# “Where Did I Put That?” – Effectiveness of Kinesthetic Memory in Immersive Virtual Environments

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**Abstract.** Kinesthetic memory is an essential factor in human interaction with the outside world. It helps adept keyboard users to type rapidly and hit the keys without having to look at them. It enables musicians to play their instruments without consciously having to think about the necessary movements. And it can help people to find things again, based on the location where they put them. The benefits of kinesthetic memory in the physical world are well known and well used for training or in physical therapy. Yet little effort has been made to examine the effects of kinesthetic memory in a virtual environment. In our paper, we present a user study designed to explore the intensity of kinesthetic memory while interacting with a large screen immersive environment. This could be used to improve the usability and effectiveness of user interfaces for such environments.

**Keywords:** Kinesthetic memory, Virtual environments, Usability.

## 1 Introduction

Kinesthetic memory is an essential factor in human interaction with the outside world. It helps adept keyboard users to type rapidly and hit the keys without having to look at them. It enables musicians to play their instruments without consciously having to think about the necessary movements. And it can help people to find things again, based on the location where they put them, like a mechanic that places his tools in the same layout every time, to help him pick up the right tool just by letting his body recall the necessary movements.

In short, kinesthetic memory or “neuromuscular facilitation” refers to the effect that the human body is very good at remembering movements and relative positions of body parts. With this type of sensory-motor learning, a person can use her body’s “muscle memory” to remember the motor movements required to accomplish a specific goal. Especially after some repetitions, the person no longer has to concentrate on these movements, as they become part of the body’s motor memory. The more often a motion is repeated, the more accurate this memory becomes, to the point that it requires no conscious effort at all. A very striking example for this is speech, where a person does not have to think about the complex movements of tongue, lips and vocal cords, since they are controlled by her motor memory.

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The benefits of kinesthetic memory in the physical world are well known and well used for training or in physical therapy. Yet little effort has been made to examine the effects of kinesthetic memory in a virtual environment. Of course, it plays an important role in interaction with computers, as in the aforementioned touch typing on a keyboard, or in the mouse movements necessary to reach a specific item in a GUI menu. But there are no studies to show the effectiveness of kinesthetic memory in immersive virtual environments.

While interacting with a normal desktop computer, a user is limited to sitting in front of a desk and moving her hands in a very restricted fashion to interact with the machine. Since in a large screen immersive VR the user can move freely in front of the screen and reach her hands in all directions, it seems natural to assume that kinesthetic memory is addressed rather more efficiently than with a customary 2D WIMP interface. Consequentially, this could be used to improve the usability and effectiveness of user interfaces for such environments.

In the same way that normal 2D desktop interfaces make use of the kinesthetic memory with normal menus, or to a greater extend with pie menus, it might be possible to exploit this fact even more in a room-sized interaction area in front of a large screen. Different commands or menus could be associated with specific locations in front of the screen. Especially when working with large screen immersive environments, users could more easily learn complex interaction possibilities by associating different actions with specific positions in the virtual (and real) world.

Apart from the user interface, kinesthetic memory might also be beneficial to re-find things that the user herself has placed inside the virtual environment. To a small extend, this is already done in 2D interfaces with the use of a desktop metaphor. The user can place documents and links on the (two-dimensional) desktop and arrange them in any way meaningful to her. The human spatial memory makes it easier to find them again by their position, and after some time working with them the kinesthetic memory simply remembers the necessary movements to select a specific document or link, to the point that the user barely has to look at it.

While already of benefit with a two-dimensional environment, this combination of spatial and kinesthetic memory might be even more pronounced by remembering not just the relatively small hand movements while interacting with a mouse, but movements of the whole body in a large screen immersive environment. In this manner, the interface can considerably reduce the cognitive load on the user while looking for specific objects or invoking menus or other interactions.

In this paper, we present a user study designed to explore the intensity of kinesthetic memory while interacting with a large screen immersive environment. To increase the degree of immersion, a passive stereoscopic projection is used, giving the user a 3D vision with real depth perception. Our expectation is that the resulting higher sense of presence will further improve the addressing of kinesthetic memory. In this environment, we had several participants perform memory-intensive tasks with conventional mouse interaction, as well as by tracking their movements and invoking interactions depending on the position of their main hand.

The paper is organized as follows: First, we will have a look on related work in the fields of virtual environments and kinesthetic memory. Following that, we will present the design and implementation of the scenario of our study. After describing the actual evaluation process, we will present and discuss the results of the study before concluding with an outlook on future work in the area.

# 2 Related Work

## 2.1 Kinesthetic Memory

As mentioned, kinesthetic memory is the human's ability to recall muscular movements. This kinesthetic sense enables a human to know her body position and movement of the limbs by being aware of each body part's position in relation to the body itself or the environment [16, 10]. It is created by feedback in the muscles and joints of the person [3]. In this way, humans are able to build skills by sensing and storing the necessary muscle movements to accomplish a specific task in kinesthetic memory, then recall them when needed [9].

