A Comparison Between a Natural and an Inorganic Locomotion Technique

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***Abstract*—Virtual reality is becoming a more popular attraction every year not only to researchers, but the general public as well. One of the major challenges standing in the way of virtual reality becoming even more widely accepted is the adaptation of new locomotion techniques. This paper attempts to discern between two different locomotion techniques and decide which method is more efficient based on certain parameters. The two techniques being analyzed were tested in a case study, one involving inorganic movement (touch pad control) and the other natural movement. The users tested both forms of locomotion separately by navigating through a predetermined course that is comprised of multiple checkpoints. Data such as efficiency and time were recorded via applications, as well as a post test survey that each of the participants were given. After all the data was collected, the results were analyzed and the most efficient and preferred form of movement was established.**

***Index Terms*—Virtual Reality, VR Motion Sickness, Locomotion, Inorganic Movement, Natural Movement**

I. Introduction

The purpose of this study is to compare a natural and an inorganic method of locomotion in Virtual Reality. The study tested to see which method is superior when utilized by a sample of college students. At the least, we explore which method allows the users to traverse the virtual environment more efficiently. Natural methods are those that mimic something that the human body is already used to [1]. The natural method in this study is a walking in place (WIP) method, in which the user moves forward in the virtual world at a fixed pace as they walk in place. The inorganic method uses the touchpad on the HTC Vive controller to move the player forward. The touchpad movement, will control the users avatar in a way that the body has to learn. Another example of a learned method is a person using a mouse with a computer. When first introduced to a computer, moving the mouse on an x,z plane reflects to the mouse moving on an x,y plane on the computer [1]. One of the main focuses of this study is to determine if natural and inorganic methods correlate to efficiency and immersion in virtual reality. This method also moved the user at a fixed speed in the Virtual Environment (VE). In both methods the user moves in the direction the head-mounted display (HMD) is facing.

This study is important due to its emphasis on the topics that are related to the limitations of interacting with VR. While natural walking in room scale is available for Virtual Reality, it does not provide users with the ability to walk outside of the play area. Because of this and the many games that require different types of locomotion, there are multiple types of locomotion being researched in order to find a method that includes certain requirements. These requirements include not being restricted by the size of the play area, allowing users to travel far distances with reduced fatigue, and meets the requirements of the game [2]. It is also important to ensure that the method does not make the user feel ill. This gives us reasons to compare the natural and inorganic methods to find out which is superior.

Developers will benefit from this study depending on the type of game being developed. This study can give developers an idea of which method is more efficient, and which method meets their needs. If immersion is important, WIP may be chosen for a method of locomotion. If a potentially less taxing method of locomotion is required, they may choose the inorganic method for their locomotion requirement. Developers may even be able to utilize both as users may have a preference between which method they would like to use. This study may show which method is superior when it comes to cybersickness, efficiency, fatigue, and immersion. Cybersickness and fatigue are examined using questionnaires, while efficiency is determined through the time it took for players to navigate trough the VE.

The rest of this paper is structured as follows: Section II outlines the implementations of the natural and inorganic methods. Section III describes the participants, the hardware used, and the design of the study. Section IV covers the results of the experiment, and the responses for the feelings of fatigue and cybersickness. Section V includes discussion on the implications of the data and responses. The conclusion and a discussion of future work is presented in Section VI. The last Section VII contains the acknowledgements.

II. Implementation

Both implementations use the forward direction of the HMD to determine which direction the user will be translated as movement occurs. It was possible to make the direction of movement for the inorganic method dependent on the controller, but we felt it added unnecessary complexity. Both methods multiply the translation vectors by Time.DeltaTime [3] to ensure that the speed of the computer does not affect the speed of the user. All the checks for input were in the Update function [3].

Code was developed for detecting motion for WIP movement. In this code the height of the feet is compared to check if one foot is more elevated than the other. For the inorganic method, the touch pad was monitored and return values had to be towards the edge of the touch pad in order to move. This helped make the movement smoother and eliminated jerkiness while the thumb moved in the middle.

