Adaptive Virtual Reality Exergame: Promoting Physical Activity Among Workers

ABSTRACT

This work presents a Virtual Reality (VR) Exergame application designed to prevent Work Related Musculoskeletal Disorders (WMSDs). Moreover, to help adapt the tasks of the exergame, a machine learning model that predicts users' exercise intensity level is presented. WMSDs are an important issue that can have a direct economic impact to an organization. Exercise and stretching is one method that can benefit workers and help prevent WMSDs. While several applications have been developed to prevent WMSDs, most of them suffer from a lack of immersivity or they just focus on education and not necessarily on helping workers warm up or stretch. In light of this, an Exergame application that leverages VR and Depth-sensor technology to help provide users with an immersive first-person experience that engage them in physical activities is introduced in this work. The objective of the Exergame is to motivate users to perform full-body movements in order to pass through a series of obstacles. While in the game, users can visualize their motions by controlling the virtual avatar with their body movements. It is expected that this immersivity will motivate and encourage the users. Initial findings show the positive effects that the base exergame has on individuals' motivation and physical activity. The results indicate that the application was able to engage individuals in low-intensity exercises that produced significant and consistent increases in their heart rate. Lastly, the results show that the machine learning model predicted users' exercise activity level with an accuracy of 76.67%.

INTRODUCTION

Work Related Musculoskeletal Disorders (WMSDs) are a type of physical ailment that hinder workers from performing their job properly. These injuries can consist of sprains, strains, tears, as well as back pain; all induced from repetitive or labor-intensive tasks. WMSDs account for nearly 130 million healthcare visits annually [1], and for 28% of injuries and illnesses that create days away from work from the employee [2]. Therefore, WMSDs can have a direct economic impact on a company and society due to loss of productivity and increased costs.

One way to reduce WMSDs is to instill safer work practices and redesign methods of completing tasks [3]. This is something reliant on the employer to instill within the workplace and have the employees follow. Another approach to reducing WMSDs is to incentivize workers to proactively exercise and stretch their muscles to prevent tension buildup [3,4]. These exercises can be completed before, during, or after the workday for the benefits of warming up, stretching out, and relaxing respectively [4]. This can be completed in addition to safer work practices and be done during the employees' own time. However, a limitation of this approach is motivating and engaging workers to perform these activities. Hence, a potential solution would be to make exercises and stretching activities more engaging to workers, for example with the use of Exergames.

Exergames are beneficial games for promoting exercise and physical activities. These applications turn a sedentary activity into one that can benefit the user through a more involved one [5]. They can help make exercising fun and enjoyable. Studies have shown that exergames can promote better self-efficacy, positive engagement, enjoyment, stress management, and reduce depressive symptoms compared to traditional machine exercise [6]. However, most exergames have been developed with the general consumer in mind [7,8]. These exergames are not focused specifically to address WMSD issues and might not benefit workers using them. In addition, most of these exergames follow a “one-size-fits-all” design approach, which does not take into consideration individuals' unique differences [9,10]. However, customization and adaptation are an important part of exercise engagement relating to WMSDs. More importantly, most existing exergames lack immersivity that can engage the user to continue using the application and promoting physical activities [8]. Leveraging Virtual Reality (VR) technology could help improve the engagement and immersive factor of exergames that aim to promote healthy practices relating to WMSDs.

VR allows the user to be immersed within the virtual environment. Interactivity and telepresence have a significant role in immersing a user when using VR. This immersivity then contributes to the overall satisfaction of the user when engaging in the virtual world [11]. These satisfaction factors emerging from VR relate to the enjoyment of users when playing a VR game. When looking at VR headsets compared to the alternative of screen use, studies have shown that VR is beneficial for immersivity and motivation of exercising [12]. These studies show the effectiveness of VR on increasing motivation and enjoyment as well as when combined with exergames [11,12]. However, many of the existing exergame studies focus on basic exercise or rehabilitation and many do not leverage VR technologies. Standard exergames lack the immersivity that VR can provide to improve motivation for completing exercise daily. VR could play an important role in helping promote exercise through exergames to mitigate the stress put on muscles when completing repetitive or labor-intensive tasks.

In order to fully engage the player or have them receive the best exercise tasks for them, customization and adaptation are important. Users would differ based on fitness level or how they are motivated in comparison to others who engage with the exergame. Moreover, users could find different aspects of the game beneficial or detrimental based on their personality characteristics [13]. Utilizing an adaptive approach to exergame customization could also be beneficial when tailoring how the user will play the game [10]. Therefore, adaptation and customization through machine learning could be a method that benefits the user when playing an exergame.

This study presents an Exergame application that leverages VR and Depth-sensor technology for the prevention of WMSDs. Moreover, a machine learning model to predict users' exercise intensity level is introduced with the objective to help adapt the physical tasks of the application to the user. The results of an initial usability test indicate that the exergame was able to engage individuals in low-intensity exercises that produced significant and consistent increases in their heart rate. This engagement in physical activity would help motivate workers to do warming up and stretching activities to help reduce WMDs. Similarly, the results show that the machine learning model achieved a prediction accuracy of 76.67% and that a model that takes into consideration unique user data, outperforms a general model that does not take into consideration user data. The content of this paper is based on the paper: *Virtual Reality Exergames: Promoting Physical Health Among Industry Workers* (DETC2021-67608), presented at the ASME CIE 2021 conference [14].