A lot of human skills and crafts are learned by using kinesthetic memory. Examples are almost all activities that require manipulation of the environment with the person's body, like throwing, catching, walking, dancing or speech [14]. More sophisticated skills are also trained using kinesthetic memory, for example learning to play a musical instrument, machine typing using 10 fingers, or operating the pedals of a car.

This has lead to the employment of kinesthetic memory in a variety of different environments. In medicine, kinesthetic memory is often used for rehabilitation or disability care. Also, it is often employed to assist learning and education. Here, students are encouraged to learn by actively carrying out physical activities [15]. Psychology further suggests that spatially distributed information is remembered by its location relative to a person's body, as well as by the environment in which it was learned [18].

## 2.2 Application of Kinesthetic Memory in User Interfaces

In recent years, the effect of kinesthetic memory has also been employed for interaction with computers. Balakrishnan and Hinckley [3] have researched the usefulness of kinesthetic memory for two-handed interaction with a virtual environment. They aim to enhance interaction for one hand by using the other hand to form a frame of reference. A similar approach was considered by Boeck et al. [6]. In their system, they use proprioception in combination with force feedback to manipulate the virtual environment.

Another interesting application of kinesthetic memory is presented by Ängeslevä et al. in [1]. They developed a kinesthetic control for a PocketPC. Their idea is based on the fact that the display area of portable devices is very restricting for the size and complexity of menus. Because of this, they realized access to specific commands and files not via menu, but based on corresponding locations on the user's body.

Different authors have also suggested enhancing menu control in virtual environments with the help of kinesthetic memory. Mine et al. [12] proposed a virtual environment with a menu in a fixed position relative to the user's body, e.g. over her current field of view. The user could then access the menu by simply reaching up, grabbing it and pulling it inside her field of view. An informal trial by the authors found that it is possible to easily distinguish up to three different menus above the user, one directly above, one above and to the right, and one above and left.

In [7], Bowman et al. have implemented a menu metaphor called TULIP (Three-Up, Labels in Palm). In this approach, menu entries of top and second level menus are mapped to the fingers of the user's non-dominant and dominant hands, respectively. The entries are selected by using pinch gloves to touch an entry's corresponding finger with the thumb of the same hand. Using such body-centered menus, users can take advantage of their kinesthetic memory to select menus without needing to look at them.

More general information about research on body movement as an input modality can be found e.g. in [12], [10], and [11].

### 2.3 Large Screens and Physical Navigation

In recent years, the size of displays has become an increasingly important research topic for visualization. The application areas for the use of wall-sized display devices are manifold: Large Public screens enable a bigger audience to view the contents. Large displays for collaborative work provide the necessary screen real estate to show different views on data for each user. The use of larger display areas engenders a more thorough immersion in virtual reality applications. And finally, large high resolution displays enable visualization of large and complex datasets by facilitating both overview and detail views at the same time.

The main research focus for large screens lies on collaborative work, but there are also studies showing how single users profit from large screen scenarios [17, 13]. Since large screens take up a major part of the visual field of a user, the virtual world occludes a large part of the physical world. Thereby, the user has a stronger sense of being part of the environment displayed on the screen, i.e. of being immersed in the virtual environment. Especially important for searching and retrieving information on large screens is the fact that this immersion also leads to improved performance on cognitive tasks [2].

Also, large displays have the benefit of not only addressing the visual perception of the user, but rather take advantage of the whole body. Since large screens facilitate walking around in front of them and turning one's head to look at different information, they also address peripheral vision, motor memory and proprioceptive cues not available on small displays [5]. In other words, by using physical navigation rather than a virtual navigation metaphor, the user can delegate and distribute cognitive load to several perception channels. By making use of these additional resources available on large screens, the user can more quickly create mental models of data and the virtual environment than when navigating it purely virtual [4].

# 3 User Study

## 3.1 Technical Setup

As mentioned, one of our goals was to create the virtual environment for our study as immersive as possible by using a stereoscopic visualization. This was done by using our PowerWall. The PowerWall is basically a 2.9 x 2.3m back-projected canvas. Instead of projecting a single image, however, it is used to display two stereoscopic images at the same time, resulting in visualizations with realistic depth perception. The images are rendered with the correct perspective to simulate two virtual eyes. Two JVC DLA-SX21S projectors with a 1400 x 1050 resolution rear-project the stereoscopic image pairs onto the canvas. Mounted in front of each projector are polarized filters of opposing polarization direction. By wearing special glasses with corresponding filters, each eye can only see the image generated by one projector, producing the stereoscopic depth visualization.

