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Force Feedback-Based Gamification: Performance Validation of Squat Exergame Using Pneumatic Gel Muscles and Dynamic Difficulty Adjustment

Priyanka Ramasamy[1], Gunarajulu Renganathan[1] and Yuichi Kurita[1]

Abstract*—Exergames have been considered an advanced approach for enhancing the physical activities of the elderly community. Advancement includes greater immersive and enjoyment factors, which compute performance validation and sustain engagement to activate them from sedentary lifestyles. As a result, an at-home-based game design combined with squat workouts is essential to enhance lower-limb performance. We designed a virtual reality (VR) based exergame with dynamic difficulty adjustment (DDA) conditions in which the speed of the moving objects and air pressure of the PGM vary with respect to the knee shakiness feature. This letter aims to estimate the muscle loading and unloading effects of exergaming sessions at the onset and during the squat phase of the squat cycle. We acquired surface electromyography (sEMG) of five major lower limb muscles for seven subjects to evaluate the significant reduction in muscle activity during conventional and exergame-based squat sessions. In addition, we assessed the knee indicators to identify the variation in motion performance. The subjects performed 120 squats per session, followed by a maximum voluntary contraction (MVC) task. No adverse events, such as fatigue and dizziness, were reported during the study. Our results show a higher significant p<0.01 muscle activity difference for all tested muscles. We also found that knee shakiness showed a statistically significant reduction of p<0.01 during exergaming sessions (2 and 3) compared to the conventional squat.

***Index Terms*—Human performance augmentation, physically assistive devices, exergames, soft material robotics, pneumatic actuators.**

I. INTRODUCTION

PHYSICAL health management is fundamental to leading a healthy and independent life while reducing the need for frequent visits to healthcare and rehabilitation facilities. To achieve this, healthcare professionals and other experts in medical fields recommend home-based physical rehabilitation training for patients, elders, and even healthy people. Many situations, such as aging and extended working hours can result in negligence in doing physical activities, causing chronic diseases and malfunctioning of the primary organs of the human body, which mainly affect the lower extremities. Hence, medical experts suggest adapting to the newly accepted at-home physical training and rehabilitation technologies that combine exercise and gaming modules to increase motivation for all age groups [1]. In an era of a growing elderly population, the devices integrated with gaming features and exercises prospectively improve physical and mental health [2].

Integrating such user-centered gaming objects with the immersive environment could eventually act as a driving force to develop several physical training modules [3]. The study [4] implies the significance of introducing optimized difficulty levels featuring computational and systematic demands. The illusionary-based force feedback system proposed in [5] generated an imaginary movement through an immersive experience for training the lower limb muscles in the stair climbing situation. The stimuli from artificial muscles create force intensity, while the VR space provides the atmosphere of visual interaction with lower limbs for ascending the stairs.

The squat is an effective exercise for improving the functioning of the lower limb regions such as the back, core, thighs, etc. It is broadly accepted for training individuals in the fitness and sports communities. However, it is hard to define its effectiveness since the squat posture and depth are not fixed during power-strengthening exercises. Several types of research explain the different types of squat depths based on the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) forces. This study recommends a broad perspective on the relationship between upper and lower limb kinematics (knee distance $\geq$ shoulder width) and unrestrained knee movements during squatting. The study [6] ensures the natural foot positioning method maximizes hamstring activation in both free and weighted squats. Some practices of half squats were prevented from being used during performance enhancements due to increased pain and discomfort after the training [7].

Locomotive risks most commonly occur with people who ignore physical exercise and poorly manage their physical health. A subsequent and timely assessment is mandatory to gain knowledge of periodic health status. Our previous study [8] involved an artificial neural network (ANN)-based

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[1] P. Ramasamy, G. Renganathan and Y. Kurita are with the Graduate School of Advanced Science and Engineering, Hiroshima University, Hiroshima 739-8527, Japan (email: priyankar@hiroshima-u.ac.jp; m216365@hiroshima-u.ac.jp; ykurita@hiroshima-u.ac.jp)

This letter has supplemental downloadable multimedia material available at http://ieeexplore.ieee.org, provided by the authors. The Supplementary Materials contain a demonstration video of exergame-based training explained in this paper. This material is 27.7MB in size.

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real-time evaluation that determines the lower limb scores based on the input parameters of squat features and one-leg standing scores. In contrast, the output parameters include the scores of three Short Test Battery Locomotive Syndrome tests (STBLS): the sit-stand test, the two strides test, and the geriatric locomotive function scale (GLFS-25). From this study, we have obtained the idea of estimating joint angles through a depth camera via the Nuitrack library for a conventional squat session. Stealth-adaptive exergame design (SEAD), was developed based on the three characteristics of posture, pace, and progression of squat performance. It is also considered as the preliminary investigation to design the difficulty adjustment algorithm for our current study [9].

The former work [10] represented the implementation of a squat exergame with variable load based on the number of PGMs to actuate according to the user's risk level. This limits the load adjustment based on the difficulty level and quantity of force applied throughout the session whenever assistance or resistance is required. Therefore, we developed this exergame design to overcome the above limitations and manage posture and depth to reduce injuries while performing deep squats. Moreover, the system limits the evaluation of the appropriate assist and resist muscle groups for the squat exergame exosuit development. This might help in determining multiple muscle groups and the development of subject-specific exergame models and corresponding PGM exosuits.