LITERARY REVIEW

The most common practice of preventing WMSDs comes from teaching how to complete the task differently [15,16]. The Centers for Disease Control and Prevention (CDC) of the USA offers tips and information on how to mitigate the strain on muscles through improved ergonomics [15]. This would be beneficial to workers; however, the employer would need to take action and purchase the equipment required to complete the job more safely. Similarly, the World Health Organization (WHO) outlines many methods of completing tasks in a safer manner. WHO explains why different repetitive or strenuous activities are detrimental and how to complete them differently [17]. These follow the lines of the CDC in putting a focus on the teaching aspect in WMSD mitigation. However, this relies heavily on employer teaching and employee learning.

Job rotation is another method for WMSD prevention. Rather than changing the method in which the worker is completing the task, the worker could rotate through different jobs alleviating the repetitiveness of that task [3]. Although recommended, a study conducted to determine how much job rotation affected WMSD prevalence showed that this method did not reduce the number of lost working hours due to sick leave or the prevalence of musculoskeletal problems [18]. These suggestions and tips on WMSD mitigation focus heavily on intervention from the employer through large technology purchases or workplace practices. However, workers should be proactive and motivated to prevent WMSDs for themselves by warming up, stretching out, and relaxing before and after the job.

Exergames

An alternative to traditional exercise comes in the form of exergames. Exergames help promotes exercise through video games and can promote users who would not normally exercise. They can come in the form of specialized gym equipment or just a video game that can be played at home [7,19]. One of the most popular Nintendo Switch™ titles is an exergame; Ring Fit Adventure™ is ranked 12 in Switch sales, at 5.84 million units sold [20]. Through various forms of physical activity, a user's heart rate can increase, allowing the user to burn more calories in a session [21]. Exergames can provide a boost in heart rate activity through movements and increased engagement [22]. One exergame developed focusing on full-body exercise demonstrated a boost in heart rate and energy expenditure in users compared to market exergames [8]. This boost in heart rate and energy expenditure would differ based on a user's age, physical fitness, and other defining factors [23].

One method being used for exergames relates to rehabilitation, as games are motivating for those who need to complete physical rehabilitation. One such application focuses on arm rehabilitation through multiple games related to arm and hand activities. The participants in the study reported enjoying playing the games and some stated that they would buy this for themselves at home [24]. Exergames leverage the use of game design elements to motivate and engage users to perform physical tasks that otherwise they would have not found as enjoyable. However, studies have shown that individuals' preferences for game elements differ [25]. Hence, different elements might motivate users to perform better or worse depending on underlying individual characteristics, like player type and game element preferences [13]. Another important factor that has been shown to influence individuals' performance in exergames is the complexity of the physical tasks itself. The more complex the task is, the more motivated the individual needs to be in order to perform it [26].

In addition to game element customization, focus on the exertion of the user when playing the game has been looked at. Customization and adaptation have been utilized to provide a more in-depth exergame experience for users in various studies through static (before game, customization) and dynamic (during game, adaptation) measures. These can be utilized to abide by a given user's exercise plan or change the difficulty of the game based on how much exertion is being used [27,28]. Compared to static measures, adaptation within an exergame can help tailor the user's experience while playing the game, retaining the immersion. Dynamic measures could leverage a machine learning to help adapt to the user's exertion and how well they are completing the game [28,29]. By tailoring the exergame to a user's need or wants, they can become more engaged with the experience and want to play or exercise more [30]. This also relates to the notion that different people would have different heart rates based on individual characteristics [23,31]. The users would need a method of tailored exercise in order to receive the maximum benefits they could out of the exergame without going overboard.

Given individual differences and task complexity, there is a potential that exergames that follow a "one-size-fits-all" design approach, might not motivate its user to perform certain physical tasks. For example, a study examining older adults' responses to an exergame that required individuals to use full-body motion to interact with an avatar demonstrated negative effects on engagement [32]. When playing the game on a screen, it was not obvious for participants the direction to move in order to complete the objective. Participants also reported a disconnect with the avatar indicating in comments that thought the avatar did not move with their body. Therefore, exergames could overcome issues of engagement by leveraging VR and machine learning technology to provide a better first-person experience, as well as introducing adaptation mechanics.

Virtual Reality and Exergames

Taking exercise into the virtual world can improve the willingness of people to proactively do physical activity as well as benefit the heart rate of those who complete tasks [12,22,33,34]. In a study examining users' heart rate while playing exergames, the immersivity of the game played a role when comparing the heart rate after playing the game in VR versus a regular screen. A volleyball full-body exergame increased the user's average heart rate by 3 beat-per-minute (bpm) compared to the flat-screen version of the same application. Similarly, when comparing the volleyball full-body exergame versus an archery game that only works the upper body, users experience an increase of 10 bpm on their average heart rate [33]. Participants who engaged with the VR game felt that it was extremely beneficial in immersing the user and visualizing motion when completing tasks. This immersivity then translated to users moving their hands and arms larger distances compared to the flat screen [33]. Another study determined the same notion that utilizing a VR can benefit a user's experience when exercising. The participants within the study commented on the immersivity, fun, and convenience of the VR application [12]. These studies demonstrate how VR can be used for exercise, however, it is not applied in a way that could benefit those with WMSDs. An exergame based around running might be beneficial for exercise purposes, nevertheless, it might not stretch areas of the lower back or upper body where WMSDs are prevalent. Stretching can be beneficial in order to reduce muscle strain and circulation [3]. An exergame that focuses directly on WMSDs and full-body motion would be ideal for prevention.