III. User Study Methodology

In order to increase the overall understanding of the data collected from the study, all participants were asked to fill out a pre-test survey. The survey asked questions about topics such as their current energy level, as well as their experience with VR and video games. A post-test survey was also administered to gather information on how the users felt about the different locomotion methods. The post-test survey questions about feelings of fatigue, sickness, and overall enjoyment. The users experienced both methods. The order of the methods tested were randomized in order to reduce the odds of the data being affected by the ordering.

A. Participants

The participants used in this study consist of a wide and diverse range of people, both of different backgrounds and genders. There were a total of 20 participants in which 12 were male and 8 were female. They were all at one point enrolled at a university, with fields ranging from marketing to computer science and engineering. We made certain to choose more participants with no background in computer science in order to properly gauge how people outside of the field react to virtual reality. By choosing participants outside of the field of computer science and engineering, it also increased the chances that the subjects never used virtual reality before.

Most of the participants answered in the pre-test survey that they had little to no experience with virtual reality. A higher percentage of males answered that they had little virtual reality experience compared to the females. It is also worth mentioning that two of the female participants were two out of the three computer science and engineering majors used for the study. Most of the participants, both male and female, also claim to have had experience playing video games with the exception of a few that answered little no experience. There was also about an equal amount of participants that answered in the survey that their energy level was either high or low/moderate.

Most of the participants answered in the pre-test survey that they are not prone to motion sickness; the majority that answered yes were female. In the post-test survey, both male and female participants answered that they felt more motion sickness, as well as fatigue using the natural method. As a result of this, most of the participants in the post-test survey answers suggest that they prefer the inorganic over the natural method of locomotion. In the post-survey, there did not seem to be too much of a disparity between the male and females involving their level of motion sickness and fatigue. A majority of the participants answered that participating in this study increased their interest in virtual reality.

B. Apparatus

In order to avoid preventing players from being faster or slower in either method, both the organic and inorganic methods used set speeds. However, the natural methods could have been allowed to have varying speeds if deemed necessary.

We used the Unity Game Engine in order to create the application in which we had participants use (Fig. 1) [3]. Within Unity, the SteamVR asset package as well as the Hand Painted Forest Environment Asset shown in Fig. 2 [4], [5] was used. These allowed us to create an aesthetically pleasing environment for the participant to move through, as well as provide us with a library to interface the HTC Vive headset with.

C. Procedure

The participants were then introduced to the virtual reality system and the space that they were going to be spending the duration of the study in. Then the participants were given the pre-test survey to fill out. Some of the questions asked were about their experience with VR, their reason for coming, and what their major is. After completing the survey, the first locomotion method to be tested was explained to them. Once they confirmed they understood the method, they were given the headset and controllers. The participants were told that if they felt sick they could stop the testing at any time. Then they familiarized themselves with the method by exploring the VE before the test was started. The users then completed the course and data was taken.

After completing the first method, the users were given a five minute break. The break was given to reduce the odds of fatigue, along with the possible feeling of motion sickness so that results from the next method were not affected. After the break, they were briefed on the next method. When they verbally confirmed that they understood the method, they were given the headset and feet sensors. They were given time to get used to the method of locomotion, and completed the course again. The data was again recorded. Finally, after obtaining all of the data, the users were then asked to fill out a post-test survey. The survey asked questions about which method was more immersive and enjoyable. The participants were also asked to gauge how sick or tired they felt on a scale of one to ten.

Throughout each run of the course, two separate times were measured. The most important of the data collected was the overall time from the starting line to the finish. The time it took for the user to move between each checkpoint was also recorded. The data was saved as split times for easier data analysis. The final pieces of data that were collected are from the post survey. These were just a hard value given as an opinion of how motion sick and fatigued the participant felt.

