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VIRTUAL REALITY EXERGAMES: PROMOTING PHYSICAL HEALTH AMONG INDUSTRY WORKERS

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ABSTRACT

This work introduces a Virtual Reality (VR) Exergame application to prevent Work Related Musculoskeletal Disorders (WMSDs). WMSDs are an important issue that can have a direct economic impact since they can injure workers, who are then forced to take time off. Exercise and stretching is one method that can benefit workers' muscles and help prevent WMSDs. While several applications have been developed to prevent WMSDs, most of the existing applications suffer from a lack of immersivity or just focus on education and not necessarily helping workers warm-up or stretch. Hence, this work presents an Exergame application that leverages VR and Depth-sensor technology to help provide users with an immersive first-person experience. The objective of the VR Exergame is to encourage and motivate users to perform full-body movements in order to pass through a series of obstacles. The application implements a variety of game elements to help motivate users to play the game and stretch. 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 level. 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, this work explores the development and benefits that this VR Exergame could bring by motivating workers and preventing WMSDs.

Keywords: WMSD, Virtual Reality, Exergame, Physical Activity

1. 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. 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 game 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 [9]. 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 determined that VR is beneficial for immersivity and motivation of exercising [10]. These studies show the effectiveness of VR on increasing motivation and enjoyment when combined with exergames [9,10]. 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.

This study presents an application that leverages VR and Depth-sensor technology in combination with exergames for the prevention of WMSDs. 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 stretching and warming up activities to help reduce WMDs.

2. LITERARY REVIEW

The most common practice of preventing WMSDs comes from teaching how to complete the task differently [11,12]. 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 [11]. This would be beneficial to the workers; however, the employer would need to take action and purchase the equipment and material required to make the task more ergonomic. 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 [13]. 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 [14]. These suggestions and tips on WMSD mitigation focus heavily on intervention from the employer through large technology purchases or workplace practices. However, workers must be proactive and motivated to prevent WMSDs for themselves by warming up, stretching out, and relaxing before and after the job.

2.1 Exergames

An alternative to traditional exercise comes in the form of exergames. Exergames help promote exercise through video games and can promote users who would not normally do exercise. They can come in the form of specialized gym equipment or just a video game that can be played at home [7,15]. One of the most popular Nintendo Switch™ titles is an exergame; Ring Fit Adventure™ is rank 12 in Switch sales at 5.84 million units sold [16]. One exergame developed focusing on full-body exercise demonstrated a boost in heart rate and energy expenditure compared to market exergames [8].

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 [17]. 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 [18]. Hence, different elements might motivate users to perform better or worse depending on underlying individual characteristics, like player type and game element preferences [19]. 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 [20].

Given individual differences and task complexity, there is a potential that exergames might not motivate its users 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 [21]. 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 the avatar did not move with their body. Therefore, exergames could overcome issues of engagement and immersivity by leveraging VR and Depth-sensor technology to provide a better first-person experience, as proposed in this work.

2.2 Virtual Reality and Exergames

Taking exercise into the virtual world can improve the willingness of people to proactively do physical activity as well as consistently increase the heart rate of those who complete tasks [10,22]. 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 users 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 [22]. Participants who engaged with the VR game felt that it was extremely beneficial in immersing them and visualizing motion when completing tasks. This immersivity then translated to users moving their hands and arms larger distances compared to the flat screen [22]. 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 [10]. 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 [24]. Unfortunately, these games are not tailored to specific muscles or areas of the body most affected by WMSDs. Nevertheless, these exercise studies support that through targeted exercises, a VR application could motivate users to do light exercises and stretches; hence, benefiting users in the prevention of WMSD.

2.3 Exergames of WMSDs

One of the few studies that leveraged VR and games for WMSDs mitigation was presented by Sisto et al [12]. They introduced a VR game application that focuses on WMSD education. The intent of the game 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 [12]. The teaching of how to move is very beneficial to WMSD prevention; however, it would require the user to retain that knowledge when in the workplace. Knowledge retention over time can result in more incorrect choices [23]. 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. Strengthening muscles and warming up is a key part of WMSD mitigation [4], which is not reflected in this study.

Table 1 shows a summary of existing exergames and WMSD prevention methods. One key takeaway from the table is the gap between WMSD focused exergames. Many studies examine games as they relate to basic physical activity, however only one relates to WMSD prevention through education. The basic physical activities are not suitable for WMSD prevention, and 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 reader on what to do and not helping them complete it. This does not motivate the individual worker to practice WMSD prevention and is heavily reliant on employer intervention.

TABLE 1. SUMMARY OF RELATED WORKS

Study	WMSD Focused	Education	Exergame	Virtual Reality
8,17	No	No	Yes	No
10,21,23	No	No	Yes	Yes
3,11,13	Yes	Yes	No	No
12	Yes	Yes	No	Yes
This Work	Yes	No	Yes	Yes

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 presents a preventative method that focuses on motivating the user to complete stretches and exercise through a VR exergame. The method presented incorporates an engaging first-person VR experience with the goal to motivate users to play the exergame. An immersive VR exergame that encourages stretching and exercise could help lower the prevalence of WMSDs. The developed VR exergame allows players to stretch and exercise in order to succeed within the game. The immersivity and body interaction from this exergame could play a key role in promoting WMSD prevention by motivating its user to stretch and warm-up before and after the job.