A study that introduced a VR exergame application for reducing lumbar flexion, demonstrates the benefits of providing a VR experience. It reported that users were motivated to complete tasks in a fun engaging way. The results of this study demonstrated that participant's lumbar flexion was improved over multiple gameplay sessions [35]. Unfortunately, these games are not tailored to specific muscles or areas of the body most affected by WMSDs, nor to specific users. Nevertheless, these exercise studies support that through targeted exercises, a VR application could motivate and benefit a user in the prevention of WMSD.

VR Exergames for WMSDs

One of the few studies that leveraged VR and games for WMSDs mitigation was presented by Sisto et al [16]. They introduced a VR game application that focuses on WMSD education. In their game, the user is scored based on how well they move their body when completing tasks. The intent is focused on providing the user with data on what muscles need to be moved differently when completing the tasks to alleviate the WMSD risks [16]. The teaching of how to move is very beneficial to WMSD prevention, however it requires the user to retain that knowledge when in the workplace. Unfortunately, knowledge retention over time can result in more incorrect choices [36]. In this case, it may be hard for the user to remember exactly how to move without being in the game. Unless the game was tailored to the exact job that was needed to be completed it does not provide a similar enough experience to the vast number of tasks an industry worker might need to complete. Even then, that could create muscle strain if the user needed to repeat the same task after not completing the level. Another study looking at real-time feedback for construction ergonomics utilizes teaching methods through analysis of user movement with the Kinect depth sensor [37]. This falls into the same potential drawback of knowledge retention without having the device to watch every move a construction worker makes. Strengthening muscles and warming up is a key part of WMSD mitigation [4], which is not reflected in these previous studies.

One other area looked at for prevention of WMSDs was ergonomics and the working environment. These two factors can contribute to WMSDs through poor working conditions and not performing tasks properly [15,17]. Two studies utilizing VR looked at a user’s movement in a work environment [38,39]. VR is used in a way that simulates the work environment and allows for easy immersion and creates a similar experience to how the real experience would be. However, this solution directly involves changing the way the workspace is laid out or constructed. This solution would not be selfmotivated, rather the employer would need to be motivated to invest the time and money to change how the workspace is set up.

Table 1 shows a summary of existing exergames and WMSD prevention methods. One key takeaway from the table is the gap that exists in WMSD focused exergames. Many studies examine games as they relate to basic physical activity, however only one relates to WMSD prevention through education and VR. WMSD and ergonomics-focused VR efforts do not allow for the user to participate in an exergame and rely on the employer to change the workspace. The basic physical activities are not suitable for WMSD prevention, and an educational game requires good knowledge retention on how to move for specific jobs. Moreover, the others preventative methods do not incorporate VR or exergames at all, thus only educating the user on what to do and not helping them complete it nor engaging the user. This does not motivate the individual worker to practice WMSD prevention and is heavily reliant on employer intervention.

The one VR WMSD focused application takes the educational approach, which does not benefit the user’s stretching or warming up. It also requires the user to retain knowledge on how to move when completing these tasks. Looking at the benefits that exergames and VR can bring to WMSD prevention, this work introduces a method that focuses on motivating the user to complete stretches and exercise through a VR exergame. The method incorporates an engaging first-person VR experience with the goal to motivate users to play the exergame. Moreover, a machine learning model is also introduced with the intention to help adapt the application with the objective to further improve a user’s experience. An immersive adaptive VR exergame that encourages stretching and exercise could help lower the prevalence of WMSDs in working adults. The developed VR exergame allows players to stretch and exercise in order to succeed within the game. The immersivity, body interaction, and adaptation options from this exergame could play a key role in promoting WMSD prevention by motivating its user to stretch and warm up.

MATERIALS AND METHOD

Exergame Gameplay

The main focus of the exergame is to motivate full-body movements to promote exercise and stretching. This is done with diverse obstacles continuously moving towards the player. The player needs to stretch and move his/her body in different ways to fit through the obstacles. Figure 1 illustrates some of the obstacles the player will encounter and how the user will use their body to navigate them. The player is then scored based on how well they fit through the obstacle; higher scores come from not touching the obstacle when moving past them. This scoring method encourages users to continue playing to achieve higher scores, thus allowing more time to stretch, exercise, and relax their muscles to prevent WMSDs. The Unity3D game engine (www.unity3d.com) was used to develop the exergame and integrate the hardware components (see *Hardware Integration* section). 3D models for the avatar and gym pieces were imported to make the scene more realistic and immersive.

Figure 2 shows an aerial, non-first-person view of the play space with all added 3D models and the menu of the game. A key aspect of the game development were the collision boxes added to the different 3D models. These were added to the avatar, obstacles, coins, as well as menu buttons to allow the users to interact with the application using their body with the help of a depth sensor. The collision boxes will trigger a signal when two collide and can perform functions such as counting how much of the avatar body is hitting the obstacle or allow the user to press the buttons within the menu with their hand, as shown in Fig. 3. Immersivity plays a key role with the buttons. By allowing the user to press the in-game buttons with only their hands, it removes the need for an external controller which could break the immersion. Unity's voice recognition package is also used to recognize letters that can then be input into the username. This alleviates the need for a keyboard which could also hinder immersion.

