneously with the initialization of the IVR exergame (Figure 1). Immediately following the testing session, questionnaires on perceived exertion (BORG) and enjoyment (PACES) were assessed.

Figure 1. Participant donning the HMD and wrist-worn motion sensors during the IVR exergaming session while simultaneously being measured by an Athos compression suit embedded with an integrated sEMG measurement system. iPad displaying Athos app with real-time muscle activation via graduated shades of %MVIC (i.e., yellow to orange to red indicates low to moderate to high, respectively).

Statistical Analysis

The sEMG output for both systems was obtained from the raw sEMG signal following Athos' processing and filtering (linear bandpass filter at 120Hz, linear notch filter at 60Hz, and rectification). This process also included averaging both sides, as well as combining two group muscles: data recorded from vastus medialis and lateralis was combined and reported as quadriceps, and anterior and posterior deltoids were reported as deltoids. Relative muscle contribution for each muscle group during each exercise was quantified by computing the area under the curve of each exercise repetition, averaging repetitions during one specific exercise, summing all the muscle averages, and dividing by one specific muscle group average to obtain a percentage. The muscle that presented the highest muscle activity on each exercise was normalized using MVIC, which represents %MVIC relative to the maximal contraction performed during calibration. Mean %MVIC for each exercise's quartiles were calculated to examine the signal over time. Total training volume (kg) was provided by the IVR cable resistance exergaming system and split by the number of sets per exercise, and average volume (kg) per set.

Statistical analysis was performed in SPSS v27.0 (IBM, NY, USA). Continuous variables were first assessed for normality via Shapiro-Wilk tests. As some of the data deviated significantly from normality, comparisons between the percent maximal voluntary isometric contraction (%MVIC) quartiles were made with the non-parametric Friedman's test followed by Nemenyi posthoc tests. All tests were two-tailed. Statistical significance was set at $p < 0.05$. Data is presented as mean (standard deviation (SD)).

RESULTS

Six different exercises were performed and analyzed: lat pulldown, row, stiff leg or Romanian deadlift, chest press, overhead press, and squat. Muscle contributions to each exercise can be found in Figure 2. During the lat pulldown and row exercises, the latissimus dorsi muscles were activated to the greatest extent contributing by 67% and 62%, respectively. The second greatest contribution for both exercises came from the biceps brachii with 17%. Performing a bench press and overhead press showed significant contributions from pectorals (72%) and deltoids (69%), respectively. Triceps brachii was the second contributor to bench press (10%), while pectorals contributed by 11% in the overhead press, followed by triceps (8%). Glutes, hamstrings, and quadriceps were activated to the greatest extent during squats and Romanian deadlifts. The hamstrings contributed the most to Romanian deadlifts (47%), followed by glutes (31%), and quadriceps (15%). During the squat, glutes were activated to the greatest extent (33%), closely followed by the hamstrings (29%) and then the quadriceps (28%).