In this research, we discuss the performance evaluation of the exergame using squat movements. The performance estimation quantifies the gaming session's muscle activity patterns compared to time-controlled deep squats. The EMG-based assessment is crucial in defining the control strategies and identifying the control points of PGMs in developing full lower limb suits to propose well-optimized dynamic difficulty adjustment (DDA) algorithms. The evaluation also covers the estimation of the knee features, describing the significant difference in acquired parameters. Section II discusses squat biomechanics, the PGM and its role in varying the difficulty level, the DDA condition evolution, the control block for actuating the PGMs, and EMG configuration. Section III discusses the study protocol, user sessions, and findings from the statistical analysis of the muscle activity patterns and knee features. Section IV presents the discussion, and Section V explains the conclusion and future work.

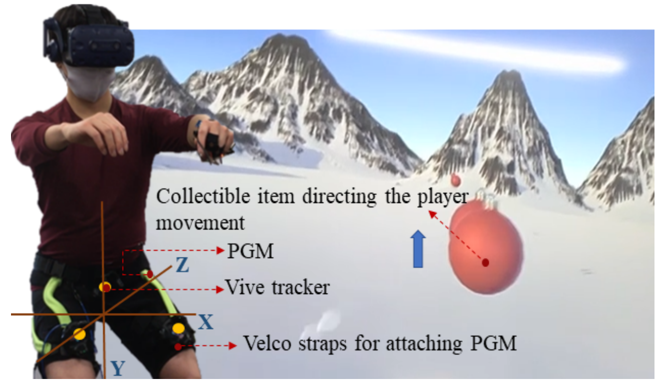

Fig. 1: The exergame sample scene illustrating the units used in the study where x, y, and z represent the sagittal, transverse, and frontal axes for the user's movement in the specified direction.

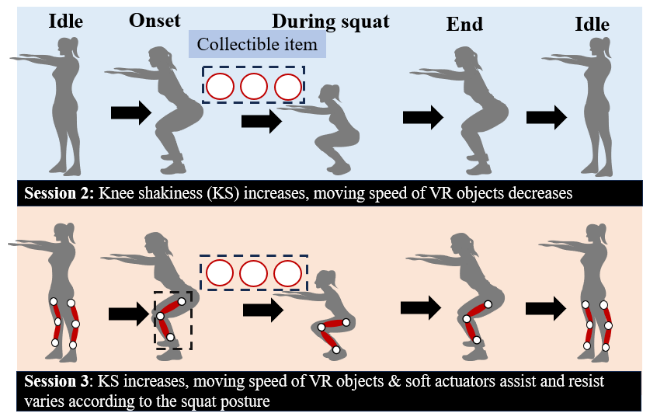

Fig. 2: Different phases of squat considered during the exergame training sessions 2 and 3.

II. METHODOLOGY

This section details the system components involved in designing the squat exergame model. It also provides information on the squat phase detection and optimization of the game difficulty through pneumatic actuators with an efficient control system.

A. Biomechanics of Squat Cycle Based on the Exergame Scenario

The proposed exergame module created using the UNITY introduces an immersive VR environment while utilizing the HTC Vive VR headset. The Vive trackers were used to monitor the movement of lower extremity joints. The knee trackers were attached just above both knees: left knee (x_{lk}, y_{lk}, z_{lk}), right knee (x_{rk}, y_{rk}, z_{rk}) and the torso tracker (x_t, y_t, z_t) was placed above the abdomen. The placements were based on the three axial points of sagittal (x), transverse (y), and frontal axes (z). The placement of the head mount display (HMD) (x_h, y_h, z_h) also plays a significant role in defining the different phases of the squat. The joint angles obtained from these trackers were used to compute the knee shakiness (KS), which decides the game difficulty level. Fig. 1 represents the sample scene with a VR interface.

The user height was used to calibrate the vive trackers. The squat phase detection parameters detailed in Fig. 2 were calculated based on the calibrated position values obtained from the vive trackers and HMD. The metrics used for detection are detailed below:

Idle: The user is standing still facing hands parallel to the ground. Threshold range= (HMD position $<$ torso threshold value)

Onset: The user is initiating the squatting movement by flexing the knees. Threshold range $=$ (torso position $>$ (left knee position $-$ 0.15) and torso position $<$ (left knee position $+$ 0.15))

During squat: The user performs the parallel squat or deep

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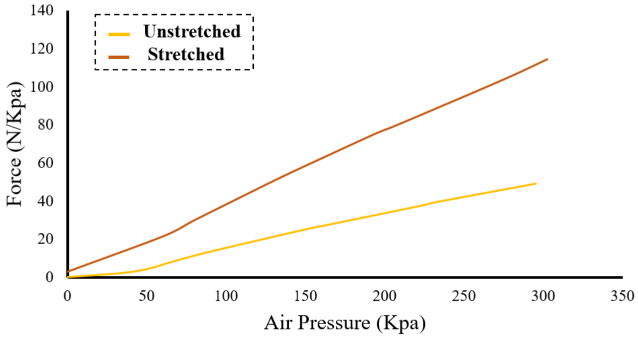

Fig. 3: Air pressure-force modeling of PGM characteristics for the 30cm natural length PGM with a stretched length of 37cm.

squat.

Threshold range = ((HMD position < head threshold value and torso position > (left knee position − 0.15) and torso position < torso threshold value)

End: The user returns to the idle phase.

Threshold range = (HMD position > torso threshold value)

We designed the DDA condition based on the above squat phases, which makes the user understand the importance of squat posture during gaming sessions.