Some game elements that were added to the exergame were the coin collection, achievements, and leaderboard. These elements could help promote physical activity within the game [40]. The coins could be collected through the duration of the game, placed in areas the player would need to stretch to in order to collect. Collecting enough allows the user to unlock a tropical beach background to play in on the second level of the application, which serves as an incentive to collect the coins. The achievements were given after completing certain tasks, such as passing 5 obstacles in a row. When the user completes one of these achievements a small window pops up in the game to notify the player that they have completed an achievement. The menu navigation, depicted in Fig. 4, allows the user to view the achievements before and after the game. The leaderboard could be used to promote competition with players who utilize the game or just to achieve a high score compared to set values. This can be viewed before or after playing the game as well. Each of these promotes some form of collection, achievement or competition that the user can work towards when playing the exergame. These game elements can be toggled on and off for the user to provide the best experience by allowing users to customize their game experience.

Hardware Integration

The Oculus Rift™ VR headset and the Microsoft Kinect™ depth sensor were chosen to provide an immersive full-body VR experience. Both of these hardware are integrated with the game that was developed using the Unity 3D game engine. This exergame utilizes the Kinect's full-body tracking to allow the user to interact with the game using their body. The Microsoft Kinect™ SDK 2.0 and Microsoft Kinect Studio are used to track user motion and translate it into the avatar motion in the exergame. This enables the avatar to mimic player motions and encourage exercise through full-body motion and stretching to fit through the obstacles that gradually come at them. The Kinect was used since previous studies show that it provides good accuracy for upper body tracking and allows for manipulation of the in-game avatar [41]. Fig. 5 shows the keypoints the Kinect tracks from the users' body, which are translated into the avatar for the exergame.

The utilization of the Oculus Rift™ allows for this immersive game experience to engage the player. Unity utilizes its own XR package to display the game on an HMD and the Oculus Integration package to link with the device. To create the most immersive experience, the user's view is from within the avatar's head (see Fig. 6). This in combination with the Kinect body tracking, has the potential to enhance the feeling of being physically present in the simulated environment (i.e., first-person experience). The avatar’s body acts as the player's body; the user can see all of the body parts match when maneuvering within the virtual world. The immersion is also improved when the users can visualize how their body fits through the obstacles by seeing the avatar's arms and legs. This immersion is important because studies have shown that it can engage the user and creates satisfaction, leading them to want to continue playing [11,33]. Depicted in Fig. 6 is a demonstration of a user observing the correlation of motion between the avatar and their own body. The Kinect allows for the translation of motion to the game world and the Oculus creates immersion through the HMD. Fig. 6 also exemplifies the connections between the hardware and gameplay enable by the Unity game engine.

Predictive Model

The objective of the proposed machine learning model is to predict users’ exercise intensity level based on the movement required to pass through an obstacle. This with the intention to help adapt the application by presenting the right set of obstacles that will help maintain a desired exercise level. Given the heterogeneity of individuals (e.g., physical fitness, age) this work proposes the use of an *adaptive-individual-task* model, similar to previous studies [29]. This model uses input data pertaining to the task, as well as to the individual. Moreover, the training data used to generate the model is updated every time new data from an individual of interest is acquired. This online learning (i.e., adaptive) approach helps to improve the model's prediction accuracy and account for variations across individuals as more data is acquired when the user plays the exergame.

Specifically, to predict the exercise intensity level of an individual after a given obstacle, the model uses as predictor the total movement, average acceleration, and average velocity of the individual's joints tracked by the Kinect on the previous and current obstacle, score achieved on the previous obstacle, coins collected on the obstacles, as well as individual and obstacle identifier data. Since the model requires data from a previous obstacle, the model is first trained with a dataset of a general population of individuals (i.e., no individual identifier). Then, as new data of an individual of interest is acquired, the training set is updated, and the model is re-trained. This online learning approach allows mitigation of the "cold start" problem.

In this work, multiple machine learning algorithms are implemented to test their capability to generate a model that can accurately predict an individual's exercise intensity level. Specifically, in this work, a Logistic Regression, Naïve Bayesian, Support Vector Machines, Random Forest, and a Neural Network classification algorithms are implemented. These algorithms were selected since they have different underlying processes for generating classification models and are frequently used in the literature [42]. The performance of these algorithms is evaluated using a 10-fold cross-validation approach. Moreover, to simulate the scenario in which new data of an individual of interest is acquired, and the model is re-trained, an iterative online evaluation approach is implemented. For this approach, the same testing sets are used in each of the instances to maintain consistency between the iterations of the procedure. Therefore, in each of the instances, the data pertaining to an individual is randomly partitioned into a 70/30 training and testing sets. In the first iteration, the training set of the model is composed of a set that does not contain data of the individual of interest . Hence, in this first iteration, the training and testing sets are person independent, which produces a general model. In the subsequent iterations, an extra tuple containing information about the individual of interest is randomly added to the training set. This procedure is followed for all the individuals in the dataset.

