Quantifying the Benefits of Immersion for Procedural Training

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ABSTRACT

Training is one of the most important and widely-used applications of immersive Virtual Reality (VR). Research has shown that Immersive Virtual Environments (IVEs) are beneficial for training motor activities and spatial activities, but it is unclear whether immersive VEs are beneficial for purely mental activities, such as memorizing a procedure. In this thesis, we present two experiments to identify benefits of immersion for a procedural training process. The first experiment is a between-subjects experiment comparing two levels of immersion in a procedural training task. For the higher level of immersion, we used a large L-shaped projection display. We used a typical laptop display for the lower level of immersion. We asked participants to memorize two procedures: one simple and the other complex. We found that the higher level of immersion resulted in significantly faster task performance and reduced error for the complex procedure. As result of the first experiment we performed a controlled second experiment. We compared two within-subjects variables namely environment and location under various treatments formed by combination of three between-subject variables namely Software Field Of View (SFOV), Physical FOV, Field Of Regard (FOR). We found that SFOV is the most essential component for learning a procedure efficiently using IVEs. We hypothesize that the higher level of immersion helped users to memorize the complex procedure by providing enhanced spatial cues, leading to the development of an accurate mental map that could be used as a memory aid.

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1. INTRODUCTION

Virtual Reality (VR) is a burgeoning field of research that has been in existence over the past 50 years. In the 1950s, radar images were displayed across huge screens to help the military in various strategic planning activities. These systems were considered to be the first Virtual Reality Systems. In the late 1960s, Sutherland put forward a novel concept of head-mounted display[13] that could depict 3D graphics. These displays also possessed mechanical tracking capabilities. Towards the end of 1990s, VR had become so popular that VR systems found their way into movies, science fiction novels, theme parks, etc. Today, many different types of VR systems are utilized in various domains. One of the well-accepted definitions of VR systems is given below:

VR system can be defined as a 3 dimensional synthetic computer generated world using real-time graphics that can be controlled by interacting with the system from a first person perspective[9].

Virtual Environments (VEs) are backed up by certain complex technologies that replace real-world sensory information with synthetic stimuli, such as 3D visual imagery, spatialized sound, and force or tactile feedback. The four technologies crucial for a good VR system are visual displays, tracking devices, input devices and graphics hardware/software[13]. Display technologies have advanced over the years. Head-mounted display and Cave Automatic Virtual Environments, like surround projectors, panoramic projectors, workbench projectors and desktop, displays, are some of the technologies that have taken immersive experience to a different level. Tracking and input devices have evolved significantly over the years. Wireless technologies have been introduced, as well as faster-responding systems. The speed of the rendering engines have been increasing rapidly as the cost of the CPU that computes these graphics goes down. Similarly, ergonomics and system latency have made significant progress. However, in spite of all these improvements, the cost of setting up a Virtual Reality system is still exorbitant.

Some of major areas for VR technology application [13] are:

1. Vehicle simulation
2. Entertainment – theme parks and virtual rides
3. Vehicle design—ergonomics, styling, engineering
4. Architectural design and spatial arrangement; submarines, deep-sea oil platforms, process plants
5. Training – NASA space training and military training applications
6. Medicine – phobia psychiatric treatment
7. Probe microscopy

Probably one of the best examples of the application of VR is the Boeing 747 flight simulator for training pilots at British Airways[13]. The system was constructed at a cost of $13 million. As Dr. Frederick P. Brooks Jr. states, "it's probably the best VR system on the planet". Similarly Disney's *Pirates of the Caribbean*[32] and *Aladdin*[57] are good examples of applications of VR in the entertainment industry. The United States military has also utilized VR for ages. The idea of simulating inaccessible, realistic scenarios and non-realistic scenarios, in some cases, has taken training and learning to a different level. Starting from flight simulators to ground-task force training in urban combat, most of the physical set-up of training simulations has been recreated to train soldiers in less hazardous conditions and help them learn and adapt easily to various scenarios.

VR has also been used to simulate many medical applications such as treating phobias and training doctors for minor surgeries. Dr. Larry Hodges from Georgia Tech, Atlanta is popularly known for his phobia application which treats patients suffering from acrophobia [24], has been very popular in the VR community. The Vietnam War simulation[13] at the Atlanta Veterans Administration Hospital is another famous application that was used to treat Post Traumatic Stress Disorder for Vietnam War veterans. Another notable application is the Virtual Laparoscopic surgery application that has a very precise haptic feedback. This application could be used to hone a doctor's laparoscopic surgery skills[63].