D. Tasks

As stated previously, after the participants were briefed on the control scheme of each locomotion method, they were

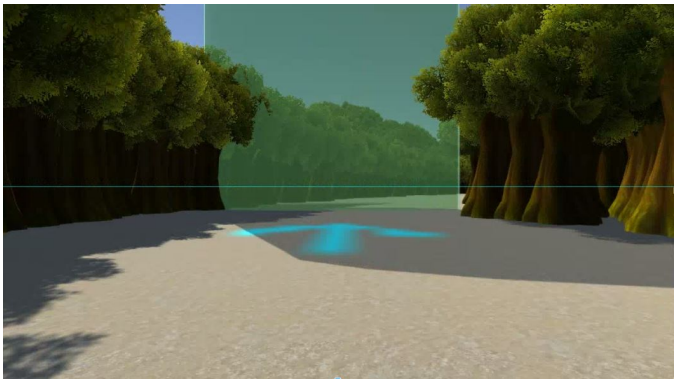

Fig. 1. A perspective view of what participants would see when the testing application starts

allowed one minute of free time in the virtual world to explore using said method of locomotion. Once their exploratory time had expired, the participant was moved to the starting zone of the application. Once they moved through the first checkpoint, the timer was started and they began moving through a predetermined course as fast as possible using the respective locomotion method. There was a single path on the ground for the participant to follow as seen in Fig. 2. In order to complete the course, the participant needed to navigate through a series of checkpoints. The current checkpoint the participant had to reach was seen as a massive translucent green screen. Once the user reached the end of the course, they were briefed on the other method of locomotion and followed the same steps.

Fig. 2. An overview of the course for each participant to follow.

Throughout each run of the course, two separate times were recorded. As mentioned earlier, the most important was the overall time from the starting line to the finish. The time it took each user to move between each checkpoint was also recorded. These values were saved as split times for easier data analysis. The final pieces of data that was collected was from the post survey. These were just a hard value given as an opinion of how motion sick and fatigued the user felt.

E. Design

In terms of variables for this study, there were not any between-subject variables. Our independent variables were all within-subject. The independent variables were the style of locomotion and how sick and fatigued the participant felt at the end of each course. Each participant performed the two styles of locomotion. The order in which the participants performed them was random. This way, the data was able to be gathered in a more efficient fashion. If each participant did one style first and the second after, then the data could be skewed towards the second movement style being more efficient. This would be because the participant would already know the course. The overall entry for this study was 20 participants, two forms of locomotion, and one course to move through. The course contained sixteen checkpoints, including the time between the last checkpoint to the finish.

IV. Results

A. Course Data

Fig. 3 displays a box and whisker representation of the overall lap times for each participant. We used a One-Way ANOVA calculator to find the p-value [6]. The p-value that resulted from the data was .024. Thus, the data between the two populations is statistically significant. The averages between each participant for each reached checkpoint were very close. However, the average times it took for each participant using the inorganic method to reach each checkpoint were faster than the average times it took for each participant using the natural method to reach each checkpoint.

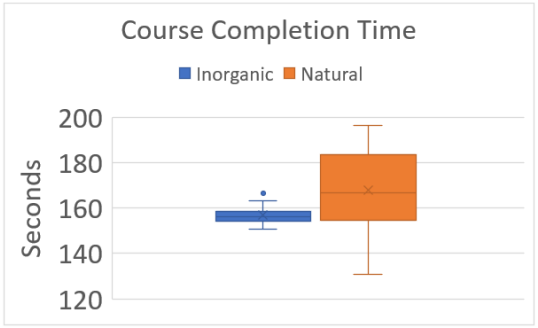

Fig. 3. Box and Whisker Plot for the course completion times of each participant in seconds. **Inorganic:** Average=156.8, Median=156.2, Outlier=166.6, Maximum=163.4 Minimum=150.7 **Natural:** Average=167.7, Median=166.8, Maximum=196.3, Minimum=130.6

B. Cybersickness Data

Fig. 4 shows the Box and Whisker Plot for feelings of motion sickness. We used a Likert scale from 1 to 10 to collect data on feelings of cybersickness. In the scale, 1 means that the user felt no symptoms of motion sickness, while 10 means they felt extremely sick. After running the data through a one-way ANOVA calculator [6], the p-value between the two populations resulted in .069. If $\alpha = .05$ the data between the two populations is not statistically significant. A fair number of participants, one half, felt no sickness whatsoever using both

methods. Some felt the inorganic method caused more sickness while some felt the WIP method caused more sickness.