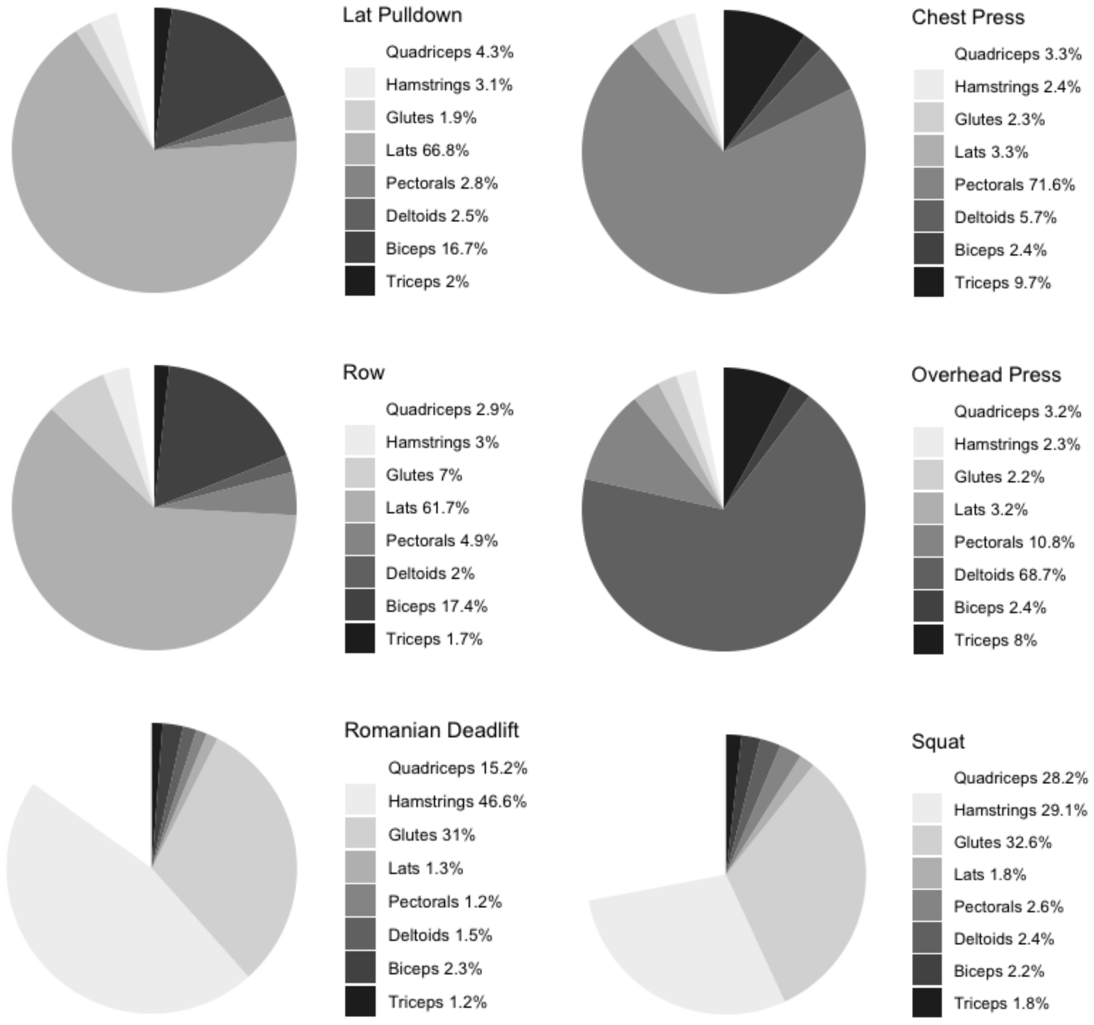

Figure 2: Muscle contribution to each exercise (normalized to 100%).

Muscle activation percentage (%MVIC) over the set time (% time) for the most activated muscle (i.e., prime mover) during each distinct exercise are represented in Figure 3 and Table 2. Friedman's analysis showed significant differences in muscle activity over time ($p < 0.001$) between quartiles in every exercise. Separated into four quartiles, each muscle group showed an increase in muscle activation from first to second quartile. Chest press, row, overhead press, Romanian deadlift, and squat presented the greatest activation (~100% MVIC) by the second quartile (25 - 50% set time) while lat pulldown highest activation came later in the set (3rd quartile, 50 - 75% set time). Following maximum activation in all exercises, a decrease in %MVIC in their respective muscles occurred to the end of the set (4th quartile).

