

# Group 8: Spring Locomotion

Thanos Soulis\*  
University of Copenhagen

Sofie Riis Endahl †  
University of Copenhagen

Luca Anna Kosina‡  
University of Copenhagen

## 1 ABSTRACT

Jumping is an alternative way of moving in VR instead of walking, flying, or teleporting. In this report we propose a technique in which users' arm movement and direction are translated into horizontal and vertical movement in the virtual world, resembling how a spring would contract and expand in response to external forces. We compare it with a baseline button-based jumping technique in regard to task performance and VR sickness. Through our study, we found that both techniques have comparable performance, with our spring-jumping technique being slightly faster but a bit less accurate than the baseline in a hurdle trail. Furthermore, we found similar levels of VR sickness for both techniques, but increases of disorientation in the hand-based technique. However, spring-jumping was reported as more fun to use by the participants.

## 2 CONTRIBUTION

We designed the technique and study setup together.

Thanos implemented the hand-jump and the baseline button-jump techniques and wrote the section **Implementation**. He also contributed to the general format of the report.

Sofie wrote the sections **Experiment Design**, conducted the study experiments, recorded the data, and made the submission video.

Sofie and Thanos co-wrote the section **Abstract**. Luca and Sofie co-wrote the section **Results/Task Performance**.

Luca analyzed the results and wrote the sections **Introduction**, **Related Work**, **Results/VR Sickness**, **Discussion** and **Conclusion**.

## 3 INTRODUCTION

Basic common locomotion techniques in virtual environments include walking and teleportation. While the first is closest to real-world locomotion, techniques like teleportation can avoid spatial limitations of, for example, tracking walking movement. They can also accelerate movements in the virtual world. The choice of locomotion techniques can therefore also depend on the design of the virtual world: For example, big worlds requiring long-distance movement suggest teleportation as a technique. While walking increases the users' presence, teleportation is considered more efficient and comfortable with less sickness. [1]

Additional complexity shows up when instead of just moving on the horizontal plane, a world requires vertical movement. Then, usually, supernatural locomotion techniques like teleportation or flying are being employed. However, it would be interesting to evaluate more natural techniques for combining vertical and horizontal movements and therefore increasing presence through naturalness, while also increasing efficiency. One option for this is jumping. However, compared to other locomotion techniques there is still little known about different jumping techniques in virtual reality (VR). Current implementations of jumping are based on tracking jumping movements in the real world or controller-based using buttons. [5]

However, these methods have different disadvantages. Firstly, frequent jumping can exhaust the user, while controller-based jumping is less naturalistic and might therefore decrease presence in the virtual world. Additionally, the methods are limited regarding their potential to combine vertical and horizontal movements - jumping usually happens on one spot in the horizontal plane. Even when forward-jumping is implemented, this limits the possibility of scaling the vertical height of jumps (as for example in [3]).

This motivated us to develop a new jumping technique in which users move through the virtual world like a spring while only using arm movements to control jumping. In this technique, the users' arm movement in the vertical direction is translated into the jumping movement of the virtual avatar. This prevents physical exhaustion compared to techniques requiring the users to jump, but also provides intuitive body movement as a scale for virtual movement compared to artificial translation through e.g. joysticks. Additionally, this gives rise to the opportunity of scaling jumping strength and height by translating the hand movement strength, the difference between hand starting position and end position - therefore, the bigger the arm movement, the stronger the jump will be.

Since the locomotion technique should combine movement on the vertical and horizontal plane, the technique allows indication of the jumping direction utilizing the tracked position of a user's hands relative to the tracked position of their head. The users can here control the strength of the jump through the height difference of their arm starting position and the position they move their hands to, easily allowing jumps of different heights and therefore adapting to different environments.

To evaluate these techniques we tested and compared a fully button-based baseline condition in which pressing a button starts jumping movement. Similarly, the tracked position of a user's hands relative to the tracked position of their head will be used to control the direction of jumping, while the length of holding the button will scale the jump strength.