C. Fatigue Data

Fig. 5 shows the Box and Whisker plot for feelings of Fatigue. When we gathered data for fatigue we used a Likert scale from 1 to 10. In this scale, 1 means the participant felt not tired, while 10 means they felt extremely tired. We found the p-values for the data received for fatigue using the same calculator [6]. The p-value is $< .00001$. We had trouble interpreting the responses from ID 16. This is because 16 answered that the inorganic method was more tiring because of walking. We assumed this was a mistake and swapped that participant's values for fatigue.

V. Discussion

A. Comfort

According to the post test surveys, most of the participants reported the inorganic method as being more comfortable with the exception of three. One of the three users that preferred the natural method mentioned that they got tangled up in the wires from the headset during the inorganic method. This probably affected their decision to choose the natural method. The other two reported that they preferred the natural method because they found it more entertaining.

There were some common trends that appeared with the participants that chose the inorganic method as being more comfortable. These trends included the users being able to stand still while moving as compared to walking in place, the ability to turn easier, and overall less physical exertion. However, there was one participant that claimed they preferred the inorganic method when walking a straight line, but they found it more comfortable to make turns using the natural method. As mentioned earlier in the participants section, the users also found the inorganic method to be more enjoyable. Perhaps there is a correlation between comfort and level of enjoyment, despite the natural method being more immersive.

B. Intuitiveness

One participant claimed to have felt that the inorganic method was more intuitive due to having played video games

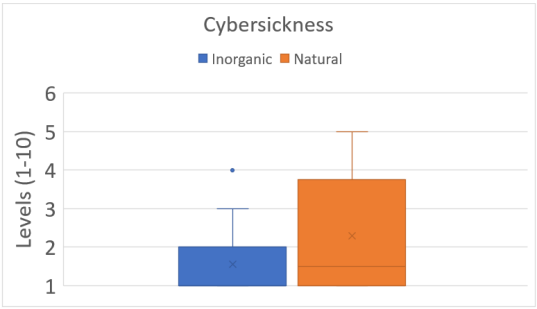

Fig. 4. Box and Whisker Plot for Cybersickness Responses. **Inorganic:** Average=1.55, Median=1, Outlier=4, Maximum=3 **Natural:** Average=2.3, Median=1.5, Maximum=5

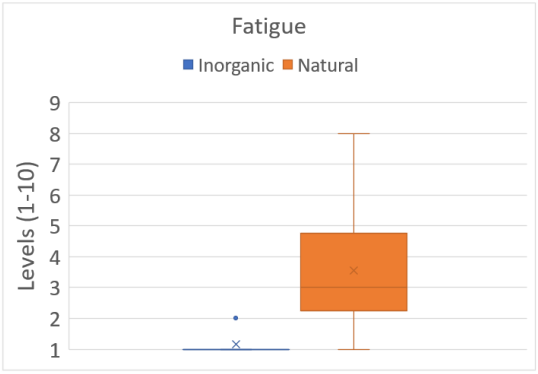

Fig. 5. Box and Whisker Plot for fatigue responses. **Inorganic:** Average=1.15, Median=1, Outlier=2, Maximum=1 **Natural:** Average=3.55, Median=3, Maximum=8

in the past. At least two participants stated that the inorganic method was more intuitive due to having experience with VR. Some participants felt that the controller method was more intuitive because of the feeling that they had more control, while at least one stated that it was more natural to them. One participant said "... I felt like the way I was walking felt more strange than just guiding with my hands." However, several felt that they had more control walking in place whereas others felt that walking in place was more natural. One participant said "the organic method was more intuitive because it was [the] easiest to control directionally, as if I were actually walking." Another said, "I thought the foot sensors felt more intuitive because the movement felt more natural."