Users strongly react when they interact with a good Immersive Virtual Reality system that has good 3D visual imagery, spatialized sound, and force or tactile feedback. To explore the reason for this, Immersive Virtual Environments are introduced in the next section.

1.1. IMMERSION

The success of the above mentioned Virtual Reality systems can be attributed to the fact that they were able to effectively replicate the real world scenario. (In general the VR application provides proper mapping between sensory stimuli and the response. For example, the goal of the VR phobia application is to treat the fear of heights and the Vietnam War simulation application is to help the subjects cope with stressful situations and memories. Performing these procedures in the real world would be very unreasonable. Therefore an Immersive Virtual Environment (IVE) helps in recreating the whole scene and instilling realistic sensory stimuli to trigger fear.) Research has proven that, auditory[13] and haptic feedback[63] is more important than visual feedback for some applications. This could be extended to the VR gaming applications such as the Disney's *Pirates Adventure* and *Aladdin*. Apart from the above advantages, immersive VE application also have a high level of realism and the experience of "being there". This subjective response from the human/user indicating the feeling of "being there" is called presence[67]. It is has been identified that presence is very crucial for applications like training[53, 13], phobia treatment[43, 24, 13] and pain reduction[43].

But there might be other applications, for example, architectural design[14] and interior residential decorations[41], which do not require presence. These require good spatial understanding of the environment. This questions the reason to use immersive virtual environment for such applications.

Thus there arises a requirement for a variable that can be measured and controlled unlike presence. This requires us to define immersion precisely. Therefore, Immersion is defined as *"The objective level of fidelity of the sensory stimuli produced by a technological system"[67]*. Immersion is theoretically measurable and controllable. IVEs have special characteristics; Intuitively, IVEs are different from 3D environments "on the desktop." An understanding of the benefits of IVEs would result in the transformation of VE's from the research mode and make it commercially viable, but, it's very hard to prove that IVEs are beneficial. It is notable that higher level of immersion has helped in treatment of phobia[24] and training[72].

From the above set of statements we can derive two important questions that would help us understand immersion better. They are:

1. *Does a higher level of immersion provide benefits for a certain application?*
2. *What component(s) of immersion are required to realize these benefits?*

It is of paramount importance to identify which component of immersion causes these benefits and what levels of immersion are required to obtain these benefits. The VR community runs controlled experiments to study how a single component of immersion affects the user's performance on a particular task. In a study where a single component alone is varied and other components are held constant, the results offer high generality[10]. But this type of study can significantly impact the results because neglects possible interactions that can happen between the components while performing the experiment. To avoid this, various components of immersion need to be studied simultaneously with multiple levels per component, maintaining a high degree of experimental control. In addition to the ability to study a single components' effect, the interaction between components could also be effectively studied. Such a study enables the simulation of real-world systems in a controlled way by combining immersion components differently[10] in a varied manner.

Some of the components of immersion that the VE community has already explored are visual immersion, auditory immersion, and touch-based immersion, also known as haptics. Immersive VEs provide better depth cues; stereo images and head based rendering, helping the user understand the stereopsis and motion parallax much better. Higher levels of immersion aid applications that require a good spatial understanding [64, 60, 75, 21]. The user will feel the sense of being there in the environment. However, it does not necessarily mean that they will learn or do the task correctly. Therefore our goal would be to empirically demonstrate the benefits of immersion for a particular set of tasks and applications so that it will give developers good reasons for choosing as to whether or not they need to use Immersive VEs. One of the main advantages of immersion is the ability to establish a link between academic studies of VEs and the commercial use of Immersive VE technology.

The motivation for the work, described in the next section, is a novel application of VR. The study at hand investigates the benefits of immersion for a medical training application that uses IVEs to help doctors train their students. Also Included in this study is an exploration of how VR techniques compare to conventional classroom training.

1.2. MOTIVATION

Immersive Virtual Environments have proven to be a good substitute for replicating many real-world applications as they provide the user a close to real experience. Having seen many IVE applications, a decision was made to implement a medical training system at Virginia Tech in collaboration with the Carilion Hospitals in Roanoke. The goal of this system was to help doctors train their interns to make decisions in a trauma room situation. Often, these are life-and-death decisions that have to be made in a real-time, stressful environment. Interns who came to Carilion Hospitals were initially trained in classrooms using textbooks. They had a dummy body that could simulate heart rate, blood pressure and a few vital signs. They did not have a dedicated training system though. The interns were taught how to handle a scenario in a classroom-based training system. Therefore, the interns were not able to individually play the role of the doctor individually when treating the patient for that trauma scenario. This significantly reduced the effectiveness of the training as the interns did not acquire a hands-on realistic experience of the trauma scenario. There were many other disadvantages that we identified with their existing system. The real world training could not offer as many training scenarios as a virtual system could; high cost and more resources were required to setup every training session. In general, real world classroom training was also observed to be very rigid. Further the doctors felt that the interns would learn the concepts better and acquire the skills by practicing and playing the role of an actual doctor. This justified the requirement for a system that could deliver the same experience as real world training; enabling the doctors to play their roles while offering more flexibility. To satisfy all of the above conditions, a Virtual Reality system proved to be a good idea.

