ArmSwing: Using Arm Swings for Accessible and Immersive Navigation in AR/VR Spaces

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ABSTRACT
Navigating in a natural way in augmented reality (AR) and virtual reality (VR) spaces is a large challenge. To this end, we present ArmSwingVR, a locomotion solution for AR/VR spaces that preserves immersion, while being low profile compared to current solutions, particularly walking-in-place (WIP) methods. The user simply needs to swing their arms naturally to navigate in the direction where the arms are swung, without any feet or head movement. The benefits of ArmSwingVR are that arm swinging feels natural for bipedal organisms second only to leg movement, no additional peripherals or sensors are required, it is less obtrusive to swing our arms as opposed to WIP methods, and requires less energy allowing prolong uses for AR/VR. A conducted user study found that our method does not sacrifice immersion while also being more low profile and less energy consumption compared to WIP.

ACM Classification Keywords
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Author Keywords
virtual reality; locomotion; navigation; arm swing; immersive.

INTRODUCTION
Navigating virtual spaces in VR often causes Virtual Reality (VR) sickness. It might be a critical barrier to use VR as effective rehabilitation and training tool. One attempt to overcome VR sickness is to simulate locomotion [13]. Current research implementation related to locomotion in VR such as WIP methods aim to create a more realistic sensation of walking, thus negating motion sickness by avoiding contradiction with the body's sense of balance and spatial orientation [27]. However, as VR usage becomes more mainstream, WIP suffers from several issues, mainly 1) jogging in place looks strange to others, and 2) it becomes tiring after a slightly extended period of usage, unless it was designed for energy consumption like sports simulation in the first place. This creates a barrier for some, such as elderly consumers or just the general public who wants to use VR more socially. Unlike foot or head-based WIP which enables locomotion through foot motion or head bobbing, ArmSwingVR enables users to navigate a VR scene simply through arm swing, allowing for a more socially acceptable interaction while preserving the realism of walking that is natural to human gait, as well as consuming less energy. The user simply needs to swing their arms in a natural movement as they do when walking, providing them the freedom to look around without affecting the walking direction. No feet movement is required, making any additional sensors or 3rd party peripherals unnecessary. Users also do not need to deliberately bob their head to allow a better immersion and focus in the VR scene during locomotion.

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This paper pursues 3 major goals: to develop a virtual space locomotion solution that feels natural, preserves immersion and is more socially acceptable, ensure that users can easily utilize the system without additional devices, and evaluate users' feedback on the energy consumption, ease of use and immersion factor of ArmSwingVR compared to existing WIP methods such as VR-Step [26]. Other locomotion solutions in VR like the omni-directional treadmill [6], brain interface [8], etc. has been developed towards the similar goal of immersion, yet they involve hardware that are not easily accessible, too costly for the average consumer, or simply adds to the number of peripherals for VR systems that are already plentiful by default, making these solutions viable only in research labs or specific applications. This makes software approaches like ArmSwingVR preferable. Furthermore, with the inclusion of hand position tracking controllers for the current and future generation of VR solutions (HTC Vive, Oculus Touch, Google Daydream, etc.), users do not need 3rd party tracking devices. Arm swing was never a necessity for human locomotion, however this motion feels natural for humans when walking or running [1], and simulating this gesture in VR has the potential to induce the sense of navigation while maintaining immersion.

We perform a user study to compare with another WIP solution, VR-Step [26], to evaluate its effectiveness, immersion, and energy consumption. We use the NASA Task Load to evaluate the physical demand, presence questionnaire to evaluate immersion, and a score-based method to evaluate effectiveness. As with most other locomotion studies, we also compared if ArmSwingVR causes more motion sickness over VR-Step using the Simulation Sickness Questionnaire (SSQ). From the results, we found that ArmSwingVR does not sacrifice on immersion and can be used for an extended period of time, where all participants agree that it is a viable solution to be used publicly given its low profile nature.

To summarize, the contributions of this research are as the following:

- Develop a VR locomotion solution that feels natural, preserves immersion (no significant decrease in immersion compared to VR-Step in terms of realism, possibility to act, quality of interface, possibility to examine and self-evaluation of performance), and is more socially acceptable.
- Ensures that users can easily utilize the system with any current and future VR tools without 3rd party devices.
- Evaluate users' feedback on energy consumption (52.9% lesser in terms of rise in heart rate and 26.4% lower score in NASA task load), ease of use and immersion factor compared to VR-Step through quantitative and qualitative analysis.