3 MATERIALS AND METHODS

3.1 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

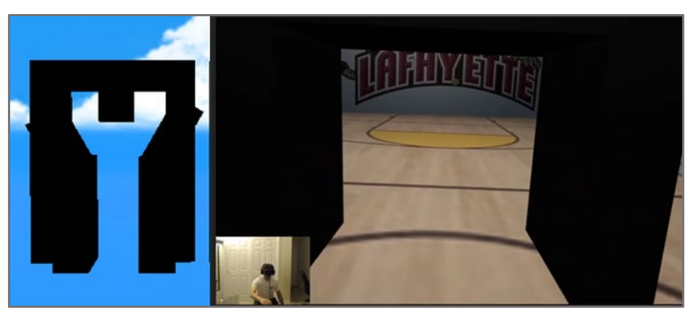

FIGURE 1. Y-SHAPED OBSTACLE & USER IN VR CROUCHING UNDER OBSTACLE

FIGURE 2. EXERGAME PLAY SPACE

FIGURE 3: USER INTERACTING WITH BUTTON

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 section 3.2). 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, 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. This help improve the immersivity, which plays a key role with user interface. Moreover, 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 to provide the username of the player. This alleviates the need for a keyboard which could also hinder immersion.

Some elements that were added to the exergame were the coin collection, achievements, and leaderboard. These elements could help promote physical activity within the game [27]. 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 level to play in, which serve 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. These game elements can be toggled on and off for the user to provide the best experience by allowing them to customize their game.

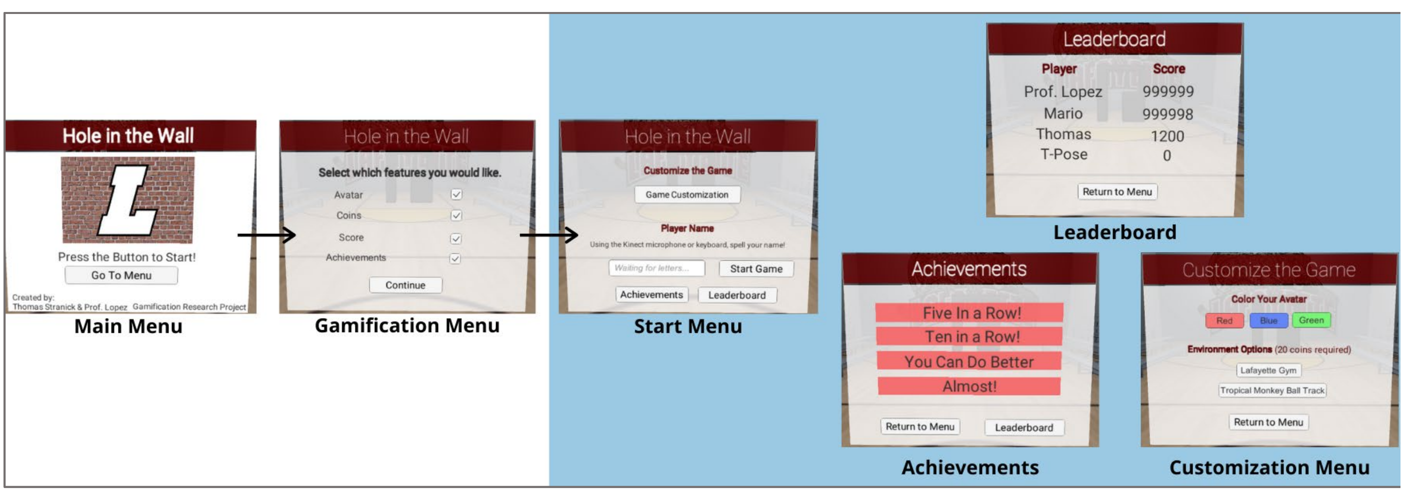

FIGURE 4: NAVIGATION THROUGH MENUS

3.2 Hardware

The Oculus Rift™ and the Microsoft Kinect™ were chosen to provide an immersive full-body VR experience. Both of these components are integrated with the game that was developed using the Unity 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 of 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 and collect the coins of the game. 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 [25]. Fig. 5 shows the key points 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 VR HMD and the Oculus Integration package to link specifically 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 facilitate a 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 his/her 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 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 [9,22]. 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 interrelationship between the hardware and gameplay enable by the Unity game engine.