To track the position of the user, we used an Ascension Flock-of-Birds electromagnetic tracking system. It consists of a transmitter unit that generates an electromagnetic field. The second part of the system consists of one or more sensors that have to be held or worn by the user. By analyzing the local structure of the magnetic field, each sensor determines its position and orientation.

## 3.2 Scenario

The objective of our user study was to validate the influence of kinesthetic memory when interacting with a large screen immersive environment and whether this effect can be used to help users re-find known objects in virtual environments by using physical navigation rather than virtual navigation metaphors. To this end, we created an evaluation scenario that requires users to remember virtual objects based on the navigation and movements they had to make to select them.

We kept the virtual scenario deliberately simple to avoid any influences that might falsify the results in one direction or the other. Ultimately, we decided to use a three-dimensional game to give users a "winning" motivation. The game is based on the well-known "Pairs" type of table game. Here, a set of upside-down playing cards is laid on a table. The set consists of card pairs ordered and arranged randomly. Normally, two players take turns in selecting two cards each. If the selected cards are a pair, the player wins this pairs and can select the next two cards. Goal of the game is to win more card pairs than the opponent.

In our version of the game, the cards were not arranged two-dimensionally on a flat surface, but rather were floating in virtual space, with their front side averted from the user. To reduce the time required for playing the game, we only used 27 cards, arranged in a regular 3x3x3 Matrix. Also, the cards contained no pairs, but individual picture motives. Participants were given time to get familiar with the cards. Then, they were shown one motive from the set and had to find the matching card from the matrix. In this version, participants didn't play against an opponent, but rather were encouraged to find 10 different cards in as little time with as few errors as possible. The exact course of the evaluation will be explained in the next section.

## 4 Evaluation Process

During the user study, we evaluated 10 persons using a within-subjects approach. About half the users had more than casual experience with computers. Each of the participants was introduced to the scenario presented in the previous section. They had to complete two sessions of the game, each with a different set of cards and different navigation methods.

For the virtual navigation part, the participants were standing on a table positioned approximately 3 meters centrally in front of the PowerWall, as shown in figure 1 (left side). Interaction was realized using a mouse. The user could change between three different virtual viewpoints to look at the scene, each located in front of one depth plane of the 3x3x3 card matrix. In this way, the user had a visual focus on a 3x3 set of cards. She could change between these viewpoints by using the scroll wheel of the mouse. To select one card of the 9 cards in the visual focus, she would use the mouse and left click on the card, causing it to turn around and reveal its picture motive.

Using physical navigation, the participant could move freely in front of the PowerWall (figure 1, right side). A tracked Flock-of-Birds sensor was placed in her preferred hand (right for all participants) and a mouse for triggering a click in the other. The area in front of the display was divided into 27 regions, corresponding to the 3x3x3 matrix of cards in the virtual environment. The user could select cards by walking closer or farther away from the wall (causing the visual viewpoint to change between the three depth planes), then moving the sensor to the correct spatial position of the intended card, and left clicking.

We aimed to keep the actual interaction (clicking with the mouse) and the stereoscopic large screen visualization the same for both navigation metaphors, so the two sessions would only differ in the mode of navigation. In this way, we aspired to enable the use of spatial memory to the same extend in both variations and only measure the effect of kinesthetic memory for navigation.

**Fig. 1.** A participant of the study, trying to find the matching pair in a 3x3x3 matrix of playing cards. Left: Virtual navigation metaphor using a mouse to scroll through the depth planes and selecting cards. Right: Selecting a card with physical navigation. The user has to make use of his whole body by walking and raising his hand to the corresponding area of the desired card.

Half of the participants started the study with the physical navigation, the other half with virtual navigation. In both cases, the session started with a set of national flags to give each participant opportunity to experiment with the system and get familiar with the navigation and interaction. This part of the session had no time limit, so each user could experiment with the application until she felt comfortable with it. After that, the set of cards switched to the actual picture motives for the evaluation. Each participant was then granted a time span of 3 minutes to learn and try to memorize the location of the motives. After that, she was shown one of the motives included in the card set and had to find the corresponding card with as few errors as possible. This was repeated for a total of ten motives.

Once the first part of the study was completed, the cards changed back to the flag motives and the participant had again opportunity to get familiar with the second navigation type. Again, the time for this part was not limited. After the experimentation phase, the cards changed to a second evaluation set with picture motives and another 3 minute memorization phase started. Once complete, the user had to find another random sequence of 10 motives. Participants were encouraged to find the matching pairs as quickly as possible, but time was not measured due to the inherently more time-consuming movements for the physical navigation.

Our hypothesis was that the whole-body movement of the physical navigation would better address the kinesthetic memory of the users, thereby resulting in a better performance (less failed attempts) for finding the matching cards.

Finally, the participants had to fill out a questionnaire including a subjective appraisal of the two navigation methods.