B. Pneumatic Gel Muscle (PGM)

The PGM is a pneumatic actuator developed to be operated with a minimal compressed air range of 0.05 MPa to 0.3 MPa. The internal structure includes a soft tube made of a specific material: a styrene-based thermoplastic elastomer, to increase flexibility, and is externally guarded by a plastic mesh [11]. Compared with the conventional McKibben PAM, which demands a large quantity of air pressure to provide higher force, the soft nature of the inner tube in the PGM requires only the lower volume of air pressure mentioned above. This makes it a more suitable option for developing augmented motion-assist and resist suits because of its flexibility and soft nature. The PGM can deliver a specific amount of torque to two sides of the lower extremity joints when the upper and lower ends are attached to the appropriate joint counterparts. Fig. 3 represents the force generation characteristics influenced by the air pressure change for the maximum stretched length modeled with the experimental setup in our previous work [11].

In this investigation, we used three different pairs of PGMs as mentioned in Fig. 4. Each set has two PGMs attached to each leg and 4 PGMS for each pair. The HF pair is connected parallel to the rectus femoris (RF), vastus medialis (VM) and vastus lateralis (VL) muscles. The HE pair is connected similarly to the biceps femoris (BF) muscle, and the KF pair is connected parallel to the gluteus maximus (GM) muscle. One end of the PGM is sealed, while the other end is connected with a plastic tube to acquire air pressure optimization from the control segment. The PGMs were fixed onto the velcro-based straps, ensuring more stable attachment throughout the session without detaching even when more force was applied.

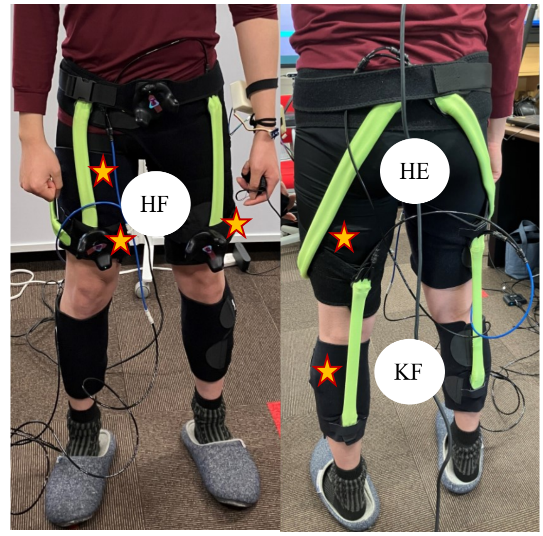

Fig. 4: PGM placements in the lower limbs where HF and KF denote the hip and knee flexion acquiring assistance and HE denotes the hip extension acquiring resistance. The stars indicate the EMG sensor locations for attaining muscle activity patterns.

C. Dynamic Difficulty Adjustment (DDA)

This letter focuses on the unique design of the exergame model, which enhances the healthy functioning of the lower extremity through squat motion. The developed study recognizes several aspects of implementing the DDA concept to achieve proper squat posture and depth to reduce muscle damage and estimate muscle strength in different squatting patterns. It also helps in improving the performance of the user in accomplishing the task with increased motivation throughout the session. The KS parameter determines the condition for dynamic difficulty optimization. We implemented two DDA conditions based on the KS value obtained during gaming sessions.

DDA Condition 1: if the KS value is between 0.03 m/s - 0.04 m/s, the collectible moving object speed was reduced from 1.3 m/s - 0.5 m/s, respectively.

DDA Condition 2: if the KS value is between 0.03 m/s - 0.04 m/s, the force applied for the PGM assistance increased from 60.17 N to 75.34 N for the HF pair and 25.01 N to 32.45 N for the KF pair. Also, the collectible moving object speed was reduced from 1.3 m/s - 0.5 m/s, respectively.

The above condition helps the user to control the gaming speed. As a result, the user adjusts the squat depth by performing parallel squats, to collect the moving objects. The risk of knee injuries was prevented in such cases. The previous work [12] and Fig. 5 illustrate the difficulty levels, the corresponding range of movement speed and the force applied to the PGMs.

D. Squat Exergame Suit Design and Assist-Resist Control Mechanism

The PGM suit is designed to detect the squat cycle by providing assistance and resistance based on the DDA condition. Fig. 5 shows the control mechanism and its components