RELATED WORK

Navigating a virtual space highly depends on the kind of system being used. For example, mobile systems like the Google Cardboard and Gear VR does not have any physical controls, making these choices rather limiting when it comes to any form of interaction in VR space, since the user essentially only has gaze-based interaction. The Oculus Rift DK1 and DK2, as well as Sonys PlaystationVR relies primarily on a gamepad controller for both interaction and navigation, while the current generation of VR devices, namely HTC Vive and the new Oculus Rift has controllers that are tracked in physical space. With such variability in VR systems, various researches have been conducted to determine the best possible locomotion method in VR space. One of the biggest advantage offered by the HTC Vive is the room-scale VR experience, where the user can physically walk around within a confined physical space thus improving the sense of presence [24]. The Vive uses a Chaperone bounding system for the user to see the physical boundaries in virtual space, so the boundary does not need to be integrated by developers [2]. This allowance for actual walking is in line with a human's psychological requirement that physical movement is more important than a rich visual scene when it comes to locomotion [22]. It was found that both transitional and rotational body movement helps for efficient navigation [23], though another research showed that physical rotation is sufficient for actual walking, implying that immersive locomotion can be achieved without the required physical space [21].

Current Locomotion Methods in VR

More natural interactions where the user simply performs a jogging action on a spot to navigate in VR methods have been gaining popularity because spatial information is the same as the real environment, therefore humans require the correct motion to adapt to any change in the virtual world [19]. One of the more popular methods is called walking-in-place (WIP), where the user simply performs a jogging action on a spot to navigate in VR. VR-STEP was one of the newly developed method aimed for mobile VR that leverages inertial sensors in the smartphone to provide the user with a realistic method of locomotion [26]. However, this system only caters for mobile VR. Another WIP implementation is by using a Wii balance board [32]. Since the board has pressure sensors, it was relatively straight forward to use it as a locomotion device for virtual environments. This proved reliable and that the Wii board can be easily obtained, though users still need to rely on this additional peripheral to couple with the already arguably cumbersome head mounted display (HMD) and controllers for a VR setup. The same can be said about another work that uses the Microsoft Kinect to detect walking [34]. The depth sensors in Kinect allows accurate skeletal tracking of the user by measuring the angle between the hip, knee and ankles. Compared with the Wii board, gesture based recognition means that the user is at least not in physical contact with the peripheral, preserving relatively more immersion. Other approaches for WIP are by attaching calibrated sensors on the legs and calf [36], however, WIP methods tend to be more tiring and a continuous jogging motion may cause perspiration and to a more serious degree, nausea. This is the reason why VR applications rarely use head bob, which is a way to show that the virtual character is moving by bobbing the camera [28].

Arguably, the best method for locomotion in VR is by using an Omni-directional treadmill (ODT) [6]. It was initially developed for the U.S. Army's Dismounted Infantry Training Program and it allows the user to realistically perform walking motions, yet still remain at a single spot. The main disadvantage is that a custom treadmill like the ODT is surely too costly for average consumers, if even accessible at all.

There are also more unconventional methods for VR locomotion, such as a flight based locomotion by manipulating the sense of scale [18], rotating the virtual environment [20] or simply using head angle [25]. One of the more unique methods of navigation is by using brain-computer interface [8]. In this method, electrodes are attached to the user's head to obtain electroencephalogram (EEG) signals that are used as input values for the virtual environment. However, brain interface tends to have inherent issues such as the presence of noisy data, as well as it not being accessible for the average consumer.

With this current generation of VR systems, most developers rely on on-rails sequences, controller-based, or teleportation-based navigation. On-rails simply mean that the user is not given the freedom to walk around and is confined to a fixed rail that usually consistently moves which can be seen on games like London Heist: The Getaway and Walking Dead. Blink teleportation is a new method proposed by Cloudhead Games [3] for the Vive where the user simply points and teleports to the designated spot. Lastly, controller navigation using a gamepad, normally maps the left analog stick to locomotion and the right stick to head movement. For these three methods respectively, the user has no freedom of movements, teleportation is not realistic, and gamepad controls induces motion sickness.

The closest to our work is research by Mc Cullough et al. and Wilson et al. [14, 33]. Both use an arm swing method similar to the one proposed. However, they require additional hardware (the myo-arm band). The band has to be adjusted in a specific angle (susceptible to shifts and not placement-independent). They are also using simply angle changes on the upper arm or velocity to detect the walking speed, not the trajectory of the walking direction. The user in AR/VR walks in the direction of their head orientation not in the direction of the arm swing. Our approach in comparison works without additional hardware, is sensor-shift/orientation robust and uses arm swing trajectory for walking direction. The user can look in any direction while walking.