Therefore a Virtual Reality system that could offer sensory stimuli that are realistic was built, enabling proper mapping between the sensory stimuli and appropriate responses. This project was done in Virginia Tech. The system was built using real time 3D graphics engine that could render a realistically modeled 3D trauma room. The virtual trauma room also had virtual characters to represent the nurse and the patient. It also contained essential medical equipment such as x-ray machines, vital sign monitor that kept constantly changing according to the condition of the patient and others that were requested by the doctors. A recommended auditory environment was used as suggested by the doctors of Carilion hospitals. Decision trees were built in to the scenario, after consultation with the medical professionals, to allow for various trauma room scenarios. One other notable advantage of our system was scalability, letting the user add as many scenarios as needed with just a few lines of code. A snapshot of the project can be seen in **Figure 1.1**.

Figure 1.1 Trauma room simulation project

In the initial years of medical training, doctors refrain from doing the actual operations and surgery. The interns who worked with the system mentioned that VR did help them in making decision inside the Virtual Trauma Room. Therefore, a virtual training system like this can help doctors learn various concepts and scenarios before they approach a real-world situation.

Various choices of display devices were available for this research project– desktop, large screen, CAVE, etc. In other words, what level of immersion was needed for effective decision making? This leads to a research question:

- *Is a higher level of immersion more effective in making a decision?*

Psychology literature states that a decision is made on the basis of two sources of information namely external cues filtered by the user from the environment that surrounds the user and the information stored in the long term memory of the user. In our case the environment is the virtual world that consists of a trauma room scene. Since end users were doctors who already possessed the domain knowledge, it was the question of how effective was the cues in the environment to help them take the right decision. It has been identified that a decision making process is influenced by either spatial understanding of the environment and memorization of information or combination of both. Thus disserving the research questions mentioned in the previous paragraph:

- *Is a higher level of immersion more effective in memorizing a procedure?*
- *Is a higher level of immersion more effective in understanding the spatial layout and the 3D depth cues provided by the environment?*

Before verifying how effective a higher level of immersion can affect a decision making process, we have to identify if virtual environments can be used for memorizing a procedure. It was decided to test if a Virtual Reality system such as a Cave Automatic Virtual Environment (CAVE) framework or Head Mounted Display (HMD) that has higher levels of immersion when compared to the desktop-display would be useful for memorizing a procedure. If they would be useful, what level of immersion is needed effective memorization? These questions drive our research questions and the hypothesis section.

1.3. RESEARCH QUESTIONS AND HYPOTHESIS

The potential benefits of immersion for a procedural training task need to be analyzed and experimentally verified if a higher level of immersion helped a subject memorize the procedure better. The following are some of the research questions and hypotheses.

Research questions:

1. *Does immersive VE technology help in memorizing a procedure?*

   Immersive VEs have proved to be useful in various domains, and in this thesis, it was decided to test if an immersive VE is useful for a procedural learning process.

2. *Does a higher level of immersion help in effective memorization of the procedure?*

   It was decided to test if higher levels of immersion do help in better and more efficient learning.

3. *What component of immersion leads to higher performance in memorizing a procedure in VEs?*

   If immersive VEs were found to be useful, the components of this IVE that contributed to a better and more efficient learning need to be identified and analyzed.

Hypotheses:

1. *Immersive VEs help in memorizing a procedure*

   The fact that Immersive VEs do help in procedural learning will be demonstrated using a simple experiment in which an IVE is compared with a Non-IVE.

2. *Higher levels of immersion help in effective memorization of a procedure*

   Higher levels of immersion do help in effective memorization of a procedure by giving extra cues to remember the steps involved in the procedure.

3. *Higher Field of View, Field of Regard and a matched software Field of Vision (as in when the image is not distorted) leads to better performance in memorizing a procedure.*

   The validity of this hypothesis will be tested with a controlled empirical study.