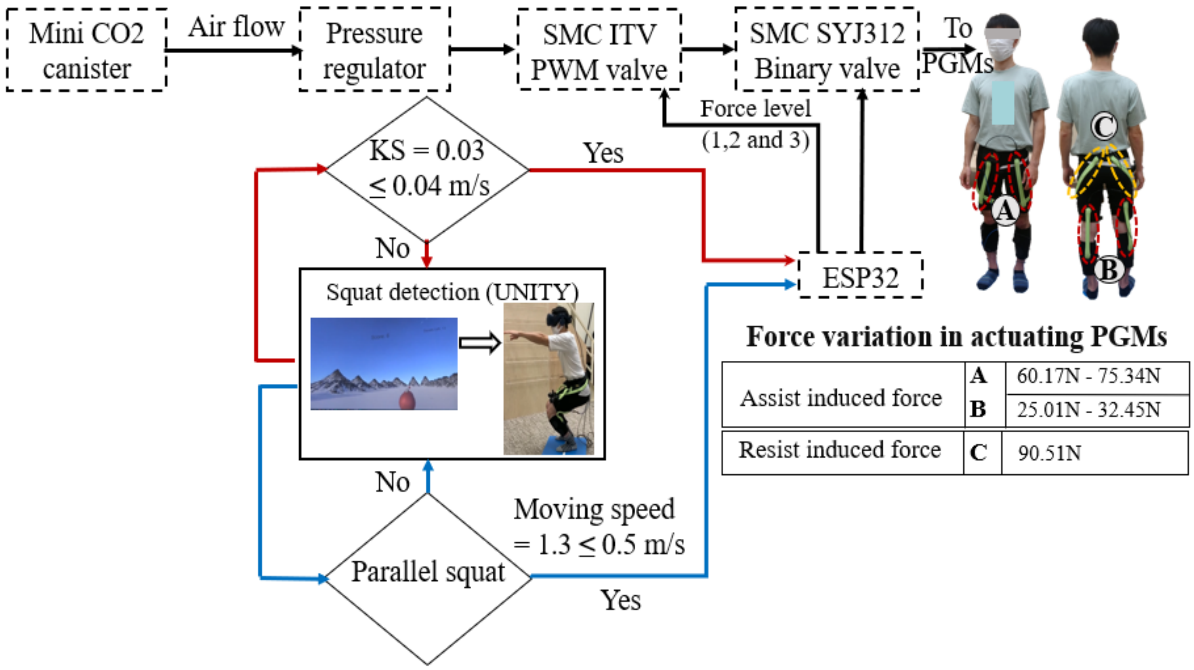

Fig. 5: The figure illustrates the control mechanism with the DDA condition utilized for the 3rd session.

evolved to inflate the PGMs using regulated air pressure. The mini-CO_2 air tanks, developed by NTG Ltd. Industries, act as a compressed air source.

A pressure regulator connected to a canister provides a constant air pressure supply of 0.05 MPa. The study employed the PWM valve from SMC (ITV0031-2L) to optimize the air pressure range needed to activate the PGMs. Besides, the binary valves contribute to the distinguished air pressure supply for assistance and resistance. The PGM pairs of KF and HF, as shown in Fig. 4 support the knee and hip flexion movements that provide assistive force, while the remaining PGM pairs of HE, as shown in Fig. 4 provide resistive force for enhancing hip extension. The ESP32 microprocessor triggers the digital control signals to establish actuation and de-actuation. KS was the deciding parameter for the DDA condition, which will be recorded through the Vive trackers. A specific range of KS $\geq$ 0.03 m/s induces PGM assistance while the PWM valve adjusts the air pressure when required. Regardless of KS, the resist binary valve supplied PGM-based resistance throughout the session whenever the end of the squat phase was detected. The linear polynomial equation denoted in the study [13] helps determine the resultant force acquired during the PGM actuation.

E. Electromyographic (EMG) Configuration

Based on the previous study [12], it was confirmed that the users got motivated and showed improved performance with the motion data analysis. But to evaluate the system's performance and core muscle strength relationship, we assessed the muscle activity reduction with EMG pattern at five lower limb muscles. We employed the Delsys sEMG system (Delsys, Boston, MA) with the following specifications: Sampling rate: 1259 Hz; Bandpass filter: 30-500 Hz. The sensor locations

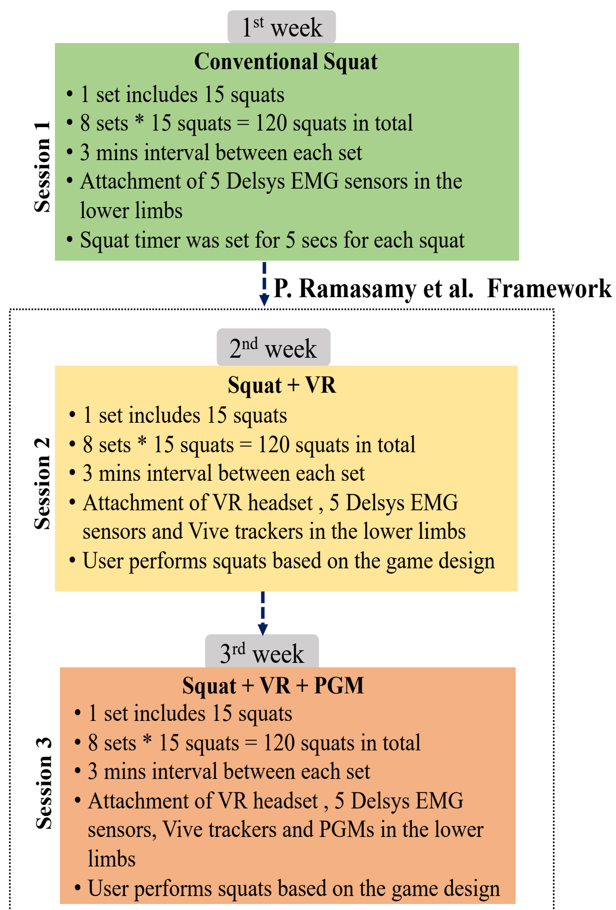

Fig. 6: Consort diagram describing the session classification for baseline and exergaming trials while the exergaming protocol utilized was proposed from [12].