RESULTS AND DISCUSSION

In order to test the capability of the VR exergame to promote stretching and light exercise (i.e., warming up), as well as the capability of the proposed machine learning model to predict an individual's exercise intensity level, an experiment in which participants interacted with the exergame was conducted. The exergame requires participants to perform full-body motions to pass through 18 different obstacles per level. Participants interact with the application for two levels. During the first level, they were given the option to collect coins in order to unlock a new background for the second level. While the participants in this experiment interacted with the non-VR version of the exergame, the findings of this study can help support the capability of this type of exergame application to promote light exercise (i.e., warming up) and stretching, which are key in the prevention of WMDs.

A total of 15 participants took part in this experiment, in which their heart rate was captured before and during their interaction with the application. Participants' age ranged from 19 to 26 years of age (M=22, SD= 2.17). A wireless heart rate monitor was used to avoid interferences while interacting with the exergame. The heart rate monitor's accuracy was validated before the experiment by taking a manual measurement of participants' heart rate.

Exercise Intensity Results

Before interacting with the application, participants were requested to relax for 5 minutes in a dimmed room with nature music in the background. This was done in order to get an estimate of the participants' heart rate at resting condition ($HR_{resting}$). Participants' maximum heart rate (HR_{max}) was estimated using the formula $HR_{max}=220\text{-}Age$. This is a well-known and used formula to approximate maximum heart rate in healthy individuals [43–45]. With participants' HR_{max} and $HR_{resting}$, their heart rate reserve was estimated ($HR_{reserve} = HR_{max}\text{-}HR_{resting}$). Subsequently, the $HR_{reserve}$ of participants was used to estimate their exercise intensity level following the American College of Sports Medicine guidelines [46]. Table 2 shows the statistics of how long participants lasted in each of the different exercise intensity levels during their interaction with the application, which lasted 300 sec (5 mins). From these results, it is clear that the exergame application incentivized participants to perform light physical activity since, on average, participants spend 90% of the time (i.e., 271.3 sec/ 4.5mins) in the *Very Light* or *Light* exercise intensity zones. These zones relate to warming up and weight control zones respectively. These findings support the capability of the exergame application to engage individuals in physical activity to warm up and stretch.

The exercise intensity achieved by an individual after performing a physical task depends on both the physical fitness of the individual as well as the complexity of the task itself. Tasks that require more rapid movements will result in higher energy expenditure which would directly increase an individual's heart rate [47]. This is supported by the results that indicate a positive correlation between participant's average heart rate per obstacle and the total distance moved ($\rho=0.18$, p-value<0.001), as well as the average acceleration ($\rho=0.34$, p-value<0.001) and average velocity ($\rho=0.34$, p-value<0.001) of all their joints tracked by the Kinect before each obstacle.

Predictive Model Results

The results of the 10-fold cross-validation indicate that the Support Vector Machine (SVM) algorithm generated the model with the largest average accuracy (M=0.7667, 95%CI=[0.7287-0.8017]). Figure 8 shows a summary of the accuracy results of the 10-fold cross-validation benchmark analysis. From this figure, it is clear that all the algorithms, with the exception of the Naïve-Bayesian, generated a model that had an accuracy greater than the non-information rate of 0.6372 (red dotted line in Fig. 8). Moreover, while the SVM has on average the largest accuracy, this was not statistically significantly different than the accuracy of the model generated with the Logistic Regression (LR), Random Forest (RF), and Neural Network (NN). These findings indicate that a machine learning model can accurately predict the exercise intensity level of individuals prior to completing an obstacle.

For completeness and to assess the value of considering individual's information, the proposed model was benchmarked against a model that does not consider an individual's identifier data (i.e., general model). This benchmark analysis was performed using the SVM algorithm and a 10-fold cross-validation approach. The results show that this general model only achieved an average accuracy of 0.6630 (95%CI=[0.6214-0.7028]), which was statistically significantly lower than the *individuals-task* model's accuracy and not statistically significantly different than the non-information rate. This indicates the value of considering an individual's information, given the heterogeneity of users. When looking at the importance of the features, the features with the largest weight were the average acceleration and average velocity of all the joints on the previous and current obstacle. These findings are in line with the previous results, that show a positive correlation between these independent variables and individuals' heart rate. These findings support the value of considering individuals' movement information to predict their exercise intensity level.

Similarly, to test the performance of the proposed machine learning model as new data of an individual of interest is acquired and the model is re-trained, an iterative online evaluation approach is implemented. Since there were 36 data points per participant (i.e., 18 obstacles by 2 levels) and a 70/30 training and testing partition was used, 11 obstacles per participant were randomly assigned to a testing set, while 25 obstacles were assigned to a training set. This iterative approach had a total of 26 iterations per participant. The first iteration used a general model to predict a participant's exercise intensity level on the testing set (i.e., model trained with no data from the individual of interest). The model was subsequently re-trained with a new data point of the individual of interest until all the training set was used to train the individual-task model on the 26th iteration. Figure 7 shows the average accuracy of the model as new data of an individual of interest is acquired and the model is re-trained. On the 1st iteration, where the general model was training, an accuracy of only 0.60 (95%CI=[0.5209,0.6753]) was achieved, while in the 26th iteration, the individual-task model shows an accuracy of 0.7212 (95%CI=[0.6462,0.7881]). Moreover, the results show a significantly positive correlation between the accuracy and the iterations (ρ=8738, p-value<0.001), indicating that the model accuracy improves as more data of an individual of interest is provided. These results show the capability of the *adaptive-individuals-task* model to accurately predict an individual exercise intensity level as the user interact with the exergame.