Arm Swing in Human Locomotion

Using the arm swing movement is often only limited to bipedal locomotion [1], and is a rather interesting proposal as studies have shown that arm swing reduces the moment about the vertical axis of the foot while walking [17]. This means that a relationship does exist between arm swing and foot reaction, despite it not being necessary while walking. In fact, total energy consumption with arm swing is lower than without during walking even though energy is consumed for arm movement, therefore overall reducing the cost of walking [5]. Because of these traits, researchers have utilized arm swing for walking rehabilitation [12] and robotics [4].

METHODOLOGY

The mechanics of ArmSwingVR relies solely on the users' arm swing motion, akin to normal walking gait. No form of additional pressure sensors is required for the feet movement tracking, or that deliberate head bobbing is necessary. It is important to note that the facing direction and walking direction should be different as well. This means that the user should be able to continuously walk in the direction their body is facing, yet still may freely look around. A solution for this will be further explained in the next few paragraphs. Since ArmSwingVR is achieved using purely motion recognition, no buttons are actually required, and can be reserved for other forms of interaction. This is shown in the user study, where a simple task is assigned for the participants using the trigger buttons. ArmSwingVR was developed using the HTC Vive because as of this moment, only the Vive comes with positional tracking controllers. Therefore, only the Vive controllers and headset are necessary for the user to fully use ArmSwingVR. The tracking space used for development is 1.6m x 3.1m, though for the user study, the tracking space will be maximized (4.6m x 4.6m). The entire system was built using the Unity development environment for seamless integration with the SteamVR plugin. C# was used as the primary coding language. For a smooth VR experience, a desktop Windows PC equipped with a Core i7-6700 processor and an Nvidia GTX 980 graphic card was used which is above the recommended specifications.

$$\overrightarrow{AB} = \overrightarrow{B} - \overrightarrow{A}$$

$$\hat{A} = \frac{\overrightarrow{A}}{|\overrightarrow{A}|}$$

$$\overrightarrow{AB_z} = \overrightarrow{AB}.\hat{A}_z$$

Gesture Recognition

Finite state machine was used to enable the system to recognize the position of both controllers relative to the position of the HMD [25]. The relative positional vectors for the controllers and the HMD must first be determined so that the system knows which of the objects are in front of the other regardless of the facing direction. We are only interested on the forward vector component because the height and side vectors are not important for arm swing. For the relative positions between controllers, relative vector AB is found by subtracting vector A with B. The transform vector of A is then normalized and the dot product between AB and the normalized A is used to find the forward vector component. This procedure is repeated to find the relative position between the HMD and the left controller (called vector AC), as well as between the HMD and the right controller (called vector BC).

Six states were constructed for the motion detection, which are *Idle*, *RightFront*, *LeftFront*, *RightFront2*, *LeftFront2*, and *Walk*. Figure 1 illustrates the algorithm that connect each of these states together through a series of decision making. The *Idle* state is the default state of which the user is standing or interacting with the virtual environment. In this state, no velocity is induced and the system checks the positions of the controllers. If AB is positive, BC is positive and AC is negative, this means that the right controller's position is in front of the HMD whereas the left controller is behind. This changes the state to *RightFront*. A similar decision process is made for *LeftFront*. In this next tier of state with *RightFront* as an example, we then check the duration t of which we are in the state. If t is within 1 second and the position remains the same, the state reverts back to *Idle*.

Otherwise, if the position switches such that the left controller is now front, *LeftFront2* is then initialized. *RightFront2* and *LeftFront2* is a safety state layer that ensures that the user does not accidentally walk, and will only do so on purpose. Similarly, the duration is checked again, and if the arm positions switches once more, we finally enter the *Walk* state. The actual walking motion is conducted in this state. Velocity is induced based on the walking direction. The walking direction is not the same as facing direction, which is common in most first-person view camera applications. In real life, we may walk in a direction yet face another. To achieve this, the walking direction has to depend on the forward vectors of the controllers. The resulting walking vector D is found by summing vector A and B. Figure 2 depicts these vectors from a top-down view. Linear interpolation is then used to smooth the change of vector D when the controllers are constantly swaying back and forth. Furthermore, only the rotation about y-axis of the vector is important since we just wish to know which way it is facing and not if the vector is facing downwards or tilting.