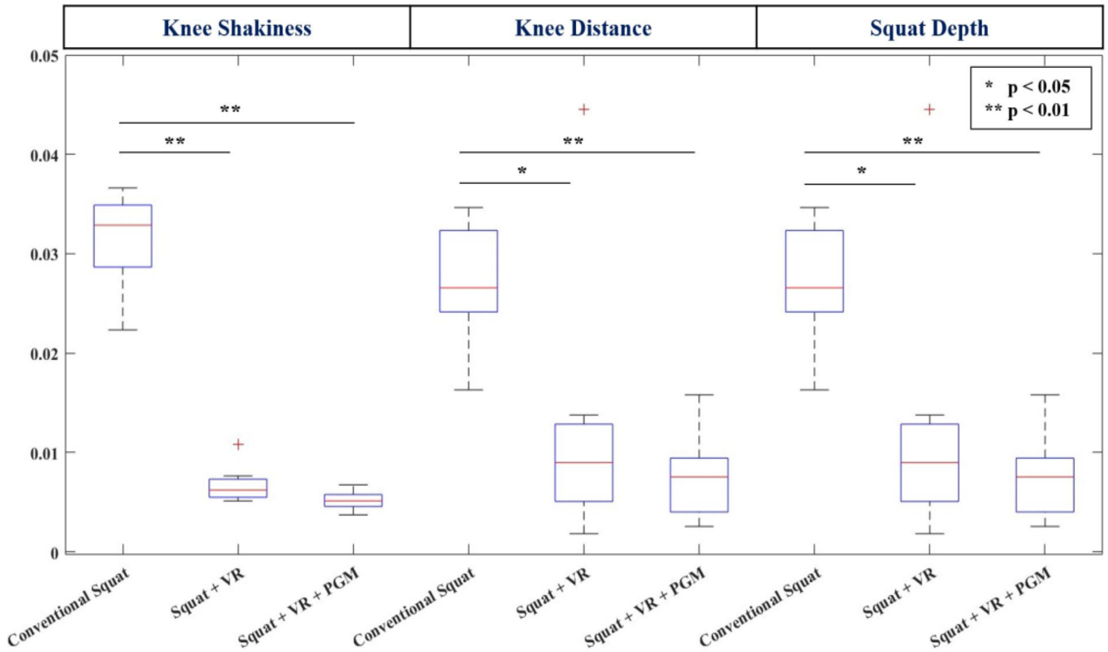

Fig. 7: Motion data analysis of the knee features: knee shakiness, knee distance and squat depth.

tested in each subject were RF, VM, GA, VL, and BF, illustrated in Fig. 4. The sensor locations were determined using the guidelines reported in the sEMG-based non-invasive assessment of muscles (SENIAM). Before the experiment, the anatomical locations were wiped with an isopropanol alcohol pad, and skin hair was shaved, if necessary [14]. The MVC was obtained by strongly contracting the test muscle to compare the muscle force levels. The task was repeated thrice for each tested muscle, with a 2-minute rest between each trial [15]. The MVC data acquisition for each muscle was executed according to the assessment tasks carried out [16]. The subsequent sessions 1, 2, and 3 as mentioned in Fig. 6 were conducted on alternate weeks, and the EMG data were collected for each session.

III. PERFORMANCE VALIDATION OF SQUAT EXERGAME WITH LOWER-LIMB MUSCLE ACTIVATION PATTERN

A. Experiment Protocol

We performed the user study with seven healthy male subjects. The subject's age was 22.85 $\pm$ 1.21 years, weight was 57.85 $\pm$ 8.2 kg, and height was 171.71 $\pm$ 6.12 cm. The participants are university students without known neurological complexities or a history of treatments in their lower limbs. They are found eligible to engage in the study after a comprehensive assessment of their ability to accomplish five trial squats. The evaluation also includes concerns about their previous experiences involving exercise games and workout activities. After augmenting the game-play modules and soft actuators to perform the exergame training, the subjects confirmed no discomfort. All subjects were asked to sign the informed consent approved by the Institutional Review Board (C-342) under the ethical guidelines in the Declaration of Helsinki (Hiroshima University).

B. User sessions

Session 1 (Conventional squat): The user was instructed to perform a time-indicated conventional squat for 5 seconds based on the timer set with the app to ensure proper squat timing. During this session, the user performs only the traditional squat, which acts as a control group without introducing the VR space with exergame training.

Session 2 (Squat + VR): The novel technique proposed in the present study employs collectible game objects on the user's ski course. The collectible items were designed to be easily attainable by the user if a half squat was done appropriately. After calibrating the initial position through the HMD, the height of the collectible objects was adjusted according to the user's dimensions, coded with the UNITY algorithm. This session utilizes DDA condition 1 during the experimental training.

Session 3 (Squat + VR + PGM): This session combines session 2 and the PGM exosuit. This session utilizes DDA condition 2 during the experimental training. The participants were briefed on the sessions and gaming parameters before the experiment. The user gets familiar with the gaming conditions and difficulty level during session 2. In addition to the subcomponents of Session 2, the users were also asked to attach the PGMs to the predefined locations in Session 3. The data acquisition includes joint angles from Vive trackers and the depth camera (RealSense D235i) and muscle activity from the EMG sensors. The control block was maintained separately and not backpacked to the user to avoid hindrance and discomfort during the training session. Fig. 6 illustrates

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the user study flow, differentiating the sessions and related equipment employed during the training.

C. Results

We obtained the knee features for all the sessions and presented them to evaluate the motion data variation and their effects on the performance of knee functioning during squat-based exergame training. For session 1, the joint angles obtained from the real sense depth camera were used to calculate the knee features such as knee shakiness, knee distance (KD) and squat depth (SD). The acquired data were normalized, smoothed and cleaned through the advanced machine learning toolbox of MATLAB 9.12.0 (R2022a). For sessions 2 and 3, UNITY-based in-house built-in algorithms were used to calculate the knee features. The acquired parameters were then compared using Analysis of Variance (ANOVA).