Usability Results

Finally, after interacting with the exergame, participants were asked to complete a short post-experiment questionnaire. The questionnaire was composed of five statements, in which participants reported how much they agree or disagree using a 5-point Likert scale, followed by an open-ended question about what they liked or disliked about the application. Table 3 shows the summary statistics of the post-experiment questionnaire responses. A series of t-test indicates that, on average, participants' responses were statistically significantly greater than the neural response at an alpha level of 0.05 (i.e., 3 in the 5-point Likert scale).

When looking at the opened-ended question, only 11 participants responded. A Semantic Network Analysis was performed based on participants' responses (see Fig. 9). Similarly, a word frequency analysis showed that the top 5 most frequent words, after removing for English stop words, were: (i) *obstacles*, (ii) *see*, (iii)*motion*, (iv) *fun*, (v) *time.* Lastly, sentiment analysis of the responses was performed using the VADER rule-based model [48], where the sentiment ranges from -1 to +1 (negative values represent negative sentiment). The sentiment analysis result shows that, on average, the responses had a positive sentiment of 0.34 (Min=-0.46, Max=0.9, SD=0.50). A non-parametric t-test shows that the average sentiment was significantly different than 0 (p-value=0.03).

From the analyses of the open-ended responses, it is clear that participants liked the application. For example, as stated by some of the participants: "*It was fun and interesting. I would do another experiment like this again*.". However, participants also reported having issues with the Kinect sensor and some of the obstacles. For example, some participants stated: "*The obstacles with the jumps could be made easier*", "*The motion sensor didn't, at times, accurately capture my movements*", "*Couldn't see the obstacles with the avatar/person in front of it*." The issues with the Kinect sensor not accurately tracking the body of participants was related to participants' non-infrared reflective cloth (e.g., dark color cloth). Also, in this non-VR version of the application participants complained about not being able to clearly see the obstacles. This issue would be mitigated by leveraging VR technology to provide a first-person experience.

Overall, the results show that participants found the applications useful, motivational, interesting, and that would like to continue using the application in the future. These are key characteristics of an engaging and motivating application. Nevertheless, these results also indicate that there is room for improvement. Hence, leveraging VR technology could potentially improve the capability of the application to engage and motivate individuals to perform light physical activities (i.e., warming up) and stretching, which are key for preventing WMDs.

CONCLUSION

Work Related Musculoskeletal Disorders are a serious issue that takes industry workers out of work for extended periods of time. This issue could be prevented by promoting healthy exercise and stretching habits. One method for promotion can be through the use of exergames, which engage the user with gameplay and game design elements. However, many of the current exergames do not address WMSDs specifically or integrate VR for a more immersive experience. Studies that do address WMSDs focus more on the teaching of how to move your body rather than stretching and exercise of muscles. Exercise and stretching are two key preventative methods that do not require knowledge retention such as teaching how to position your body when performing a task.

This work presents a VR exergame that can be used to promote exercise and stretching for the prevention of WMSDs, as well as a machine learning model to predict users' exercise intensity level with the objective to help adapt the physical tasks of exergame. Results from an initial usability study of the base exergame show promise in utilizing the exergame for motivating and engaging users to stretch and exercise. Similarly, the results indicate that by training an individual-task machine learning model, a user's exercise intensity level can be predicted before completing a task with an accuracy signifyingly greater than random chance. This type of individuals-task model can be used to help adapt the task of an exergame by predicting a user's exercise intensity level on a given obstacle, based on the movement that the obstacle would require the individuals to perform, as well as the movement they performed a previous obstacle. Leveraging VR and machine learning technology could help increase the immersivity and engagement of exergames. Other studies present the immersivity and motivation VR can bring to the exergame [12,32]. The VR exergame facilitates a true first-person experience that could motivate the user to continue playing the exergame; thus helping prevent WMSDs.

Future work will explore the impact of the added immersivity and engagement of VR compared to the non-VR application. The exergame could also be fine-tuned to stretch and exercise areas of the body that are specific to WMSDs; introducing new obstacles or levels that could be tailored to the individuals. Similarly, educational content could also be added to leverage both the benefits of stretching and learning about WMSDs prevention. Lastly, although VR is immersive, the field of view of most VR headsets is limited, which creates an issue that limits the user’s first-person perspective in-game. Future work could focus on designing the obstacles to mitigate issues that might arise due to the reduced field of view of VR headsets.