It is important to use Quaternion rotations for this because a controller that faces downwards, which is common when walking, will be subjected to gimbal lock if Euler rotations were used. If the user wishes to stop walking, several conditions need to be met. One of the most important parameters is finding the speed, s of the controller. If the speed of the controllers approach zero, it is highly likely that the user has

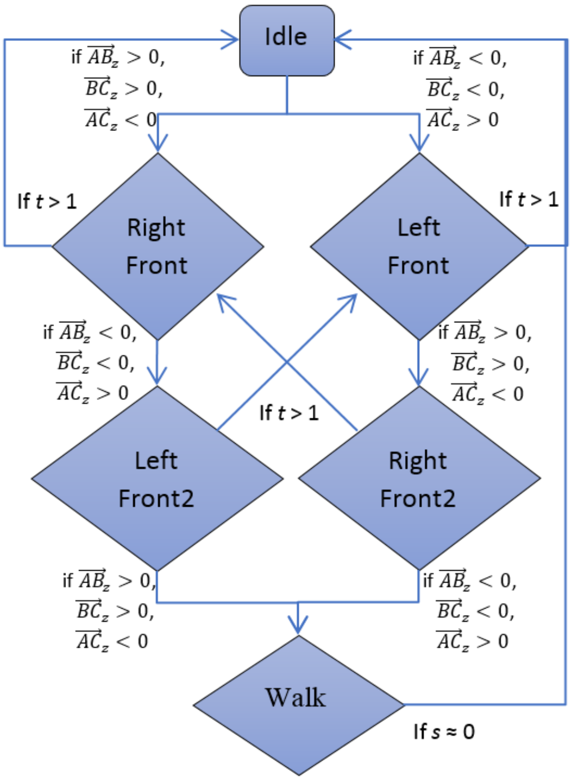

Figure 1. Finite state machine algorithm.

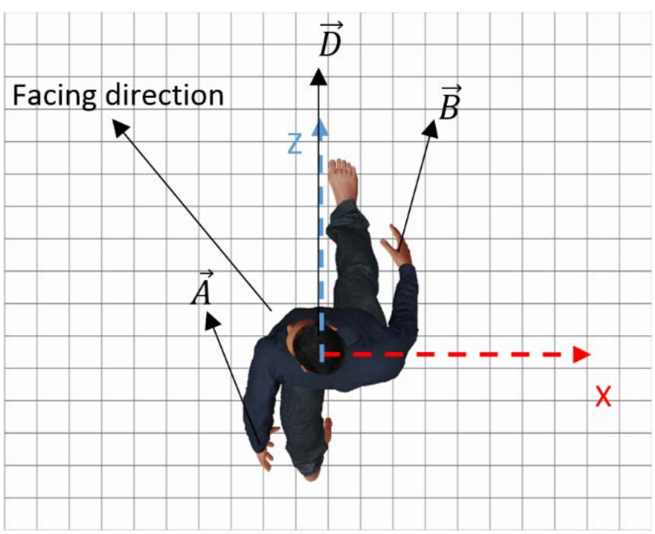

Figure 2. Top-down view of the directional vectors.

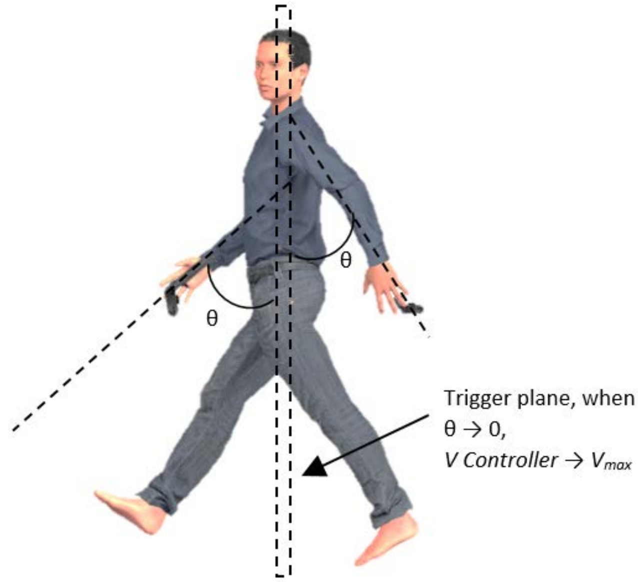

Figure 3. Placement of the trigger plane for determining the point.

stopped swinging their arms. However, the speed also approaches zero at the amplitude or maximum swing of the arms. To solve this, we created two conditions: walking is halted when the controllers' velocity approaches zero and are close to the HMD at the z-axis, or when the controllers speed remains close to zero after a period of time. The first condition uses the vector *AC* and *BC* computed previously to determine if the user has stopped any motion and is standing still. The second condition uses a Coroutine that delays the next checkpoint by 2 seconds. If the controllers are still relatively static after that period of time, the state finally reverts back to *Idle*.

The user can control the walking speed depending on the speed of arm swing. However, as mentioned earlier, the speed approaches zero at the maximum or minimum swing point. This causes a jerky movement as the velocity of the movement constantly fluctuates between zero and the current arm swing velocity. Therefore, we created a trigger plane placed on the HMD as shown in Figure 3 and only take the velocity of the arms at the point of collision with the trigger plane to ensure that only the maximum velocity value is used.