## 5 Results and Discussion

Before doing the actual study, we tested the evaluation with three different users. During these tests, the participants were not restricted in how many tries they had to find the matching card in the card pool. As it turned out that users started turning cards at random after some negative attempts, we restricted the allowed tries for finding each card to three. After three failed attempts, we assumed that the participant did not remember the location of the card and skipped to the next one.

This restricted the dependent variable of failed attempts to the discreet values 0 to 3. Since the independent variable (interaction mode) was also discreet, we used a chi-square test (see table 1) to test the null hypothesis, i.e. that the number of failed tries is independent of the mode of interaction. Analysis revealed that the p-value for the null hypothesis was below 0.001, showing that the results are statistically significant with a probability of over 99.9%.

The left diagram in figure 2 shows the overall number of failed attempts of the first pass with virtual and physical navigation. As can be seen, both types of navigation performed comparably well during the first stage of the study. Interesting to note is the fact that, apart from one exception, participants that rated their own computer knowledge as below average seemed to perform better with physical navigation than with the mouse, indicating that there may be a connection between the usage of kinesthetic memory and familiarity with the mouse in the case of virtual navigation.

**Table 1.** The contingency table for the chi-square test

| | # failed attempts (expected values) | | | | |
|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | Rows total |
| Mouse | 102 (114) | 21 (25,5) | 28 (17,5) | 49 (43) | 200,00 |
| Tracking | 126 (114) | 30 (25,5) | 7 (17,5) | 37 (43) | 200,00 |
| Columns total | 228,00 | 51,00 | 35,00 | 86,00 | 400,00 |

As shown by the right side diagram in figure 2, almost all participants performed significantly better with physical navigation during the second pass. Again, the users least familiar with computers performed best and showed the highest improvement in comparison with virtual navigation. This seems to bolster the hypothesis that kinesthetic memory is indeed addressed to a higher degree when navigating virtual environments using movements of the whole body. All in all, this led to the result that only two of the ten participants performed better using a mouse. One user made the same number of errors with both navigation metaphors, while for all others physical navigation resulted in a much better performance.

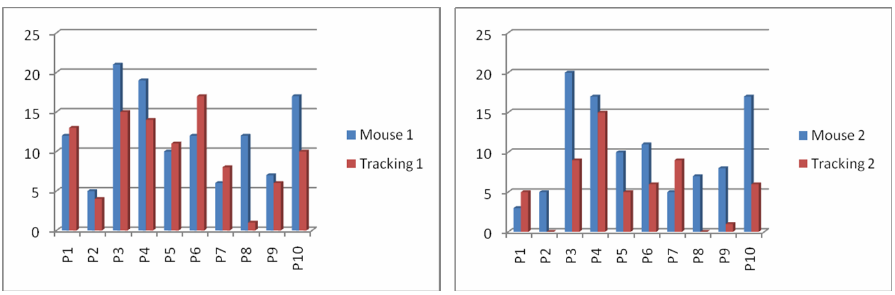


**Fig. 2.** Error numbers for virtual and physical navigation in the first pass (left) and in a second pass with the same card sets

The analysis of the subjective comparison of virtual and physical navigation in the questionnaire yielded dichotomous results. As was to be expected, with the exception of two participants, virtual navigation was rated as faster and less tiring. Because of this, most of the participants preferred the virtual navigation task to the physical one despite the weaker performance. On the other hand, physical navigation was rated as more intuitive by most of the participants, but difficulties with selecting game cards because of noise in the electromagnetic tracking data led to an overall evenly-matched rating of the general ease of use of both navigation metaphors.

This suggests that further studies concerning the performance between physical and virtual navigation should consider a more natural scenario with less straining movements to navigate the virtual environment. Also, a more precise and less intrusive method for tracking the participant's position should be used to avoid irritation of the users by having to wear sensors and jumpy data.

## 6 Conclusion and Future Work

In this paper, we presented a user study designed to examine the impact of kinesthetic memory on physically navigating an immersive large screen virtual environment. The evaluation scenario consisted of a three-dimensional variant of a Pairs game that participants had to solve with virtual and physical navigation. Results of the evaluation and an associated questionnaire indicate that, although more participants seemed to have initial difficulties with the unfamiliar physical navigation, error rates changed in favor of this approach with more practice. Also, most of the participants made less errors overall with physical navigation. Unfortunately, although the results of the study give encouraging indication that kinesthetic memory may indeed help users to remember the location of virtual objects in immersive virtual environments, the data is as yet too dispersed to make an absolute statement. Because of this, we are planning to continue the study with a bigger and more varied pool of participants.

Additional research questions we are planning to tackle are whether the effect of kinesthetic memory is influenced by gender, age, or computer experience of the participants. Additionally, we will try to determine whether the degree of immersion, for example depending on the size and dimensionality of the display, is affecting the effectiveness of the participant's kinesthetic memory while physically navigating a virtual environment.

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