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Figure Captions List

Table Caption List

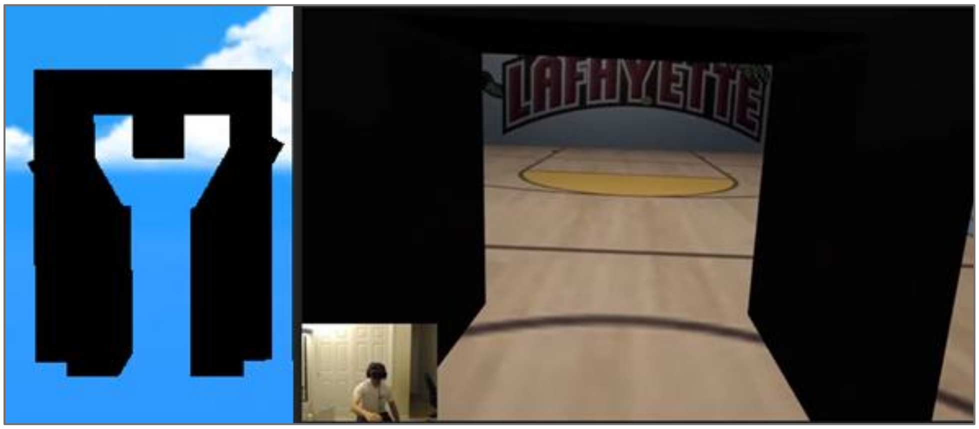
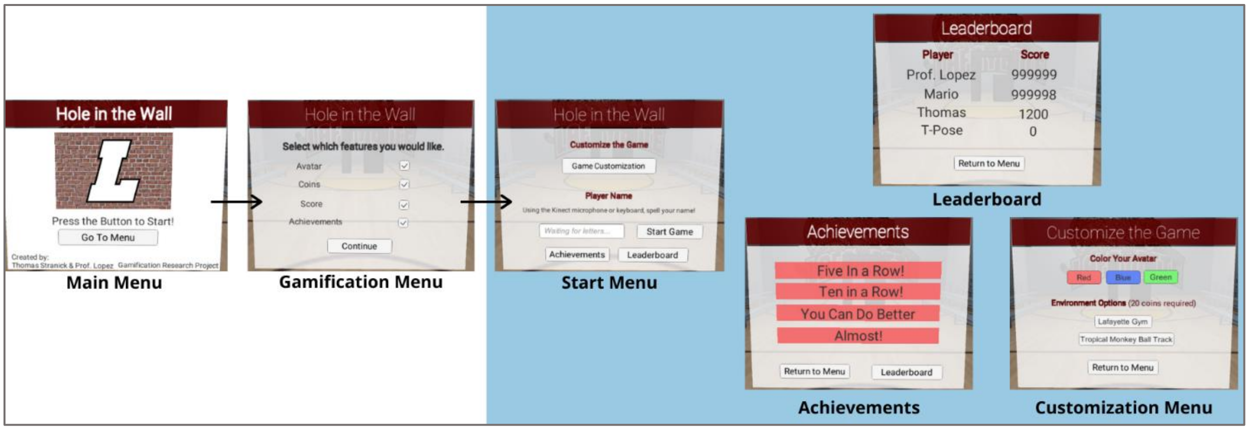


Fig. 1 Y-shaped obstacle & user in VR crouching under obstacle

Fig. 2 Exergame play space

Fig. 3 User interacting with button



Player	Score
Prof. Lopez	999999
Mario	999998
Thomas	1200
T-Pose	0

Fig. 4 Navigation through menus

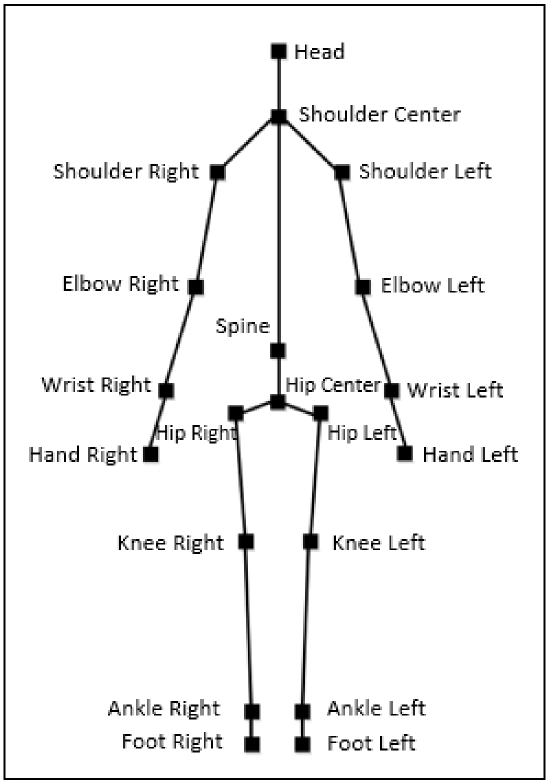


Fig. 5 Depiction of Kinect body tracking [49]