The resulting system is a relatively solid locomotion method with low accidental stops and walks, while allowing the user freedom to look around and control their walking speed without the push of a button.

USER STUDY

The user study focuses on a direct comparison between the mechanics present in VR-Step (used to represent WIP-based solutions) with ArmSwingVR, both which are easily accessible for consumers and are software-based solutions. Furthermore, since this study is aimed towards standing VR experiences, to some degree, the users are able to physically walk around a fixed amount of space due to the Vive's tracking. Our implementation of VR-Step was based on the HMD's spatial tracking data. The user firstly needs to press both the grip

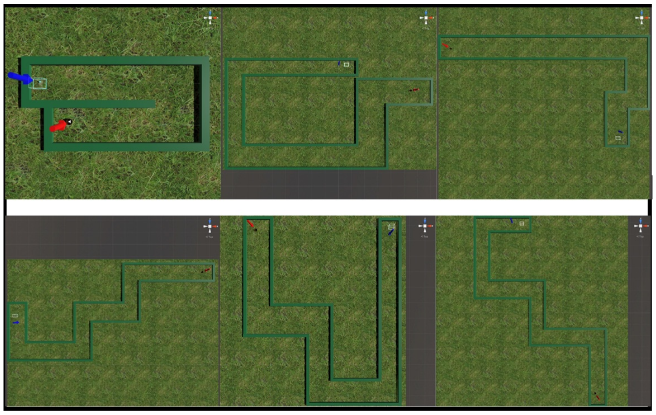

Figure 4. Virtual routes for the user study.

buttons while standing still to calibrate the height data. This creates a trigger collider above the HMD that can only be triggered when the WIP state is activated. This is as similar to VR-Step in which a distinct jogging motion is required [26]. For this method, a slightly modified state machine algorithm was used, composed of five states; *Idle*, *Transition*, *Triggered*, *Walk*, and *Walk2*. After determining the height of the collider, the system checks if the user's head enters the collider. If it does, the *Transition* state activates. This state acts as a transitional phase or safety measure to determine if the user desires to walk or was simply performing other forms of interaction. In this state, the system checks the user's head's location within 0.5 seconds. If the head has exited the collider, the *Step* phase is initialized. Otherwise, it goes to the *Triggered* state. This state activates when the user's head has been in the collider for a period of time. If the head exits the trigger again within 0.5 seconds, *Step* is registered. Otherwise, it returns to the *Idle* state. In the Step state, velocity is induced to the rigid body, creating a forward motion at the facing direction. Unlike ArmSwingVR, facing direction and walking direction are not independent. Maintaining this velocity depends on the user's capabilities to alternate the head position from entering and exiting the collider, i.e. a head bobbing motion. Therefore, *Step2* was created for when the head enters back the collider while in the *Step* state. *Step2* then reverts back to *Step* when the head exits the collider again, for a continues induced velocity. If none of this conditions are met, the state reverts back to *Transition* to check again, and no more velocity is induced. Each participant is given about 5 minutes to familiarize themselves with the locomotion controls for both methods before the study is initialized.

To ensure that the speed of movement of the participant for both the locomotion methods are the same, the previously mentioned feature regarding controllable locomotion speed is disabled. We obtain the immersion and Simulator Sickness data through the Presence Questionnaire and Simulator Sickness Questionnaire (SSQ) [11]. To determine its effectiveness, the participant is required to navigate a series of routes shown in Figure 4 while picking up virtual balls that they find using the trigger button.

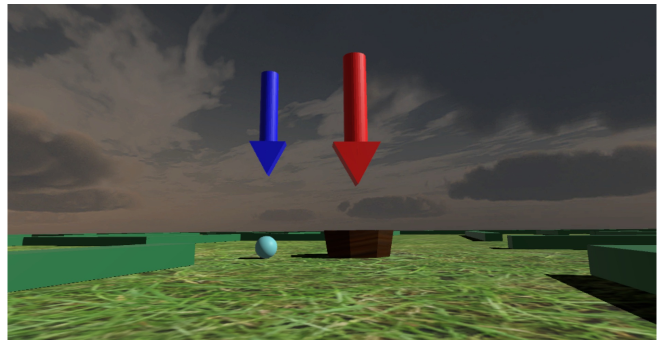

Figure 5. View of the participant, where the blue arrow is the location of the ball and red arrow is the location of the basket.