1.4. EXPECTED CONTRIBUTIONS

A preliminary study and a formal experiment will be conducted to test these hypotheses. These results will contribute significantly towards two research communities namely VE and Learning and Training Psychology. These learning communities identify

VR as one of the potential tools to teach procedures with specific immersive conditions suggested by our thesis. Secondly, the need for more research in this area of VR will be demonstrated. Various researchers have explored the benefits of immersion in VR for various domains like architecture[41, 14], 3D interaction[41, 1, 14, 52], tasks that require spatial cues[64, 52, 11, 45, 57, 60], information visualization[56, 11], Collaborative VEs[45], information rich VEs[1, 52] and many notable projects. This research would contribute to that list. Our results will also contribute significantly to the VR community and knowledge base of the benefits of immersion. The validity of the hypothesis for any procedural learning process, higher levels of field of vision, field of regard, and an undistorted software field of vision help in better learning performance will be tested. Therefore any procedural learning task irrespective of the domain can employ the findings as a baseline to start training subjects on memorizing a procedure. This will be further explored as part of this research work.

1.5. ROADMAP

This thesis is split into five chapters with the first chapter being the introduction. The second chapter is the related work section, where in learning, training and memory, and how people have explored training is discussed. In the third section, the preliminary study is provided where the correlation between higher levels of immersion and procedural learning in VR are further analyzed in the fourth chapter, the formal study is presented in detail and the results are analyzed to see if they match the proposed hypothesis. Finally in the conclusion, the results are summarized and the contributions of this thesis to the VR community are provided. Areas for future work are proposed in the last section of this thesis.

2. RELATED WORK

The terms that are used throughout this thesis are defined in this section. This is followed by the discussion of the existing psychology of memory models and applications of these models in the fields of learning and training. A few of the popular training applications are discussed in detail as well. Further, the application of VR in the areas of training motor skills and spatial decisions are explored. An extensive literature review is conducted in the domain of "Training in VR".

2.1 HUMAN INFORMATION PROCESSING

The Human Information Processing model proposed by Wickens[76] help in better understanding of the memory models and their applications.

The Wickens' model is divided into many phases namely

1. Sensory processing
2. Perception
3. Cognition and memory
4. Response selection and execution
5. Feedback
6. Attention

The phases that will help strengthen the research hypothesis are analyzed in detail and this helps answer the question of why a more immersive VE is a better choice for our experimental design.

In sensory processing or STSS(Short Term Sensory Store), information and events reach the brain through visual and auditory receptors[78]. In the perception stage, the human brain processes raw sensory data and analyzes it, associating it with a specific content from the knowledge base. After having perceived the data, it is stored in the memory using cognitive aid, such as an external stimulus to help in assisting the subject in processing the information mentally. The border between perception and cognition is not clearly demarcated. Cognitive operations generally require greater time, mental effort and attention because they are carried out in working memory[7], which stores active information. The main features of these operations are that they are conscious activities which transform or retain information and are resource limited[47].

Once the information is stored in the memory, the brain starts analyzing it. After having understood the information that has been gathered through perceptive processes and augmented through cognitive transformation, a response is selected and later executed.

The presence of a feedback loop in the above illustrated process ensures that the intended goal is achieved. It has a couple of important implications. It ensures that the information flow can be started at any instance. Secondly, it enables a continuous flow of information. Every stage needs attention in order to process information much more precisely.

A VR system offers information and data that can be perceived through sensory stimuli. A higher level of immersion replaces more of the real-world sensory stimuli with the virtual world. A greater percentage of the sensory stimuli are things the user needs to attend to. Irrelevant stimuli from the real world are blocked out to a greater degree. Therefore, we can say that a higher level of immersion produces less distraction[80] and focuses the user's attention. Thus more immersive a VR system is, the more it offers a better quality of information and data that can be perceived much better than a low immersive system without much distraction. Therefore a more immersive virtual environment serves as a better cognitive aid to remember the steps involved in the procedure and store it in the long term memory. This model supports our claim that a VR system with a higher level of immersion will act as a good cognitive aid and ensure a continuous flow of information minimizing distractions, thereby helping in better understanding and memorization of the procedure.

An overview of how an information processing model can be molded for a decision making process has been discussed briefly in the following section.