To evaluate this in the different conditions participants had to complete a virtual hurdle race with targets at different heights and horizontal positions. We measured the number of hit targets as well as the duration for completion. For the success of the jumping technique, we hypothesize the performance of the arm-based conditions to be higher than the fully-controller-based one. Nevertheless, we suspected potential increases in VR sickness in these techniques due to falling uncontrollably in the virtual environment without actual jumping movement of the real body and therefore also measured users' sickness.

We hypothesized that our hand-based technique performs better than the button-based technique and might reduce VR sickness due to physical movement being congruent to visual stimuli.

We found that either technique performs better in hitting targets or completion time respectively indicating differences in usability and accuracy or potential learning curve differences. VR sickness levels, however, did not show significant differences between the two techniques.

Our results suggest that both techniques could be promising methods for jumping locomotion combining horizontal and vertical movement with potential for different application areas and future research.

\*e-mail: atso@di.ku.dk

†e-mail: msc685@alumni.ku.dk

‡e-mail: tpn338@alumni.ku.dk

## 4 RELATED WORK

Paris et. al. [2] have shown that continuous movements such as walking outperform compared to discrete ones such as teleportation. To keep advantages of teleportation when trying to efficiently move up- or downwards in an environment, it would therefore be useful to test alternative locomotion techniques which can be more efficient than walking, but continuous.

Wolf et. al. [3] examined the translation of physical jumps into the virtual environment and found that independent of scaling, the jumping movements increase presence and immersion in comparison to teleportation. They also note that participants' immersion and motivation were higher for scaled jumping variants than forward-jumping. [3] The open question here is if this difference is technique-specific since physical jumps forward while blinded by VR glasses feel unsafe or if forward jumps in VR in general decrease presence and increase, for example, sickness and discomfort through forward-falling.

Hayashi et. al. [4] also analyzed a physical jumping technique, however utilizing redirected jumping with different mapping of user movement to the virtual space. They confirmed that manipulation of jumping movements in terms of distance, height, and rotation angle is possible without users' perception. [4] This would implicate our technique could be manipulated in the same way and therefore increase possibilities of use in different environments where users have to jump higher or lower, for example.

Weißker et. al. [5] conducted a study comparing jumping and steering regarding their impact on spatial awareness and simulator sickness. They found that jumping can be a good alternative to steering, offering reduced simulator sickness symptoms and similar spatial awareness effects, while steering also took significantly longer than jumping.

## 5 IMPLEMENTATION

For our technique implementation and our study development, we used Unity 2022.3.14f1, the Meta Quest 2 HMD (Head Mounted Display), and the Oculus v4.1.2 Unity package.

### 5.1 Motivation

For our main implemented locomotion technique, we aimed to improve on the jumping technique introduced by Wolf et. al. [3]. We felt that physically jumping while immersed in VR could be dangerous and the user would not be able to immerse themselves if they were worried about their footing. We compare our proposed locomotion technique versus a simple baseline technique that we thought was quite universal in interactive applications - jumping with the press of a button. Each of the implemented techniques requires a means to calculate *Direction* and *Intensity*.

### 5.2 Direction

Across both implemented jumping techniques, the direction mechanism of the locomotion is the same. The user decides the direction of locomotion by approximately pointing their tracked hands in the way they wish to move towards. The mechanism is purposefully not related to gaze direction, allowing the users to choose the jump direction regardless of where they are looking.

For each frame, we are polling if the controllers are actively tracked. If at least one of the controllers has lost tracking, the direction of the jump is the local axis origin for that frame and essentially the user would jump in place.

Otherwise, we compute the vectors that originate from the HMD's tracked position to each of the hands' tracked positions. Using those vectors we calculate their normalized bisector vector which, as illustrated in Figure 1, provides a jump direction regardless of gaze direction. This resulting *Direction* vector is normalized to avoid any unintended amplification of magnitude when applying *Intensity*. For

the same reason, the value of the *Direction* vector on the Y-axis is always zero.



Figure 1: An illustration of the bisector vector (blue) defined by the two vectors originating from the HMD tracked position and ending up at the end of each hand's tracked position.