Fig. 6 Depiction of hardware integration

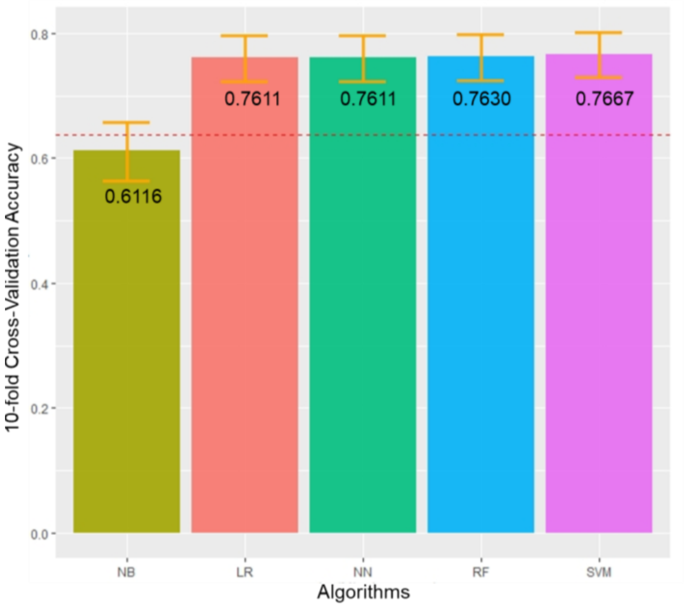


Fig. 7 10-fold CV Benchmark results

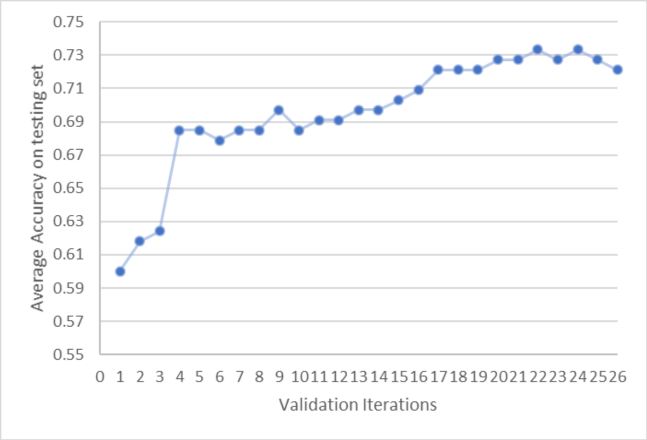


Fig. 8 Online training model performance

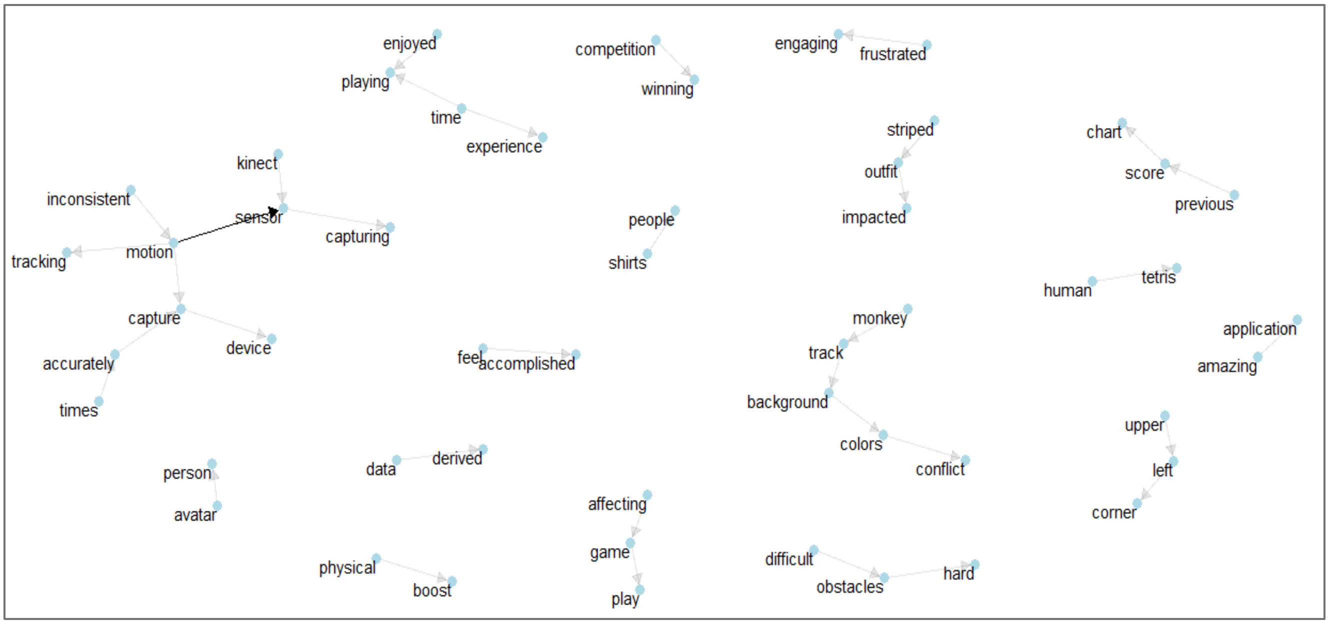


Fig. 9 Semantic network analysis of participants’ responses

Table 1 Summary of related works

Study	WMSD Focused	Education	Exergame	Virtual Reality
[38,39]	No	No	No	Yes
[7,8,19,24,32]	No	No	Yes	No
[12,22,33–35]	No	No	Yes	Yes
[27,29]	No	No	Yes	No
[28]	No	No	Yes	Yes
[3,15,17]	Yes	Yes	No	No
[16,37]	Yes	Yes	No	Yes
This Work	Yes	No	Yes	Yes

Table 2 Time spent [sec] by participants in different exercise intensity zones

Level:	Very Light	Light	Moderate	Vigorous
reserve [%]	<30%	30%-39%	40%-59%	60%-89%
Min.	52.91	0.00	0.00	0.00
Mean	196.14	75.19	27.43	0.95
Max.	299.73	188.71	147.28	14.32
SD	76.85	50.31	43.69	2.65

Table 3 Summary statistics of post-experiment questionnaire

Statements	Min	Mdn	M	Max	SD
1) I found the application useful	2	4	4.13	5	0.74
2) I was motivated by the application	3	5	4.46	5	0.74
3) I found it easier getting real-time feedback	2	4	4.13	5	0.99
4) I found it interesting to interact with the application	3	4	4.33	5	0.62
5) I will be interested to continue using the application	2	4	3.94	5	0.88