2.2 INFORMATION PROCESSING MODEL OF DECISION MAKING

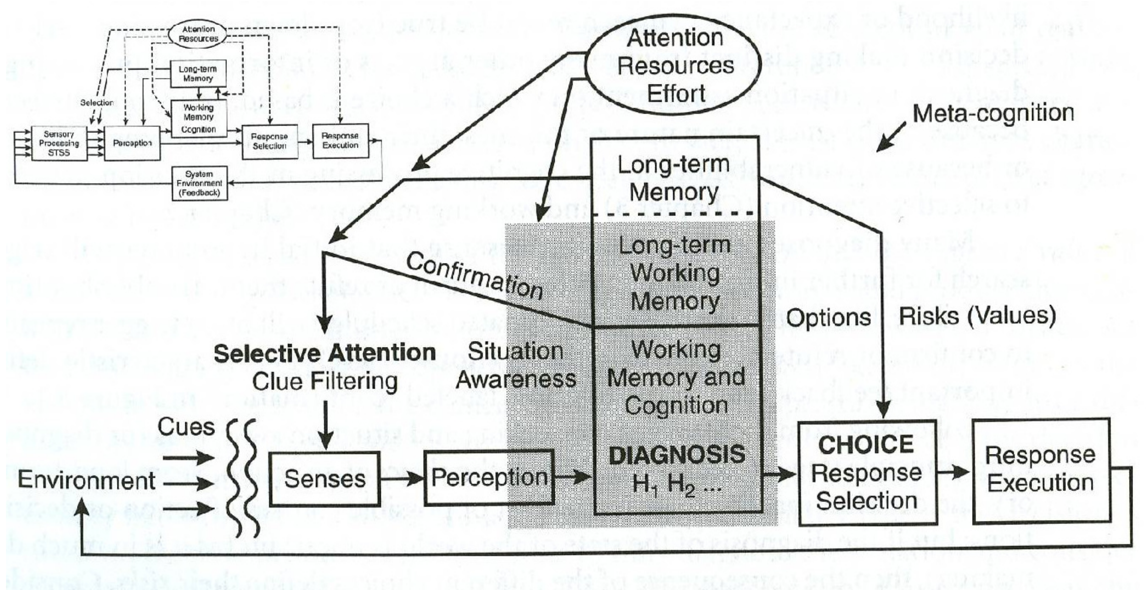

Figure 2.1. Key processes and components involved in an information processing model of decision making. It highlights concepts, operations, and terms more typically associated with decision making.

Figure 2.1 presents a model of human information processing that describes how decision making functions. It elaborates on situational awareness which explains how information is processed to take a decision. Since learning is our final target through this thesis, discussing about situated learning and how it can relate to situational awareness at this instant would elucidate the understanding of learning in through this model. Situated learning focuses on the relationship between learning and the social situations in which the training, memorization of steps or the learning occurs [39]. Situational learning can be interpreted as certain form of social co-participation; what kind of social engagement provide a good context for learning and training instead of questioning the types of cognitive process and conceptual structures involved[39].

It can be identified from the model that a decision maker must find the cues or sensory information from the environment. The environment in our case is Virtual Environment that provides appropriate 3D depth and spatial cues which enable better understanding of the current scene in the virtual environment. But these cues are processed through phase of uncertainty. Hence selective attention helps in playing a critical role in decision making, in choosing which cues to process and which to filter out. It is evident that these cues are perceived form the basis of awareness of the situation that is confronting the decision maker [58]. The user analyses the current situation to make hypotheses about the current and future state of the environment around them. This is referred to as situational assessment or situational awareness. Situational awareness combines operation in perception, working memory and long-term working memory [37]. Various examples can be quoted to support the above discussion. A physician should diagnose a patient's ailment before deciding the treatment, a battle field commander must be aware of the enemy's intent before he can choose the course of actions, etc. Therefore we see that these diagnoses is based on information from two sources namely external cues supplied by the environment to the user so that he can filter out the unwanted cues with selective attention and long-term memory which helps in contemplating the various possible hypotheses of system states and its correctness.

It can be seen that stages of cue seeking and situational awareness lead to choosing the action in decision making in the third level. This is done from long-term memory where a choice of action is chosen from various decision options already stored. The feedback loop helps in accessing the correctness of the decision made. First, feedback of decision outcomes is sometimes used to assist n diagnosis of the decision taken by the user; the second may be employed in the learning sense, to improve the quality of future decisions which also includes the estimation of risks involved because of the decision taken. Finally the role meta-cognition [59] in the model is to magnify the importance of situational awareness. This influences decision making. It raises questions like, Is one aware of the decision that the user makes? Does the decision-maker possess enough knowledge to take the correct decision?

To understand decision making better, it is required to analyze how memorization of information and learning functions, which will be dealt in the next couple of sections.

2.3 MEMORY

A very famous Memory model that was proposed by Atkinson-Shiffren[6] as show in Error! Reference source not found.**Figure 2.2**.