### 5.3 Intensity

The following techniques define the *Intensity* of the jump; how high and how far the user will travel. *Intensity* scales linearly relative to each technique's **manipulation factor**, bounded by a common upper and a lower limit. To make both techniques' *Intensity* comparable, an empirical factor is used for each of the linear slopes, as explained below.

#### 5.3.1 Spring Locomotion Technique

To assist in an embodied feeling of movement for the user, without actually having the user physically jump, we developed a technique where users can jump by moving their arms. Similarly with tracking the difference in the HMD's height to apply a gain in a specific direction [3], we focused on how far users' hands move between a starting point and a release point when jumping.

To control spring locomotion, a user presses both controller triggers to mark a starting point. After moving their hands up or down, and by releasing both controller triggers the user marks a release point and is propelled in their chosen *Direction*. (Figure 2) The *Direction* of the resulting jump for Spring Locomotion is decided on the frame where the user marks the starting points of each hand.

This choice of controls is inspired by the idea of mimicking the tension of a coiled spring; just like a spring needs to contract from a starting point to a release point to propel in a direction, our technique requires users to do the same with their hands.

The *Intensity* of the Spring Locomotion is defined as such:

$$intensity_{Spring} = \begin{cases} b + a \cdot mF, & \text{if } b + a \cdot mF \leq c \\ c, & \text{otherwise} \end{cases}$$

where:

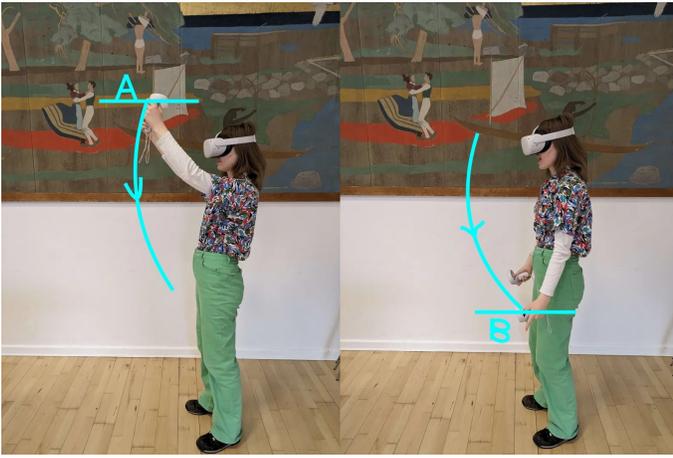


Figure 2: An illustration of spring locomotion from the starting point (A) to the point of releasing (B). The spring locomotion is triggered at point B.

$a$  is an empirical factor to make both locomotion techniques comparable

$b$  is the common lower *Intensity* limit

$c$  is the common upper *Intensity* limit

$mF$  (short for manipulation factor) is the sum of the Left and Right controller distances between the starting and release points, averaged.

$$mF = \frac{distance_{LH} + distance_{RH}}{2}$$

Simply put, the bigger the distance between the starting and release point for both hands, the higher the *Jump Intensity*.

### 5.3.2 Button Baseline Locomotion Technique

In video games pressing a button is a common way of jumping, making it practical as a candidate baseline locomotion technique. Additionally, the aforementioned direction mechanism made sense to be used in this paradigm. Furthermore, we chose button-jumping as a baseline instead of the one proposed by Wolf et. al. [3] as we were not comfortable with the idea that any of our implemented techniques should require physical jumping. In this technique, the user has to hold the designated Jump button for a desired amount of seconds and release it to be propelled in the chosen *Direction*. In our study, the designated button is the A button on the right controller.

The *Direction* of the resulting jump for Button Locomotion is decided on the frame where the user releases the designated Jump Button.

The *Intensity* of the Button Locomotion is defined as such:

$$intensityButton = \begin{cases} b + d' \cdot mF', & \text{if } b + d' \cdot mF' \leq c \\ c, & \text{otherwise} \end{cases}$$

where:

$d'$  is a different empirical factor to make both locomotion techniques comparable

$b$  is the common lower *Intensity* limit

$c$  is the common upper *Intensity* limit

$mF'$  (short for manipulation factor) is the time the Jump Button is pressed in seconds

Simply put, the longer a user presses the designated button, the higher the *Jump Intensity*.