C. Immersion

A few participants reported that the inorganic method was more immersive while the majority felt that the natural method was more immersive. Many felt that the walking was more realistic, since they were actually moving their legs rather than just using a controller. One participant said the inorganic method felt more immersive because "it felt as if [the participant] was actually moving through the simulation rather than just gliding through it." However, there was one participant that felt that the inorganic method was more immersive because the participant "did not have to think about walking as much." Based on the responses, the natural method appears to be superior when it comes to higher levels of immersion.

D. Cybersickness

Cybersickness is a condition that likely occurs in certain individuals that may be caused by conflicting senses like viewing movement through eyes, while other cues such as vestibular cues tell the brain that there is no movement. [7] One of the main aspects that keeps VR from becoming even more widely accepted is cybersickness or VR motion sickness. Another important factor that applies to developing a successful locomotion method is the level of VR motion sickness it induces. This part of the study focuses on which locomotion method induced the most VR motion sickness. The

intention for this subsection is to discuss how participants felt about both methods.

Participants were asked about the level of motion sickness they felt using both methods in the post-test survey. Several stated that they felt sick from the inorganic method while making turns, "there was a little motion sickness because of turns." A participant that felt sick from the WIP method said: "Because I was actually moving, there were times where I would turn and almost fall over, it felt as if my body was moving faster than my legs." It is possible that this could be due to the speed of the simulations as the users moved somewhat fast in the VE. Another said: "I felt like I was losing my balance a few times and my stomach kept flipping." But the same person said: "[I] Only got a little disorientated going around sharp corners" when talking about the inorganic method.

We were surprised that users felt sicker from the natural method. There were 9 people who reported to not feel sick at all, which may be why the medians are so low for both methods. Overall, at least according to the averages, WIP seemed to cause more feelings of sickness. It also seemed to cause more intense feelings of sickness to users who are affected by cybersickness.

E. Fatigue

As expected, the majority of users found WIP to be more physically exhausting than using the touchpad. Some felt that the difference between the physical exertion from the two methods was large, while some did not seem to really notice it at all. It is worth mentioning that ID #20 said that he/she was feeling tired that day. Some responses for how users felt how tiring the natural method was includes: "Slightly Winded", "more movement involved, as if I was exercising", and "I didn't expect to exert as much physical energy as I did." Most felt little to no physical exertion from the inorganic method.

The inorganic method does not require much effort, which is why there is almost no variability. The natural method on the other hand did have noticeable variability. This could be due to different effects of exercises on participants and because the speeds vary due to the many different ways users can give input for walking.

As mentioned in the participants section, there was an equal amount of users who reported high and low/moderate levels of energy before participating in the study. Even most of the participants that reported having high levels of energy still said that the natural method was more physically strenuous. There were a few exceptions who reported not feeling tired at all after testing the natural method, one participant stated "It didn't require noticeable physical exertion." Therefore, it is safe to conclude that the inorganic method is better in terms of lower levels of fatigue. In a later section, we discuss how this observation could have affected the user's level of enjoyment for each method.

F. Efficiency

According to the average time it took for users to complete the course, the users were faster using the inorganic method. One user said, "I thought the controller-based movement was the most efficient because I was able to move at the same speed throughout the test. Also when making turns when using foot sensors, it felt disorientating." Another said "I think the inorganic method was most efficient in terms of speed. It also required the least amount of movement. However. moving felt more difficult to control (directionally)." Several others mentioned that they felt the inorganic method was more efficient due to it being easier to use than natural. Another felt that the smoothness of the inorganic method was preferable, "The inorganic method because it was just smoother overall and it provided continuous in-game movement."