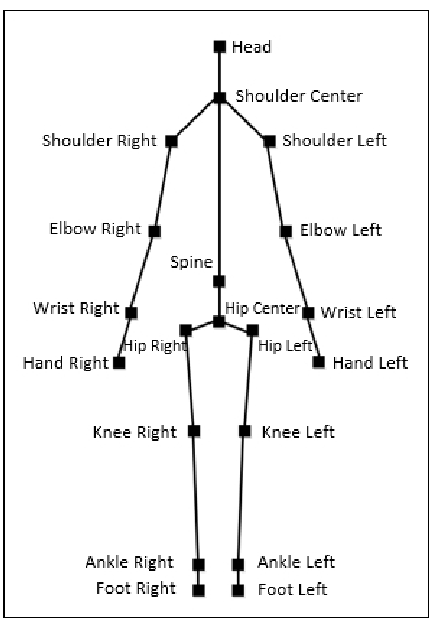

FIGURE 5: DEPICTION OF KINECT BODY TRACKING [26]

FIGURE 6: DEPICTION OF HARDWARE INTEGRATION

4 RESULTS AND DISCUSSION

In order to test the capability of the VR exergame to promote stretching and light exercise (i.e., warming up), an experiment in which participants interacted with the exergame was conducted. 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 applications 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. Moreover, 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 [28–30]. 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 following the American College of Sports Medicine guidelines [31]. Table 2 shows the statistics of how long participants lasted in each of the different exercise intensity zones 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 warmup and stretch.

TABLE 2: TIME SPEND [SEC] BY PARTICIPANTS IN THE DIFFERENT EXERCISES INTENSITY ZONES

Zone:	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

Moreover, 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).

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

Moreover, when looking at the opened-ended question, only 11 participants responded. A Semantic Network Analysis was performed based on participants' responses (see Fig. 7). Similarly, a word frequency analysis showed that the top 5 most

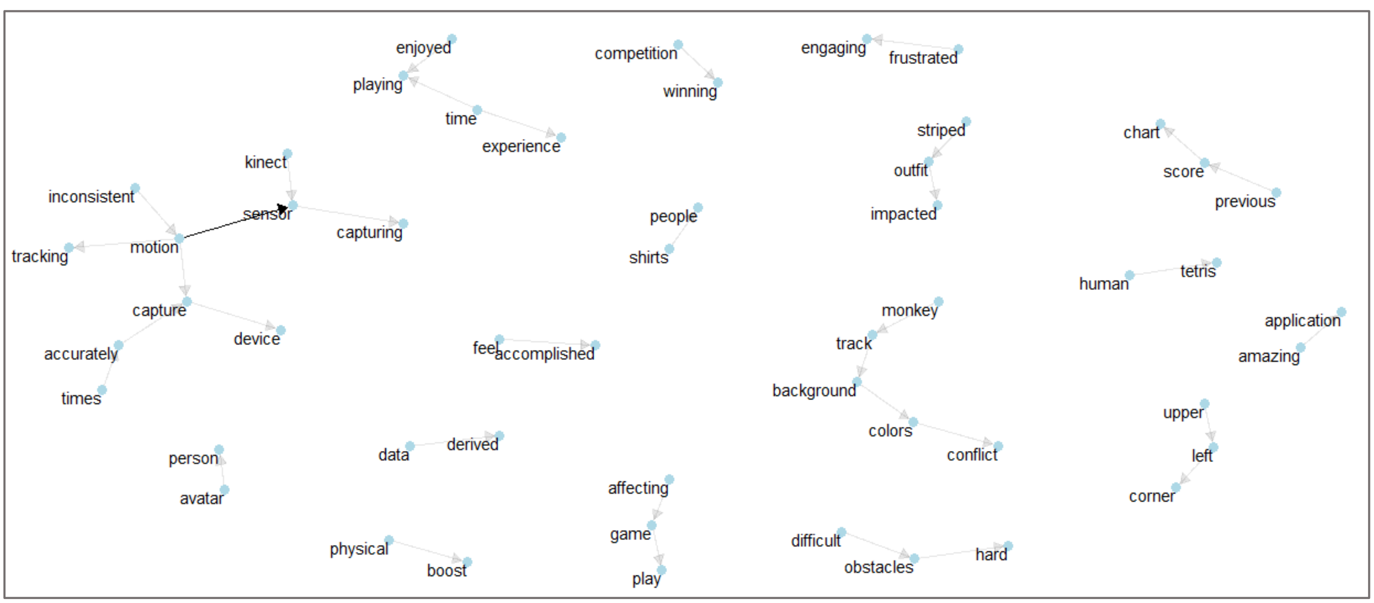

FIGURE 7: SEMANTIC NETWORK ANALYSIS OF PARTICIPANTS' RESPONCES

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 [32], 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 that provide a first-person experience by placing the participants' field of view directly on the dead of the avatar.

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 for 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.

5 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 nor 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 exercising. Exercising 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 could be used to promote exercising and stretching for the prevention of WMSDs. 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. Leveraging VR technology could help increase the immersivity of the exergame. Other studies present the immersivity and motivation VR can bring to the exergame [10,21]. The VR exergame facilitate 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 can be tailored to the individual. 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 headset are limited, which creates an issue that limits the user's first-person perspective in-game. Future work should focus on adapting the obstacles to mitigate issues that might arise due to the reduced field of view of VR headsets.

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