## 5.4 Combining Direction and Intensity to Jump

Both of our implemented jumping techniques share the same *Direction* mechanism, which relies on the placement of the user's tracked hands. After the *Direction* and *Intensity* of the jump is calculated, a final three-dimensional vector is calculated as such:

$$\overrightarrow{jumpForce} =$$

$$(direction.x, jumpIntensity, direction.z) \cdot forceAmplifier$$

where:

*direction* is a three-dimensional vector, signifying the *Direction* chosen by the user

*jumpIntensity* is a float number, signifying a Locomotion technique's *Intensity*

*forceAmplifier* is a value that is applied to empirically adjust the resulting force.

The final  $\overrightarrow{jumpForce}$  is then applied to the RigidBody of the Player, propelling them to the desired *Direction* and upwards with the appropriate *Intensity*.

## 6 EXPERIMENT

We wish to investigate if the hand jumping technique makes the user able to move and act faster, and if it makes the user less VR sick.

### 6.1 Participants

We have 6 participants in different age groups (17, 21, 23, 24, 52, 53) and with an equal gender difference. The average age of the participants are 32 years and the standard deviation is 15 years. Furthermore the participants were asked to rate their prior VR experience on a scale from 0 (not experienced) to 3 (very experienced), where the average experience level was 0.67 with a standard deviation of 0.82.

### 6.2 Design

We have one independent variable, the jumping technique, with two different levels: Button jumping and hand jumping. To ensure that the order of the presented techniques does not influence the results, as training might make the participant perform better on the second technique, we counterbalance the order of the techniques in the following two permutations: (Button, Hand) and (Hand, Button), so each permutation is tried by 3 participants. We use the same Oculus Meta Quest 2 headset for all of the tests, and all tests are evaluated by Sofie to ensure coherency in the same living room with a player space of 8 square meters.

The dependent variables of the study, that we wish to measure, are the time it takes the user to finish the study trail, how many targets they reach and the level of VR Sickness each technique induced. The score and time were measured on a phone, while watching a cast of the participants experience. For measuring VR sickness we use the Simulator Sickness Questionnaire (SSQ) questionnaire from the slides, [6].

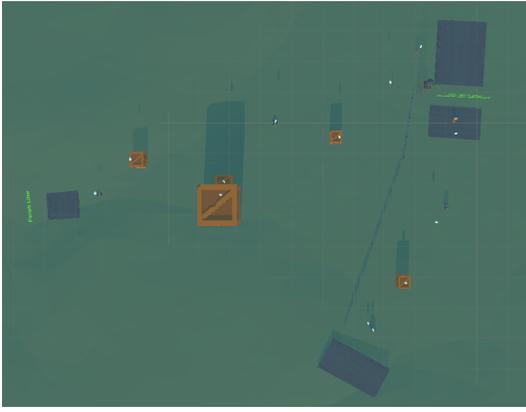


Figure 3: A birds-eye perspective on the test trail (to the right) and study trail (above).

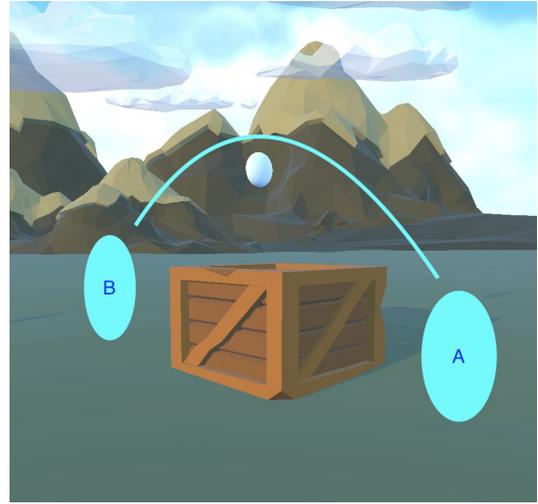


Figure 5: An example of a hurdle and target in our Study. In our study the user has to jump from A to B through the target with each of our implemented jumping techniques across different hurdles.



Figure 4: The study trail from the perspective of, where the player starts, but from above.