These balls must then be placed into a virtual basket located further down the route, where it counts for 1 point per ball. After each score, the next route appears and the participant must repeat the process. Figure 5 shows a giant arrow hovering over both the ball and the basket so that their positions are known. The routes were designed in a way that forces the participants to navigate in all four directions. They are also straightforward to eliminate any requirement for the participant's spatial awareness. This task runs for 15 minutes per participant, for each of the method. Even though extended VR sessions are not advisable [15], VR is improving every day and full story-based 3D games are being developed for VR as of this moment, therefore we deemed it necessary for participants to spend 15 minutes for each method to determine the outcome and energy expenditure.

At the end of each locomotion experiment, the participants are required to complete the SSQ to determine their feedback on any induced motion sickness [10]. To determine the immersion and sense of realism, the presence questionnaire [35] was deemed suitable because it covers a wide area of applications including locomotion in VR. We chose to exclude the sound and haptics-based question as they are not related to the current study. To determine energy consumption and workload, the NASA task load and heart rate monitoring is used [7]. For the quantitative analysis of performance, we compare the score achieved through both methods. The participant's beats per minute (BPM) is taken three times each, prior to and after both studies to determine the heart rate, for a total of 12 readings per participant. Even though heart rate data can be further improved by coupling it with accelerometer, we determined that since the movement mechanic for both of the methods are fundamentally different, using an accelerometer is not suitable. Furthermore, BPM data can be easily obtained from various health monitoring devices, in our case, the Samsung Galaxy S6 Edge+ smartphone. Thus, data from both the NASA task load and heart rate monitoring are sufficient and relatively accurate to determine energy consumption [7, 9, 31]. Additionally, we use both the NASA task load and heart rate because relying on only one of them may not achieve the accuracy we desire. Relying on a purely qualitative analysis is rather subjective, while heart rate monitoring is also associated with stress level [30]. However, for the purpose of this user study, since the participants will mostly be actively engaging in the VR environment using both locomotion methods, it is more than likely

Figure 6. User study for ArmSwingVR (top) and WIP locomotion (bottom).

that the rise in BPM is due to physical activity. A total of 18 participants were recruited, comprising of 12 males and 6 females aged between 20 to 27. All of them do not have prior cardio-related health issues related and are inexperienced with both mechanics of ArmSwingVR and WIP.

RESULTS

Comparison was already made between actual walking and WIP [29], however, ArmSwingVR is a novel method that has not been developed or studies up previously when it comes to VR locomotion. Starting with the overall score for the participants, the average score for ArmSwingVR is 7.44 while for WIP is 7.22, suggesting that they both perform equally under equal locomotion speed. Figure 7 shows the SSQ analysis results for both methods based on the SSQ computation method [11] with regards to nausea, oculomotor, disorientation, and the total score.

Interestingly, one of our assumptions was that ArmSwingVR does not cause more motion sickness compared to VR-Step's solution. Yet, our results show that ArmSwingVR produces less sickness with regards to nausea and the total SSQ score, whereas WIP method shows to be better in terms of oculomotor by a small margin and disorientation. Disorientation in particular is interesting, because the participants seems to be less disorientated compared to the rest state as well. A T-test analysis for each of the category between ArmSwingVR and WIP shows no significant difference except for nausea with a score of $p = 0.0022$. This was reinforced with an Analysis of Variance (ANOVA) for nausea that showed statistical significance between pre-test, ArmSwingVR and WIP ($F(2) = 10.951, p = 2.92x10^{-10}$).

In terms of presence, the results are divided into the following sub categories; realism, possibility to act, quality of interface, possibility to examine and self-evaluation of performance. Figure 8 shows the participants' feedback using the presence questionnaire for both methods.

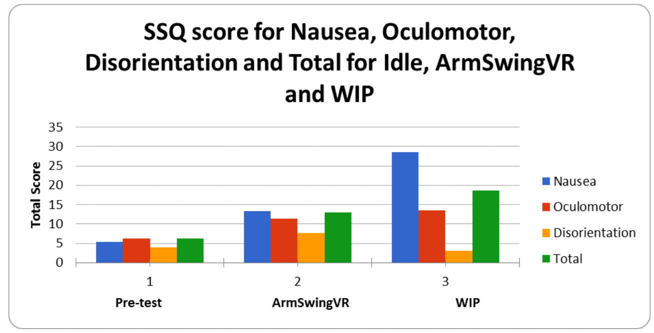

Figure 7. Chart for SSQ score.