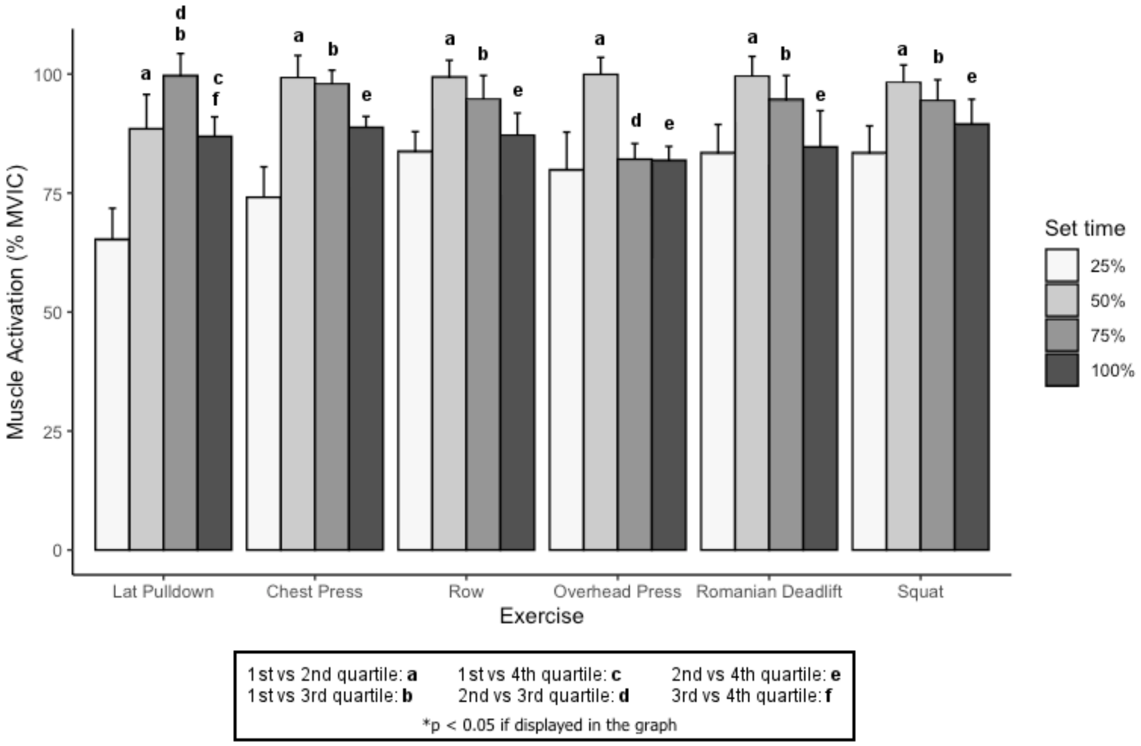

Figure 3: Muscle activation of the most activated muscle during each exercise over time: Latissimus dorsi for lat pulldown and row exercises, pectoralis major for chest press, deltoid for overhead press, hamstrings for Romanian deadlift, and gluteus maximus for squat. Bars and lines represent means and standard deviations, respectively.

Table 2: Posthoc comparisons of quartiles of the most activated muscle during each exercise. *p<0.05

Exercise	Quartiles	%MVIC (*SD*)		*p*	Cohen's *d*	effect-size *r*
Lat Pulldown (Lats)	1st vs 2nd	65.3 (6.5)	88.5 (7.2)	0.046*	3.38	0.86
	1st vs 3rd	65.3 (6.5)	99.7 (4.6)	< 0.001*	6.11	0.95
	1st vs 4th	65.3 (6.5)	86.9 (4.1)	0.046*	3.97	0.89
	2nd vs 3rd	88.5 (7.2)	99.7 (4.6)	0.046*	1.85	0.68
	2nd vs 4th	88.5 (7.2)	86.9 (4.1)	1.000	0.27	0.14
	3rd vs 4th	99.7 (4.6)	86.9 (4.1)	0.046*	2.94	0.83
Chest Press (Pectorals)	1st vs 2nd	74.1 (6.4)	99.2 (4.7)	< 0.001*	4.47	0.91
	1st vs 3rd	74.1 (6.4)	97.9 (2.9)	< 0.001*	4.79	0.92
	1st vs 4th	74.1 (6.4)	88.8 (2.3)	0.306	3.06	0.84
	2nd vs 3rd	99.2 (4.7)	97.9 (2.9)	0.954	0.33	0.16
	2nd vs 4th	99.2 (4.7)	88.8 (2.3)	0.022*	2.81	0.81
	3rd vs 4th	97.9 (2.9)	88.8 (2.3)	0.090	3.48	0.87
Row (Lats)	1st vs 2nd	83.8 (4.1)	99.4 (3.5)	< 0.001*	4.09	0.90
	1st vs 3rd	83.8 (4.1)	94.7 (5.0)	0.017*	2.38	0.77
	1st vs 4th	83.8 (4.1)	87.1 (4.7)	0.619	0.75	0.35
	2nd vs 3rd	99.4 (3.5)	94.7 (5.0)	0.619	1.09	0.48
	2nd vs 4th	99.4 (3.5)	87.1 (4.7)	0.017*	2.97	0.83
	3rd vs 4th	94.7 (5.0)	87.1 (4.7)	0.307	1.57	0.62
Overhead Press (Deltoids)	1st vs 2nd	79.9 (7.9)	99.9 (3.6)	< 0.001*	3.26	0.85
	1st vs 3rd	79.9 (7.9)	82.1 (3.3)	0.954	0.36	0.18
	1st vs 4th	79.9 (7.9)	81.9 (2.9)	0.954	0.34	0.17
	2nd vs 3rd	99.9 (3.6)	82.1 (3.3)	0.006*	5.15	0.93
	2nd vs 4th	99.9 (3.6)	81.9 (2.9)	0.006*	5.51	0.94
	3rd vs 4th	82.1 (3.3)	81.9 (2.9)	1.000	0.06	0.03
Romanian Deadlift (Hamstrings)	1st vs 2nd	83.5 (5.9)	99.5 (4.2)	< 0.001	4.12	0.84
	1st vs 3rd	83.5 (5.9)	94.7 (5.0)	0.046*	2.05	0.72
	1st vs 4th	83.5 (5.9)	84.7 (7.6)	0.954	0.18	0.09
	2nd vs 3rd	99.5 (4.2)	94.7 (5.0)	0.619	1.04	0.46
	2nd vs 4th	99.5 (4.2)	84.7 (7.6)	0.006*	2.41	0.77
	3rd vs 4th	94.7 (5.0)	84.7 (7.6)	0.160	1.55	0.61
Squat (Glutes)	1st vs 2nd	83.5 (5.6)	98.2 (3.7)	< 0.001*	3.10	0.84
	1st vs 3rd	83.5 (5.6)	94.4 (4.4)	0.046*	2.16	0.73
	1st vs 4th	83.5 (5.6)	89.5 (5.2)	0.726	1.11	0.49
	2nd vs 3rd	98.2 (3.7)	94.4 (4.4)	0.508	0.93	0.42
	2nd vs 4th	98.2 (3.7)	89.5 (5.2)	0.017*	1.93	0.69
	3rd vs 4th	94.4 (4.4)	89.5 (5.2)	0.402	1.02	0.45