### 6.3 Procedure

Each participant first gets a brief explanation of the technique presented, then is given the VR headset and offered help to adjust it for correct sight. The initial player lounge contains a barrel with a red button, which the participant is instructed to press to teleport to the test trail. The test trail (see figure 3) contains 5 targets, white circles at different heights and upon different obstacles, which the participant must touch, so they turn green, see an example in figure 5. After getting familiar with the techniques the participant can press the red button on the barrel at the end of the test trail to teleport to the study run. The study run consists of 8 targets at different heights and on different obstacles, see figure 4. The participants were asked to fill out the SSQ before entering the virtual world, after the first study run, and after the second study run.

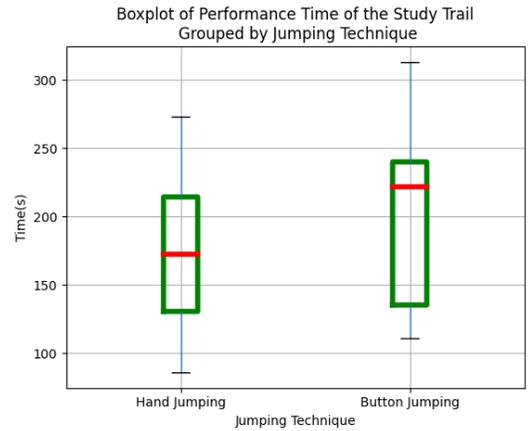


Figure 6: Boxplot of the performance measured in time for the two different jumping techniques.

## 7 RESULTS

### 7.1 Task Performance

#### 7.1.1 Time

In figure 6 a boxplot of the time it took for the participants to finish the study trail is visualized grouped by jumping technique. Here we notice that the median is lower for the hand jumping (172.5s) than for the button jumping (221.2s) and that the 1st and 3rd quantiles follow the same pattern. The standard deviation for button jumping is slightly higher though (79,4s for button-based against 62,3s for hand jumping). The averages for each different technique therefore lie within the other's standard deviation. We should note that the small amount of participants might influence the significance of the differences between scores.

#### 7.1.2 Score

In figure 7 the number of targets the participants hit during the study trail is visualized. Only one participant reached all 8 targets with hand jumping, the rest reached 7, whereas 4 out of 6 participants reached 8 with button jumping. Therefore the average of hit targets

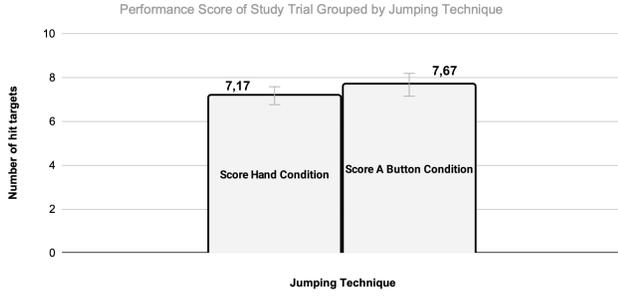


Figure 7: Barchart of the performance measured in targets hit for the two different jumping techniques.

in the hand-based technique was lower at 7.17 (SD=0.41) compared to the button-based technique with 7.67 (SD=0.52).

Sofie furthermore noticed that the target on top of the really high box was especially hard for the participants to reach using hand-jumping, as they could not jump high enough or did not go far away from the box when jumping, so they collided with the box.

Thus it can be concluded that hand jumping is slightly more time-efficient, but button jumping is slightly more precise in reaching all targets.

## 7.2 VR sickness

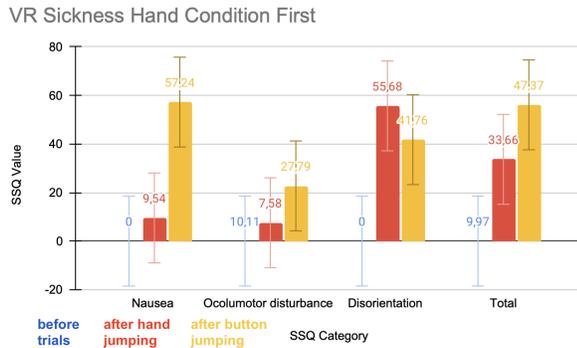


Figure 8: Median VR sickness for participants starting with the hand-based condition with standard deviations for both conditions respectively