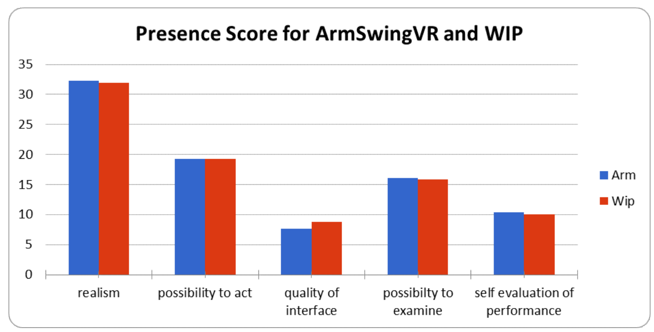

Figure 8. Chart for Presence score.

Performing a T-test for these forms of presence gives us a p score of 0.94, 0.97, 0.37, 0.88 and 0.81 respectively, proving that there exists no statistical significance between ArmSwingVR and WIP. This also means that no significant sense of presence was sacrificed for the participants and the immersion level is comparable and preserved.

By observing the heart rate, we can clearly indicate that the WIP method causes a much higher BPM for the participants since it requires more motion and energy for a continuous jogging motion, as opposed to ArmSwingVR. Figure 9 shows the general BPM readings for the participants. Figure 10 shows the rise in heart rate for the participants for both ArmSwingVR and WIP, by subtracting the heartrate with its pre-test values. Overall, it can be seen that the highest rise in heart rate for a participant is 51.66, which was a rise from 78.67 BPM to 130.33 BPM for WIP approach. ArmSwingVR has a significantly less rise in heart rate with the highest value being at 24.33, which was a rise from 87 BPM to 120.33 BPM. This clearly indicates that WIP methods generates a higher heart rate, which is associated to a higher expenditure of energy. To enforce this, the NASA task load data in figure 11 illustrates a quantitative take on this analysis on energy expenditure. This score is taken after each participant answers the questionnaire for mental demand, physical demand, temporal demand, performance, effort, and frustration, followed by weighting each of these factors.

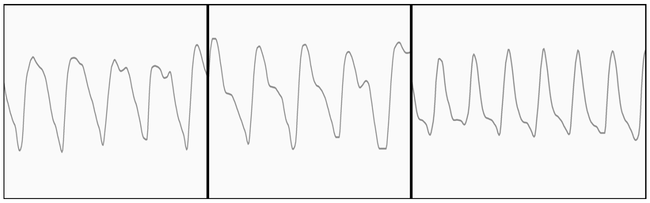

Figure 9. Heart rate against time during idle (left) around 80 BPM, ArmSwingVR (middle) around 95 BPM, and WIP (right) around 120 BPM.

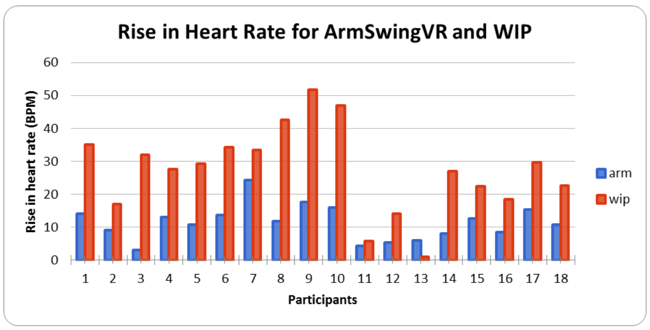

Figure 10. Chart for each participant’s rise in heart rate.

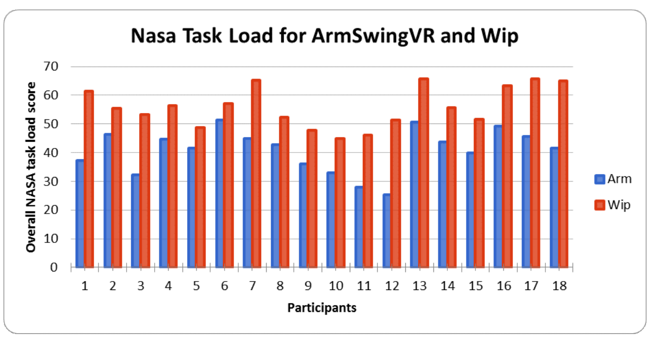

Figure 11. Chart for overall Nasa Task Load score.

It can be seen that the participants unanimously score higher for the WIP solution with the highest score at 65.67. The average ArmSwingVR score is 39.87, while for WIP is 54.18.