The increased shakiness in the knees ensures the weak functioning of the lower extremity and causes mobility problems in a very short time. It is mandatory to have continuous monitoring of knee functions. Fig. 7 illustrates a more significant reduction of the KS parameter based on the p-value ($p<0.01$) comparing the conventional squat with squat + VR and squat + VR + PGM sessions. The estimation shows the interpretation of the controlled pattern of squatting under exergaming conditions.

The controlled pattern reduces knee muscle damage, whereas traditional squats lack KS management. It was also observed that the KD and SD also reveal a significant reduction based on the p-value ($p<0.05$) comparing the conventional squat with squat + VR and p-value ($p<0.01$) comparing the traditional squat with squat + VR + PGM. The results of KD confirm that subject-oriented eased training transforms into game-oriented focused training without external environment distractions in exergaming sessions. From the results of SD, we found that it is impossible to distinguish the posture (parallel or deep) while doing traditional squats. But in sessions 2 and 3, with the calibration, the collectible objects will appear in such a way that users align themselves to do controlled parallel squats lowering the depth.

The recorded EMG data were rectified and normalized using the MVC to obtain the %MVC. Each trial was normalized to a squat percentage (0% to 100%) using MATLAB to compare the squat phase and sessions [17]. The averaged muscle activity between the three sessions for both assist and resist groups is depicted in Fig. 8 and 9. The resist group shows a high muscle activity reduction compared to the assist group. The EMG data were analyzed using the paired t-test to determine the significant differences between the sessions. We normalized the data using the logarithmic transformation to perform the paired t-test using the subject's average data. However, our normality check was negated in this case; a nonparametric method called the Wilcoxon Ranked test was used to check for significant differences.

The average %MVC for all muscles measured is presented in Fig. 10. Table I shows a significantly more significant reduction in %MVC for all the tested muscles. During the squat motion, the assist group (RF, VM, GA) and resist group (VL, BF) showed decreased muscle activity in session 3 compared to session 1. This confirms that PGM actuation helps reduce muscle activity compared to traditional squats. However, in this case, the resist group was provided with a fixed force of 90.51 N throughout the sessions. The assist group's muscle activity variation was lower than that of the resist group. This is because the force range varies according to the subject's squat type. Also, a significant difference exists between sessions 1 and 2 for VM, VL, BF, and GA. This confirms that the exergame gaming conditions maintain the squat type based on DDA parameters.

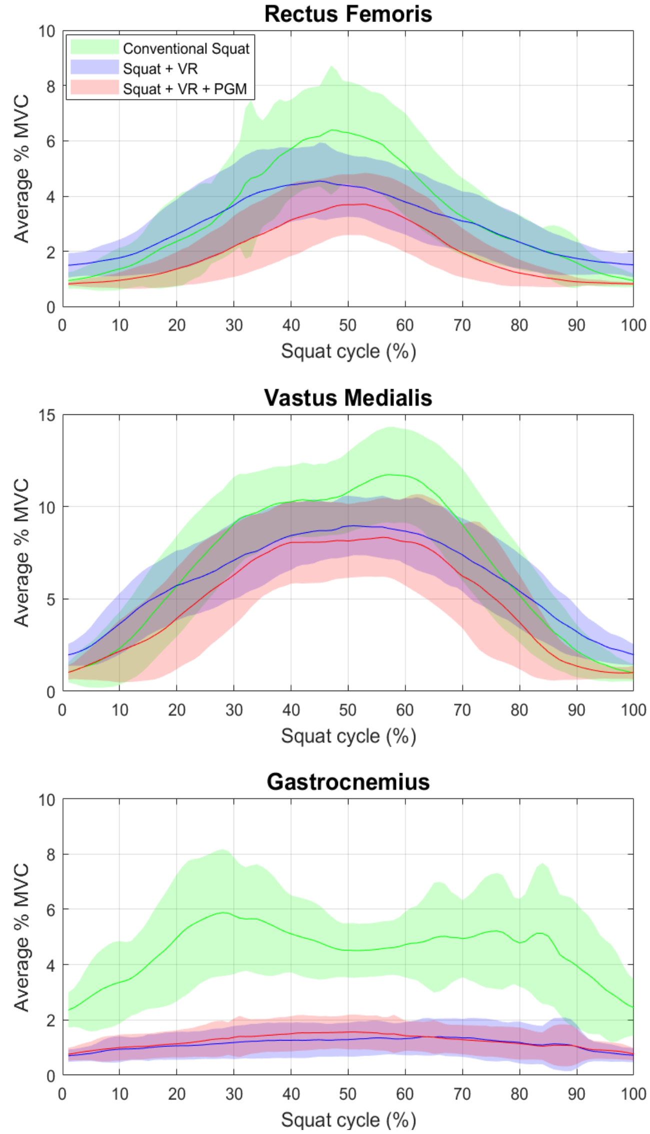

Fig. 8: Normalized averaged EMG pattern for RF, VM and GA (assist muscle group) during three squat sessions.