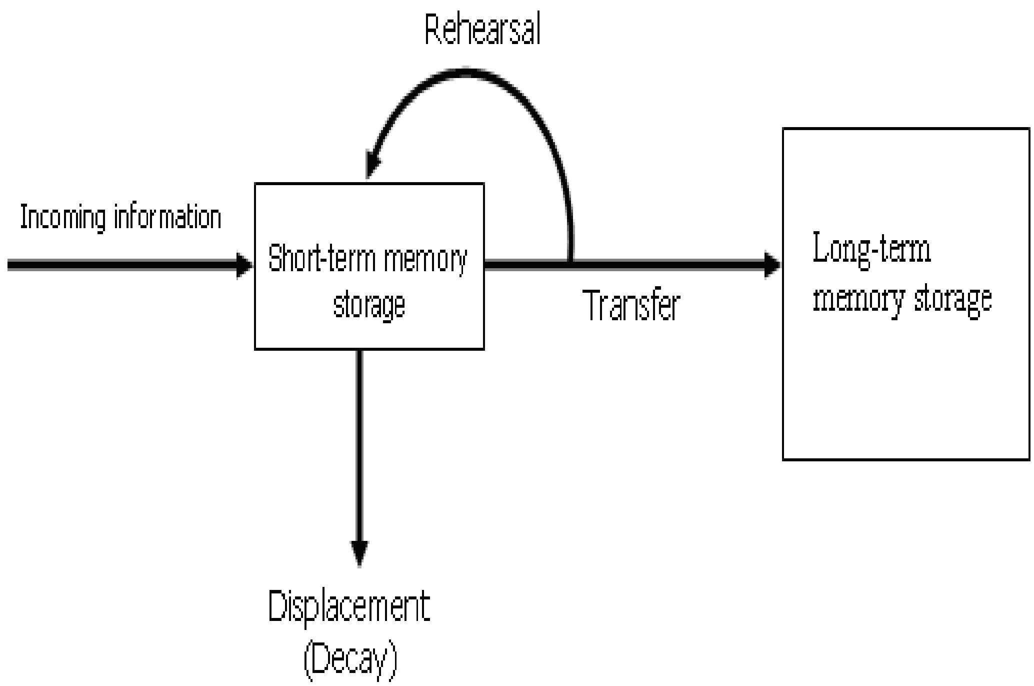

Figure 2.2. The original 2-stage model of the Atkinson-Shiffrin memory model (Picture was taken from Wikipedia)

Any memory model has three processes. The perceived data is first encoded and this data is then stored based on cognitive aid finally retrieved when data is recalled.

A memory can exist in 3 forms:

1. Sensory memory

2. Short-term Memory

3. Long-term Memory

Sensory memory is where the information is obtained from sensory inputs. This part of the data decays immediately as there is no mental processing, unless this data is passed onto the working or the short-term memory. One unique aspect of the sensory memory is that it has the ability to freeze the visual input and select which aspects of the input be further processed[16]. In short-term memory, data can be retained for 15 to 30 seconds[51]. Short term memory converts memory acoustically[17] and can retain visuo-spatial images. When short-term memory is encoded constantly over a period of time, or is supported by a strong cognitive aid, then it moves into long-term memory where it can last from minutes to forever. One more advantage of long-term memory is that it acts like a hard drive with limitless capacity, encoding mainly in terms of meaningful schemas[7]. It also retains procedural skills and imagery.

From the above paragraph, it can be inferred that sensory memory can freeze visual input and the constant use of a good cognitive aid can help transfer the information perceived into the long-term memory. It can thus safely be concluded that for a procedural leaning purpose, every step in the procedure could be remembered better with a VR system that posses higher levels of immersion. These high levels of immersion act as significant cognitive aids in providing good visual cues for enhanced spatial understanding along with auditory feedback in comparison to a less immersive system.

Short-term memory is also called working memory. Researchers have identified that some amount of kinesthetic association with the information perceived helps in a better memorization process [79, 68]. In this case, working memory is mapped to specific positional and patterned movements of the body that are done while obtaining information from the sensory input. This can be mapped to the spatial knowledge of the particular task. Spatial memory is responsible for recording the spatial orientation of an environment. The knowledge of spatial memory can be transferred from the virtual environments to the real world[75]. It has also been found that visual displays are more effective than auditory displays for tasks that demand spatial working memory[77]. Thus a procedure can be encoded spatially, to allow people use their spatial memory for learning the procedure.

Short-term memory can slowly transform into long-term memory by means of constant rehearsal and meaningful associations[18]. Spatial knowledge is observed to be stored in a long-term memory. Long-term memory is divided into two main classifications; declarative memory and procedural memory. Any *memory that is consciously available* can be said to be *Declarative*[76, 5]. *Procedural memory* on the other hand *refers to the use of objects or movements of the body*[76, 5]. Procedural memory depends on position and body movements, which brings in the concept of proprioception. Proprioception can be defined as a person's sense of position and orientation of the body and its several parts[8]. The head and body orientation are used to understand the spatial knowledge of the particular task. The concept of proprioception could therefore be applied to learn a procedure which in turn would help in storing information in the procedural memory. Thus procedural memory helps in memorizing steps of a procedure.