Additionally, all participants had to fill in the SSQ questionnaire for VR sickness before the trials and after each trial. The SSQ scores were measured by participants rating symptoms on a scale from 0 (no perception) to 3 (severe perception) and then the different symptoms were weighted for its categories. Total category factors were calculated using the formulas from [6]:

$$N = sum_N \cdot 9.54 \quad (1)$$

$$O = sum_O \cdot 7.58 \quad (2)$$

$$D = sum_D \cdot 13.92 \quad (3)$$

$$Total = (sum_N + sum_O + sum_D) \cdot 3.74 \quad (4)$$

Since we had either half of the participants start with one of the techniques respectively, we split the data into two groups: the one that started with the hand-based technique in figure 8 and continued with the button-based one and the other group with the other way around in figure 9.

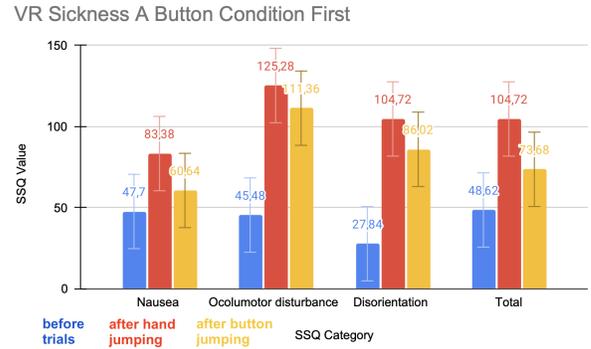


Figure 9: Median VR sickness for participants starting with the hand-based condition with standard deviations for both conditions respectively

For almost all categories of VR sickness, the values increased from the beginning through the first trial to the second one - regardless of the technique being tested first. Therefore, in figure 8 we can see higher sickness values in all categories for the button-technique compared to the hand technique. In contrast, in figure 9 the hand-based technique shows higher sickness values than the button-based one.

One exception is the disorientation value after the hand-technique when starting with the hand-technique in figure 8: it is higher for the first trial than the second indicating a potential for disorientation through the hand technique.

In both variations the average increase of sickness from baseline to after the first trial is bigger than from the first to the second trial and technique.

Overall, the median sickness values for the group of people starting with the hand condition are lower. Interestingly, this is also the group of people without any VR experience who therefore also have lower sickness values than the people with VR experience. Since the groups analyzed consist of only three participants these group differences might also have a higher impact and distort results.

In the group of people using button first, even the baseline sickness value is  $> 20$  and therefore in the concerning area. In the hand-condition first group the baseline value is in the minimal sickness areas  $< 10$ . Also, the nausea and oculomotor disturbance value after the first trial is  $< 20$  and therefore in the significant area.

The area with the highest sickness values and therefore most significantly impacted compared to baseline sickness by both jumping techniques is disorientation where all values are in the concerning sickness area. In all second trials values are also in this area.

## 8 DISCUSSION

Our goal was to create a jumping technique that takes up less space than real-world jumping while increasing immersion of users needing locomotion on the vertical as well as horizontal axis. We tested jumping techniques utilizing either buttons or hand movements. We hypothesized that our new hand-based technique would help participants perform better due to intuitive movements.

Our results of the performance of users in a hurdle race show that while the time participants needed to perform the trials was indeed lower for the hand-based condition, they hit fewer targets in it. Since the score was instead higher for the button-based technique it indicates that the accuracy of the button-based technique might be better than the one in the hand-based one. Meanwhile, the intuitive nature of arm movements might contribute to quicker movements with the hand-based technique.

Seeing as how participants indicate that the hand-based technique

is more fun than the button-based one this might support that intuition of the technique is higher. However, the lower rate of target hits suggests users struggle with the accuracy of the technique.