Utilizing the Borg usability scale, each participant reported an RPE (rate of perceived exertion) value after the workout session and the average RPE score reported by participants was 13.6 (*SD* 1.3) which is categorized as "somewhat hard to hard" in regard to perceived full-body exertion. For the PACES enjoyment scale, the average score was 4.27 (SD 0.38) proving IVR to be an "enjoyable" experience for participants.

Participants collectively achieved their greatest volume on the squat exercise, with a mean lifted volume of 6,283 kg. This exercise also exhibited the highest standard deviation between participants at 2,711 kg. Meanwhile, the lowest mean volume and lowest standard deviation between participants were demonstrated for the overhead press exercise at 1487 kg (*SD* 479). A minimum of two sets per exercise were completed by each participant, with all participants exceeding this two set minimum for multiple exercises. The most-often performed exercises were lat pulldown, chest press, row, and overhead press (mean = 4 sets), and the least-often performed exercises were Romanian deadlift and squat (mean = 3 sets). Table 3 displays the average volume per set for each exercise, highlighting squat as the largest average volume per set observed at 2094 kg/set (*SD* 440). Overhead press proved to have the lowest average volume per set across all participants at 381 kg/set (*SD* 85). Finally, the mean total training volume of all exercises was calculated to be 23,174 kg per participant.

Table 3: Training volume of the workout by exercise. Means (SD)

	Volume (kg)	Sets	Average vol/set
Lat Pulldown	5082 (928)	4 (1)	1438 (272)
Chest Press	2983 (1209)	4 (1)	719 (186)
Row	4305 (1010)	4 (1)	1287 (434)
Overhead Press	1487 (479)	4 (1)	381 (85)
Romanian Deadlift	3234 (1464)	3 (1)	1128 (227)
Squat	6283 (2711)	3 (1)	2094 (440)

DISCUSSION

We believe this to be the first study to date characterizing myoelectric activity using an immersive virtual reality platform with integrated cable resistance. Six different exercises were analyzed via sEMG and compared to previous literature: lat pulldown, row, stiff leg or Romanian deadlift, chest press, overhead press, and squat. The main muscles engaged during chest press were pectoralis major (72%), triceps (10%), and deltoids (6%). However, previous research suggested that anterior deltoid has the greatest activation among all muscles involved during a bench press (43). The difference might rely on the position, as bench press with free weight requires a greater deltoid activity to stabilize the weight compared to exercising in a standing position with a cable machine. On the other hand, overhead press findings were consistent with previous research that reported the greatest contributions to deltoids and pectorals (15). During the squat exercise, glutes (33%), hamstrings (29%), and quadriceps (28%) were the major contributors. Although previous research might present variable data, it should be noted that squat depth is imperative in determining muscle activation, and therefore controlling for that measure is critical for proper comparisons (7, 10, 41). Romanian deadlift data, instead, was aligned with previous research that reported the greatest contribution by the hamstrings, followed by glutes, and quadriceps (33). Lastly, muscle contributions for both lat pulldown and row exercises were similar to the traditional exercises. Latissimus dorsi presented the greatest contribution followed by the biceps brachii (17, 20).

The data from the current study also revealed that every exercise recorded during the exergaming session showed a similar myoelectric activity pattern over time, which might reflect the effectiveness of the adaptive resistance to target muscle fatigue. This is worth noting because there was no input of desired resistance. The greatest sEMG amplitudes of the main muscles engaged in each exercise were achieved between 25% and 75% of the set duration, followed by a significant decline in the later quartile, 12.8% (*SD* 3.3) (Figure 3). Although it is not possible to establish a simple relationship between sEMG amplitude and force production for several reasons (62), previous studies reported higher mean sEMG amplitudes with heavy loads compared to light loads (22, 37). It has also been suggested that sEMG amplitude decreases when fatigue affects the ability to exert force (2, 31). Hence, changes in myoelectric activity still offer insight to muscle activation trends, and the decrease in myoelectric activity might be related to changes in resistance or fatigue during the IVR exergame. However, to further explore this outcome, we should first understand how adaptive resistance works.