The points listed below support the argument that a more immersive VR system can help in better procedural learning.

2.1 Visual imagery helps memory.

2.2 Spatial encoding helps memory.

2.3 Use of proprioception helps spatial understanding.

In an immersive VE, each step of the procedure can be encoded to a procedure visually and spatially mapped to a visible object located at a particular position in 3D space. This concept is used to train users to remember the procedure by physically moving their heads, bodies, arms, and hands to look and point at the objects for each step.

With lower levels of immersion, the spatial understanding will be lower [21, 60, 75], and the user will not be able to make as much use of proprioception as they do in scenarios with higher levels of immersion(due to lower FOV, lower FOR and other components of immersion.).This supports the research hypothesis put forward by this work.

A VE should allow users to memorize a procedure based on a spatial and visual encoding of the procedure. A higher level of immersion could be more effective, because of the use of proprioception and the overall higher level of spatial understanding.

A memory model is the base for any training or learning experience, because any information processing creates or maps a memory model. The next section analyzes how training and learning are influenced by memory.

2.4 TRAINING AND LEARNING

There are various learning models but most of them can be categorized under two general models that describe learning namely ACT-R[4] and Soar[46]. In ACT-R model the idea is to compare the current active information with a set of production rules. Production rules can be defined as set of steps that logically define a procedure. The last section covers the procedural and declarative memory, both of which are intertwined in ACT-R learning[4]. Generally, production rules are embodied in procedural knowledge, but their conditions and actions are defined in terms of declarative knowledge. Declarative knowledge can be defined as the conscious knowledge that is found in the memory. It has been proven that chunks of declarative knowledge that is found in these production rules are strengthened through constant rehearsals. This forms a part of the learning process. These chunks of declarative knowledge hold a particular level of activation that will determine the probability of its retrieval[5]. Retrieval can be defined as the content that is being reproduced from a set of information stored in the memory but not consciously**.** Formation of these production rules if a key part of learning. A general problem is that as the task increases in complexity, it becomes more difficult to retrieve chunks from declarative information.

The Soar[46] Model is similar to its other counterpart that rely on production rules, but this model does not distinguish between procedural and declarative knowledge[27]. It has been found that Soar Model predicts that a visual interface (something that incorporates visual information based display) helps in learning a procedure over cases where users have to remember the commands that accompany the procedure to be learnt. [27]. This model proposes that task rely more on long term memory rather than on working memory thereby freeing up resources for other tasks in the working memory. It also states that any display characteristics that facilitate the recall strategy will be more effective for training.

The Soar Model predicts that procedures learned graphically will be understood more easily than those represented simply as text i.e. display characteristics of the VR system will help in learning the tasks in the initial stages. This information is then stored in the working memory.

Once the information reaches the working memory, it has to be transferred into long-term memory. The ACT-R model predicts that sensory stimuli and human brain will help to interpret the content in working memory and to transfer it into long-term memory. Every step of the procedure is being stored as chunks of declarative knowledge. These chunks of declarative knowledge are strengthened over constant rehearsals using sufficient cognitive aid. In this case the immersive virtual environment acts as a cognitive aid. The users form their own production rules with the chunks of declarative knowledge to initiate the learning process. The focus of designed experiments is to know whether a cognitive aid, a more immersive display in this case, can deliver these chunks of declarative knowledge so that the procedure can be memorized better. Declarative knowledge helps in the efficient retrieval of the procedural knowledge by better spatial understanding of the environment.

Most of the training activities demand high working memory that impedes the learning process. Generally, if training does not turn out to be effective, a possible reason might be a limited working memory capacity. It has also been proved that when auditory instructions accompany a visual based training process, there is a better performance in learning the procedure[73]. Thus effective training can be achieved through sufficient cognitive aid[69, 70]. Repeated practice or good cognitive aids, along with information, helps in transferring the content from working memory to long term memory[18] for a procedural training process. It is essential that we understand that procedural memory is different from recall. Recall is generally very accurate and effortless. Forgetting a skill is possible only when it was not learnt thoroughly. Procedural skills are generally rapidly forgotten, unless these are associated with perceptual motor activity.