We found that the scattering and therefore standard deviations of the button-based technique are higher than for the hand-based technique. We can also hypothesize that this might indicate differences in learning curves and that the hand-based technique, for example, requires more training time. Participants may need more practice to accurately translate their arm movements into precise actions in the virtual environment. Meanwhile, the button-based technique might inherently be more familiar to different users.

On the other hand, target score and time for completion are not independent of each other since there is a possibility that exactly because participants hit fewer targets in the hand-based technique they were more time-efficient.

Since the one participant hitting 8 targets in the hand-based technique also had the longest completion time, this interaction might be relevant.

The trade-off between speed and accuracy also becomes relevant for the practical implementation of the hand-based technique - depending on the use case different techniques could be utilized. For example, if accuracy is important, the button-based technique might be better. However, when the flow and intuition of users are more important, our hand-based technique could be the better choice.

To compare the techniques further, we analyzed the VR sickness. It is interesting that the VR sickness tends to increase similarly from the first trial to the second trial regardless of which technique is used first. Since we also know that increases from baseline to first trial are more significant than increases from first to second trial in both variations, we can conclude that VR sickness is similar for both techniques. The general difference between the hand-based condition and the button-based condition might be explained by the differences in participant groups and their experience levels. Therefore, this indicates that either potential differences in the immersion or embodiment of the technique do not seem to influence sickness or there is no significant difference in embodiment.

There is also an indication that the hand-based technique increases disorientation more than the button-based one with a higher value even when this technique is used in the first trial.

A reason for high sickness values - and especially disorientation values - would be that users are in free fall which they can not control after letting go of a button in both techniques. Saredakis et. al. [7] compared measurements of VR sickness with SSQ in different studies and found that across all, disorientation scores were higher than oculomotor and nausea with similarly high differences to ours. This is in accordance with our finding that disorientation is significantly higher than the other two categories and therefore might not be jumping-related. Further investigation is required to understand the specific aspects contributing to VR sickness in jumping and falling, and potential mitigation strategies could be explored.

In addition, future research is relevant to find out if different methods for direction indication potentially result in better performance and enhance differences between the jumping techniques. Since we did not have enough participants to test further combinations of different techniques this is a question for future research.

Also, with more participants it would give the opportunity to measure and compare the embodiment of the different techniques along with introducing some haptic feedback.

Lastly, subsequent studies could also investigate the learning curve over extended periods, exploring how user proficiency evolves and whether target accuracy improves with prolonged use.

## 9 CONCLUSION

We tested a jumping technique for VR locomotion aiming to combine intuitive arm movements with efficient vertical as well as horizontal

translation in the virtual environment. We compared a traditional button-based technique for jumping with our new hand-based jumping technique. In the hand-based technique, users are moving their arms to control the jump's strength and height, utilizing arm direction for indication of jumping direction.

Our findings suggest differences in performance and similarities in VR sickness comparing the two techniques. While participants had faster completion times for the hand-based technique, they hit fewer targets compared with the button-based technique. Additionally, both techniques increased VR sickness, especially disorientation.

The observed decrease in target hits in the hand-based technique might be caused by different factors. One interacting factor might be the learning curve associated with the technique. Participants may need to get used to the relation of arm movements to virtual jumps, which then again affects their accuracy in hitting targets. The fact that the hand-based techniques show faster completion times could also suggest that the hand-based technique holds promise for higher immersion. Lastly, the differences could also be explained by the participants hitting fewer targets in this technique resulting in lower time needed to hit the fewer targets.

Increasing the number of participants and testing different combinations of locomotion techniques - especially direction indication techniques - for longer trial periods could help with a better understanding of the strengths and limitations of the proposed jumping techniques.

In conclusion, this study provides insights into the benefits and challenges of our hand-based jumping technique. Potential benefits are indicated for speed and intuitiveness, while accuracy might be higher in other techniques. The observed trade-offs between speed and accuracy well as the familiar problem of VR sickness indicate a need for future research. This could engage with questions on variations of the hand-based technique, experimenting with different methods of direction indication and different translations from real-world arm movements to virtual jumps. It will help advance jumping techniques in VR for enhanced user experience.

Our last submission commit hash is **29af2bd6** in our **Gitlab repo**. The video presenting our techniques can be found [here!](#)

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