IV. DISCUSSION

In this letter, we discussed the design and development of an exergame module to overcome the limitation of the previous study [10] of varying the PGM counts based on the risk strategy during the training. We have included the different exergaming sessions based on the dynamic difficulty

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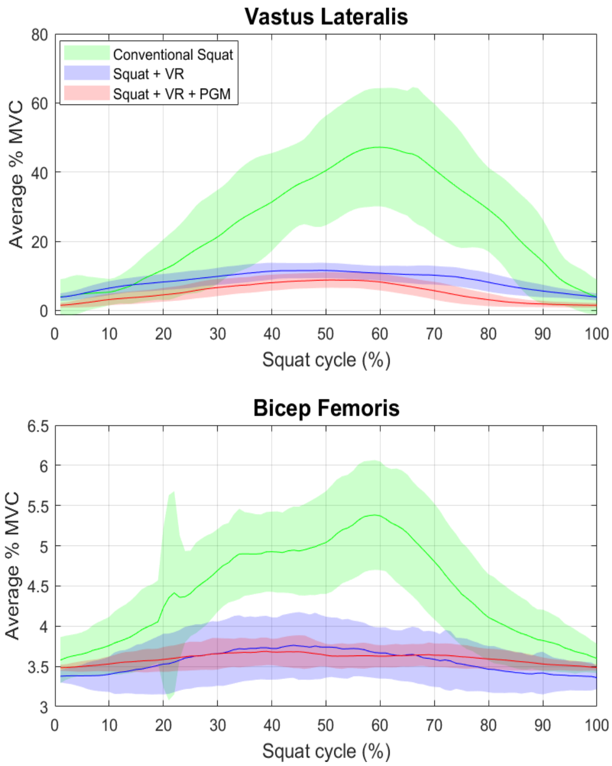

Fig. 9: Normalized averaged EMG pattern for VL and BF (resist muscle group) during three squat sessions.

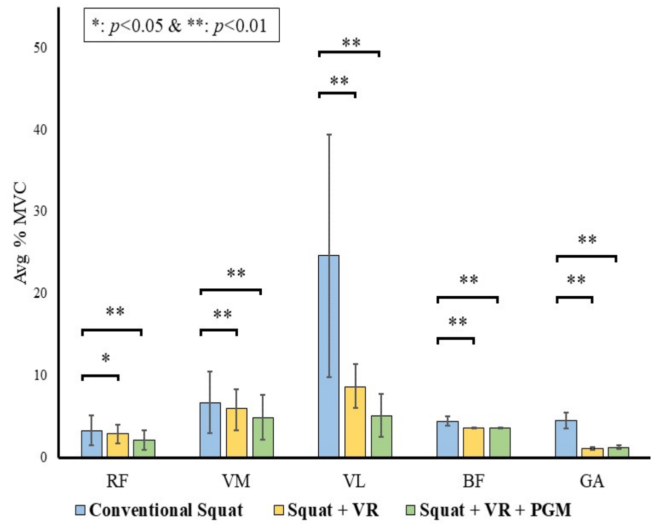

Fig. 10: Results of %MVC difference for assist and resist muscle groups of the lower limbs.

TABLE I: Comparison of muscle activity reduction between conventional squat and Squat + VR + PGM.

Muscle	%MVC difference
RF	42.28
VM	31.16
VL	131.05
BF	20.78
GA	114.75

applied to achieve this. While performing the exergaming training simultaneously, we assessed the users' knee features and muscle activity in all sessions. The work consists of a comparison of traditional-based crouching with gaming exercises. This comparison would help to understand the importance of exercise-based games through increased adherence to home exercises.

The role of the muscles connecting with the knee joints (RF, VM, and VL) must be to help in consistent contraction, which in turn stabilizes the dynamic postures. Based on the statistical results obtained from the knee features and muscle activity, it is clear that in-phase consistency of the muscle fiber contraction is achieved through the DDA technique. Although the transition of the fatigue phases causes the user to react slower, the PGM attachments help to react faster, maintaining immersion and attention towards the game.

Moreover, we can also confirm the enhancement in cognitive function and motor skills with personalized patterns of squat training. We demonstrated the possibility of muscle unloading effects by introducing varying difficulty levels while comparing the conventional and exergaming sessions. Although several previous studies on EMG muscle activity reduction have been implemented, our study quantifies assist and resist muscle groups and actuates them based on force values. Our evaluation produces better results by incorporating several enhancements such as quantified force level input, assist and resist muscle group actuation, location-specific PGM length, improvement in the actuation delay, and squat phase detection. Muscle activity reduction results are higher compared to walking studies [13].

The PGM placements were inspired by and mimicked biological muscle activation. Of the two groups, the resist muscles VL and BF showed better results for all the subjects. However, the assist group muscles RF, VM, and GA also showed better outcomes, but lesser improvements were seen due to subject-specific squat activity. The participants reported the PGM placements were comfortable and actuated effectively during the squat trial. In addition, by achieving the highest possible score, the exergame helps keep participants engaged in the activity. The knee indicators also showed a significant reduction and better progress in squat posture maintenance and the chances of a decrease in ACL injuries. Muscle activity also helps to develop enhanced control strategies using EMG and GRF-based quantification methods. These methods could configure the performance effects with an improved variation of force levels for soft pneumatic actuators. The limitations of questionnaire-based evaluation, lower limb kinematic parameters, and their impact on squat training still need to be explored.