When it comes to the averages times of how fast each checkpoint was reached, the natural method took a little longer for each checkpoint. The parameters were adjusted so that one of the authors could reach the finish line at similar times for both methods. The parameters may have had a decent effect on the results. According to the data for lap completion, the inorganic method seemed to be more efficient. The natural method was also more complicated to use which may have had an effect on speed. This is because users would have to figure out how to walk in place in a way that allowed them to move smoothly without stopping. Although it may seem that WIP should feel more natural to users, some have commented on it not feeling natural.

While some felt that the inorganic movement was faster, others felt that the natural movement was faster. One participant said, "the controller method was a lot easier, but I feel the foot controllers were faster." A participant said, "the most efficient method to me was the natural method. I felt more grounded. when I had to turn my body using the inorganic method, I found my balance to be poorer."

While the data shows that the inorganic method was more efficient, this could have been affected by the parameters used for the methods. This might be partly why users felt that the touchpad method was more efficient. Around five users felt that the inorganic method was more efficient due to it being easier to use, or because it did not require as much energy to move in the VE. The rest of the participants gave other reasons for why they thought the inorganic method was more efficient.

The natural method had more variability than the inorganic method. This may be due to the inorganic method being much simpler to use. The natural method required walking in a certain way to move as smoothly as possible in the VE. The inorganic method did not require much skill to move at a constant speed. This may be why there is not much variability with the inorganic method, but the natural method has participants who completed the laps quickly, and some who completed the laps slowly.

G. Enjoyment

A majority of participants reported that the inorganic method was more enjoyable than the natural method. Several have stated that they enjoyed the inorganic method more due to feeling less cybersickness. Others felt that the inorganic

method was more enjoyable because it required less physical exertion. When asked the question about which method was preferred, the participant said, "the inorganic method because I'm lazy and didn't enjoy picking up my feet to get through the course." It seems that fatigue may have been a major deciding factor for this part of the study. It also seems that the excitement of immersion in this case, did not outweigh the user's dislike of feeling fatigued.

However, the few participants that enjoyed the natural method gave reasons that included the enjoyment of walking itself or for the immersion. For example, one participant stated "Natural was more enjoyable because I felt more engaged with the environment." Another participant said "I found the foot sensor usage was more enjoyable. Although the turning felt a little disorientating, it still felt fun to actually walk in a simulation. It felt like I was in a footrace."

VI. Conclusions and Future Work

A. Conclusions

In this study, we have found the inorganic method to be the preferred method of locomotion within our sample. This is due to the responses received for feelings of fatigue, cybersickness, enjoyment, and comfort. We also found that the users were more efficient with the inorganic method, using the speed of the average times for completing the course as the metric. However, the WIP method was superior pertaining to feelings of immersion.

B. Future Work

This case study may have compared the inorganic and the natural methods when walking through a path, but it does not necessarily show how the methods are affected by situations in a real game scenario. However, a similar scenario as the simulation could be related to racing games, but not all games will require the player to travel a long distance without taking a break. Some games like puzzle games for instance, may only include some walking but with less continuous movement. Puzzle games may expect users to keep track of a lot of information or to be in the process of puzzle solving. The different effects of cognitive load provided by each method may have an effect on gameplay. This means that whichever method is superior depends on the type of game being played. Therefore, there could be more research done looking into these methods based on different tasks rather than walking in a lap. This research should include a better analysis of the effects pertaining to cognitive load in their respective scenarios.

The locomotion methods tested in this study are just two of the many types of locomotion methods. Another interesting method is redirected walking. Although redirected walking requires at least a 6x6 meter play area, it is an interesting method for ensuring that the user can continuously walk forward in the VE without leaving the play area [8]. An inorganic method that was not looked into is teleportation. Teleportation is where users can instantaneously move to a new position in space. This teleportation can be implemented in a number of ways. Some can include activation of the teleportation by use of the controller, blinking, stomping, or looking at a position for an extended period of time [9]. There are many more possibilities and methods. More studies can be done looking into these methods to try and find which will best serve the user's needs.

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