According to the manufacturer, the IVR system's proprietary algorithm constantly analyzes the load, repetition length, force, and speed of execution, adapting the cable resistance to push the participant near muscle failure at the desired repetition range. The resistance is adjusted so that users selecting light, medium, and heavy intensity levels perform a maximum number of 24, 13 - 25, and 9 - 13 repetitions, respectively. Reaching muscle failure does not elicit greater muscle activation than getting close to it (50). In addition, it may not provide additional benefits either and often induces excessive fatigue and mechanical stress (12, 28, 49). Therefore, the algorithm optimizes training near muscle failure while maintaining 2 - 3 repetitions in reserve (RIR). The consistent pattern of sEMG amplitude found in this study might reflect the effectiveness of the algorithm when prescribing loads and there are a few reasons to support this. Every exercise-induced maximum activation of the main muscle involved (~100% MVIC), which has been suggested to occur 3 - 5 repetitions before muscle failure (58). If we take into account those repetitions, we could hypothesize that muscle failure would happen slightly after 75% of the set duration, leaving practitioners unable to finish the set. That said, it can be speculated that the algorithm is pushing you near muscle failure and adjusting the resistance afterward to fulfill the desired repetition range, which is important to maximize the total volume. Consequently, the decrease of sEMG amplitude following the peak in %MVIC could be indicative of the reduction in resistance, apparition of fatigue, or both. These findings are relevant for novel or recreational practitioners who lack knowledge in resistance exercise programming.

Although previous research attests that total volume and its progressive overload are important factors for amplifying strength and hypertrophy improvements (45, 52, 53), this progression requires people to have an internal drive for pushing themselves to exercise harder over time. However, the reality is that physical exertion is often claimed as one of the greatest barriers to exercising (23, 38, 40, 58). Thus, finding exercise modalities that encourage high intensities while distracting participants from the perceived exertion could be a potential approach to overcome these barriers. The data from this study is consistent with our prior study that characterized physiological and metabolic demands of this technology (27), and reinforces the ability of IVR cable resistance training to attenuate perceived exertion. The dissociative focus of attention caused by the IVR exergaming's multisensory stimuli distracts exercisers from the unpleasant, fatigue-related sensations, resulting in a lower RPE than their heart rate suggests (19). Similar effects can be found with music (30, 60). However, dissociative strategies have been reported as effective tools in novel and recreational sports practitioners, but less powerful with athletes who might get more advantage from high levels of awareness (1). Participants in this study also reported an enjoyable experience while exercising at a high intensity and, although there was no control group, this finding was similar to a previous study that described increased enjoyability and self-motivation in IVR compared to non-immerse VR or traditional exercise (36). With the ability to provide a high intensity demanding exercise regimen that distracts from fatigue, is enjoyable, and potentially improves long-term exercise adherence, further investigations are certainly needed to assess the real-world applications of this technology and if it provides additional self-motivation particularly in those who find hard to adhere to exercise programs. Future studies should also focus on changes in strength and body composition when comparing long term traditional resistance training to IVR cable resistance training.

The present study has limitations. Assessing sEMG activity during different exercises helps generate hypotheses and gain insight into the neuromuscular system, but EMG activity does not necessarily imply greater motor unit recruitment, changes in force development or fatigue, neuromuscular adaptations, or differentiation between muscle fiber types (22, 62). Nevertheless, it allowed us to perform a preliminary comparison of muscle recruitment during IVR cable resistance exercises and better understand the adaptive resistance. However, it was not possible to obtain the evolution of the cable resistance during the set, as the software only provided the average resistance per set (Table 3). Collecting data from the same exercises but performed in the traditional form (without IVR), along with real-time data from the adaptive resistance, would help to make a more rigorous comparison and obtain a better understanding of the adaptive resistance progression and its relationship with fatigue.

Exergaming might be a feasible option for improving physical health and adherence to exercise among their users. Results from this study suggest similar muscle activation responses compared to traditional resistance exercises as demonstrated by prior evidence, and reinforce the ability of an IVR exergaming system to make practitioners exercise at a high intensity while distracting them from the high demands of the exertion. This might have important repercussions for improving and promoting health outcomes, especially among those populations that find it challenging to adhere to and enjoy exercise routines. Further investigations are needed to assess if IVR exergaming has additional benefits compared to traditional resistance training.

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