V. CONCLUSION AND FUTURE WORK

Our findings indicate that the squat exergame training suit can be used for developing rehabilitation regimens. Although the soft exosuit can actuate based on user activity, the wear-and-tear nature of the PGM for long-term usage is still questionable. The future scope will be improved in the following directions; employment of individual PWM valves for assist and resist blocks to realize the higher intensity of force levels, further reduction in delay time for inflating the PGMs, and conducting a feasibility study using elderly subjects. To improve the user's comfort level, force sensor-based quantification methods will be adapted. Our prospective activities include the variation of the squat phase thresholds applied based on the user's performance in the future. We will consider developing a machine learning-based approach to enhance the system's accuracy with additional kinematic features.

REFERENCES

[1] Jennifer Sween, Sherrie Flynt Wallington, Vanessa Sheppard, Teletia Taylor, Adana A Llanos, and Lucile Lauren Adams-Campbell. The role of exergaming in improving physical activity: a review. *Journal of Physical Activity and Health*, 11(4):864–870, 2014.

[2] John Bolton, Mike Lambert, Denis Lirette, and Ben Unsworth. Paperdude: A virtual reality cycling exergame. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems*, page 475–478, New York, NY, USA, 2014. Association for Computing Machinery.

[3] Kristoffer Hagen, Konstantinos Chorianopoulos, Alf Inge Wang, Letizia Jaccheri, and Stian Weie. Gameplay as exercise. In *Proceedings of the 2016 chi conference extended Abstracts on human factors in computing systems*, pages 1872–1878, 2016.

[4] Tobias Huber, Silvan Mertes, Stanislava Rangelova, Simon Flutura, and Elisabeth André. Dynamic difficulty adjustment in virtual reality exergames through experience-driven procedural content generation. In *2021 IEEE Symposium Series on Computational Intelligence (SSCI)*, pages 1–8. IEEE, 2021.

[5] Takumi Okumura and Yuichi Kurita. Cross-modal effect of presenting visual and force feedback that create the illusion of stair-climbing. *Applied Sciences*, 11(7):2987, 2021.

[6] Paul Comfort and Peter Kasim. Optimizing squat technique. *Strength & Conditioning Journal*, 29(6):10–13, 2007.

[7] Jesús G Pallarés, Alejandro M Cava, Javier Courel-Ibáñez, Juan José González-Badillo, and Ricardo Morán-Navarro. Full squat produces greater neuromuscular and functional adaptations and lower pain than partial squats after prolonged resistance training. *European journal of sport science*, 20(1):115–124, 2020.

[8] Ramin Tadayon, Antonio Vega Ramirez, Swagata Das, Yusuke Kishishita, Masataka Yamamoto, and Yuichi Kurita. Automatic exercise assistance for the elderly using real-time adaptation to performance and affect. In *Universal Access in Human-Computer Interaction. Multimodality and Assistive Environments: 13th International Conference, UAHCI 2019, Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, July 26–31, 2019, Proceedings, Part II 21*, pages 556–574. Springer, 2019.

[9] Ramin Tadayon, Wataru Sakoda, and Yuichi Kurita. Stealth-adaptive exergame design framework for elderly and rehabilitative users. In *Human Aspects of IT for the Aged Population. Healthy and Active Aging: 6th International Conference, ITAP 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part II 22*, pages 419–434. Springer, 2020.

[10] Wataru Sakoda, Ramin Tadayon, Yusuke Kishishita, Masataka Yamamoto, and Yuichi Kurita. Ski exergame for squat training to change load based on predicted locomotive risk level. In *2020 IEEE/SICE International Symposium on System Integration (SII)*, pages 289–294. IEEE, 2020.

[11] Kazunori Ogawa, Chetan Thakur, Tomohiro Ikeda, Toshio Tsuji, and Yuichi Kurita. Development of a pneumatic artificial muscle driven by low pressure and its application to the unplugged powered suit. *Advanced Robotics*, 31(21):1135–1143, 2017.

[12] Priyanka Ramasamy, Swagata Das, and Yuichi Kurita. Ski for squat: a squat exergame with pneumatic gel muscle-based dynamic difficulty adjustment. In *Universal Access in Human-Computer Interaction. Access to Media, Learning and Assistive Environments: 15th International Conference, UAHCI 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings, Part II*, pages 449–467. Springer, 2021.

[13] Chetan Thakur, Kazunori Ogawa, and Yuichi Kurita. Active passive nature of assistive wearable gait augment suit for enhanced mobility. *Journal of Robotics and Mechatronics*, 30(5):717–728, 2018.

[14] Hamidreza Barnamehei, Gunarajulu Renganathan, Fatemeh Aflatounian, Samirasadat Fatemigarakani, Ava Maboudmanesh, Aidasadat Fatahzadeh, Aram Shaabani, and Yuichi Kurita. Effect of medial-lateral, inferior-superior, and rotational positions of palms on muscle recruitment during the push-up exercise. *Applied Sciences*, 12(19):10178, 2022.

[15] Farah Zaheer, Serge H Roy, and Carlo J De Luca. Preferred sensor sites for surface emg signal decomposition. *Physiological measurement*, 33(2):195, 2012.

[16] Chetan Thakur, Kazunori Ogawa, Toshio Tsuji, and Yuichi Kurita. Soft wearable augmented walking suit with pneumatic gel muscles and stance phase detection system to assist gait. *IEEE Robotics and Automation Letters*, 3(4):4257–4264, 2018.

[17] Priyanka Ramasamy, Gunarajulu Renganathan, and Yuichi Kurita. Muscle activity and ground reaction force-based control strategies for actuating soft wearables using squat motion. In *2022 IEEE-RAS 21st International Conference on Humanoid Robots (Humanoids)*, pages 680–685, 2022.