DISCUSSION

We showed the feasibility of ArmSwingVR. Studies have already proved that dynamic walking overall induces less motion sickness compared to static walking in VR [10]. This can also be mentioned as a comparison between room scale VR where the user is required to physical walk around and interact, with sitting VR where physical motion is kept to a minimum. According to the feedback of some of the participants, almost all of them agree that locomotion by arm swing is low in profile yet remains immersive, making it suitable for public use. Furthermore, cables on VR HMDs caused some annoyance for WIP and rarely for ArmSwingVR, though as VR evolves, wireless solutions are more than likely. Some of the participants noted that there is some gliding issue with regards to both methods. Gliding is when the participant stops moving, and the system takes an additional second to actually stop. This gliding issue does cause some motion sickness. However, similar to VR-Step, the gliding issue is not perceived once variable speed control is activated [26]. This is because even though gliding may still exist, since the system accelerates and decelerates according to the user, it is more difficult to notice. The immersion factor of WIP cannot be ignored, however, a continuous jogging motion is quite tiring as most if not all participants ended up sweaty and panting after just 15 minutes in the VR session. This is the reason why nausea scored high for the WIP method, since sweating was taken into consideration in its scoring. Another issue with WIP that is worth mentioning is that since the jogging motion uses feet movement (even though it is not obligatory for the system to function), most if not all participants tend to drift from their original position. This drifting often causes them to move away from the Vive’s tracking area, or in some occasions, minor collision with the physical wall of the room. This is one of the factors that make WIP methods less desirable for social space usage.

For ArmSwingVR, most participants had no issue performing it for 15 minutes. Each participant was also clearly told to hold the controllers facing forward since the walking direction is influenced by it. However, some of them start to hold the controllers in other angles particularly after about 10 minutes, causing them to not walk straight, thus inducing a small but negligible amount of sickness. However, most participants also added that this feature is more realistic. After trying on the WIP method, they tried to do the same, and this caused some motion sickness since WIP methods rely solely on facing direction. Since ArmSwingVR requires precise tracking of the hand trackers and HMD, it is vital for the participant to maintain in the Vive’s tracking area. Thankfully, since no feet movement was present, the drifting issue can be avoided. Occlusion may still happen occasionally, but this is more of an issue for any infrared (IR)-based tracking. If sensing is based on inertial sensors, this issue is mitigated.

Overall, all participants agree that ArmSwingVR is the better choice for VR navigation use even in public spaces, unless the VR environment was designed for working out. Furthermore, since some degree of physical interaction is required for locomotion as opposed to more traditional means like button input and blink teleport, the immersion is preserved. This allows for a wider target audience including the elderly to indulge in a more immersive VR experience.

LIMITATIONS

Naturally, the main drawback of ArmSwingVR at this point of time is that it is only limited to VR systems that provide controllers that tracks both hand positions. However, as VR becomes progressively better and more main stream, such controllers will surely be adapted in other VR solutions, until the point where gesture-based recognition becomes mainstream. Additionally, ArmSwingVR was developed purely for navigation on a terrain, and was not designed for jumping because there is no noticeable or distinct arm motion when a human jumps. In this regard, WIP systems should be able to perform better, though this is another matter entirely but worth mentioning. Lastly, since the arms need to be constantly swinging, it is difficult to perform other forms of interactions that requires hand gestures while navigating. Although the same can be said with most other WIP methods, it is nevertheless a matter that needs to be considered depending on the application. Even though sitting VR experience was not covered in this study, nevertheless it is worth considering. The algorithm currently used for ArmSwingVR does not support sitting experience at the moment, though that can be easily added on. Interestingly, some of the participants did mention that arm swing while sitting would be quite acceptable as opposed to head bobbing motion which is strange with no leg movement. This is best experienced with a chair that can rotate for turning around.

CONCLUSION AND FUTURE WORKS

As mentioned previously, seeing how different VR systems can be, it is difficult if not impossible to find one best locomotion method in VR. The proposed ArmSwingVR manages to reduce energy consumption while still being immersive, making it suitable for wider audience of a different age gap, as well as for social spaces. Due to its software-based solution, users do not need to rely on additional peripherals and sensing methods like sensor-equipped shoes, etc.

In the future, ArmSwingVR will be further modified for to be used while sitting. With regards to motion tracking controllers, another tracking method that is quite likely implemented in the next few generations of VR hardware is eye tracking [16]. This is an interesting notion since eye tracking can be built into the HMD itself, thus still negating the need for additional third party sensing hardware, yet still provide an additional layer of input. By combining eye tracking with ArmSwingVR, new experiences can be developed with high immersion. This is where WIP methods may find it hard to benefit, since continuous head bobbing motion does not bode well with eye tracking. Lastly, we plan to perform an in-depth analysis on the degree of acceptance for ArmSwingVR in social spaces. Since we have gathered a rather positive feedback regarding this matter from the participants, we plan to conduct a social experiment to quantify this degree of acceptance. ArmSwingVR may not offer the subtlest of interactions, but it provides a higher immersion that is essential for any VR experience without being too obtrusive.

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