Therefore it can be concluded that for efficiently learning a procedure, the learning process needs to be associated with some kind of perceptual motor activity. This activity could be achieved in our procedure through proprioception and a good understanding of the spatial layout of the environment. The claim is that this particular condition can be achieved through virtual environments that provide a higher level of immersion. Immersive virtual environment acts as a cognitive aid by providing:

1. Realistic spatial (depth) cues
2. Objects appearing to be at real locations in 3D space
3. The ability to view the scene with physical body movements.

Thus, a human processes information and create a memory models and effectively use that model to learn a procedure or be trained on a procedure. We discuss memory model and training in detail to establish the link between the memorization and learning process. Making this connection clear helps us understand the future work in the later sections. The next section analyzes the validity of an Immersive Virtual Technology system when applied to a training process.

2.5 VIRTUAL ENVIRONMENTS – TRAINING AND LEARNING

Immersive virtual environments (VEs) have their share of inherent advantages for training. VEs allow trainees to access a wide variety of training scenarios that might be difficult to reproduce in the real world. It provides flexibility not offered by ordinary physical environments. In some types of training (e.g., pilot training, warfare training), immersive VEs can offer lower costs and reduced danger. It is notable that medical [38, 71, 50, 48, 63, 26, 34, 24] and military training [74, 54, 49, 72, 65, 13] in particular have been very popular application for immersive VEs.

However, one can observe that VEs have been successful for *specific types* of training, like training of motor skills (e.g. performing laparoscopic surgery [40, 63, 71, 26, 15, 34], endoscopic surgery[38], rehabilitation of a stroke victim[43]), decision-making that depends on 3D spatial cues (e.g. fire fighting training [72], warfare training [74, 54] and location based applications[20, 24, 41, 64]), or both (e.g. flight/driving simulators [13, 2], warfare and strategy[49, 54]). The success of these applications can be attributed to the ability of immersive VEs to allow full-body interaction in motor training and provide enhanced spatial cues [53, 44] in tasks that require spatial decision-making. But there may also be training applications like image guided surgery and medical anatomy education [25, 40] that do not incorporate any of the training strategies above. These applications were image based and VR was just used as an additional cue in training and did not play a main role in training the users.

This specific training is explored in detail in the following sections. In medicine, laparoscopic surgery requires precise *motor skills*; the laparoscopic simulation system[63] offers a combination of mechanical input device and VE. In this case laparoscopic instruments are used within a hybrid dummy on tissue or objects while using video tracking[63]. The application gives sensory feedback while performing the operation using 3D input devices, resulting in effective training.

Fire fighting requires real-time *spatial decision-making*, because the firefighter must establish a path to escape the fire. VR systems used for training firefighters [72] provide the necessary spatial cues to produce effective training. Immersive VR can also be used to help drivers learn routes [1]. Training applications using simulators, such as vehicle and infantry simulators [13, 2] can be used for *both* motor training and training of spatial decision-making.

Immersive technologies are successful in these areas because they provide the appropriate spatial cues (e.g., stereoscopy, motion parallax, etc.) and sensory-motor feedback (e.g., proprioception [44], haptics [20, 71, 34, 40]) to allow for effective training. When whole body interaction can improve the understanding of the environment, it would be necessary to explore whether VEs, in particular immersive VEs, can be effective for procedural training. But before exploring this topic, it will be necessary to ensure if researchers have already identified if VR is useful for procedural training.

In the past procedural training and conceptual learning applications of VR have been explored by many researchers. For example, several projects have explored whether users can learn a procedure through interaction with a virtual agent in a VE [33, 53, 35]. Others have hypothesized that content will be more memorable if students experience it firsthand in an immersive VE [3, 62]. Researchers in some cases have attempted to measure the effectiveness of the training/learning [e.g., 7], but it has proven difficult to quantify the benefits of immersion for learning. But with our motivation more driven towards exploring how VEs could be beneficial for memorization of a procedure, we are more inclined to studying the effects of immersion on the same.

Most of these studies have been very restricted to specific domain like military or medicine. There is no general study on abstract memorization of procedures. Studies that examine the impact of *level of immersion* on memorization of a procedure with VEs could not be found from the literature review. Therefore it was decided to implement a generic training scenario using basic primitive shapes and location matching based tasks.

3. PRELIMINARY STUDY

Given VR's popularity, researchers have attempted to identify if VR could be used for learning and memorizing a procedure. Attempts have been made to measure the effectiveness, but there have not been concrete findings in this aspect. In this thesis, these existing issues are addressed and the goal will be to provide a detailed report of the results of the preliminary and the formal study. The results are then analyzed and methods by which these findings could be incorporated into the already existing field of VR and learning community are explored.

3.1. GOALS AND HYPOTHESIS

This section analyzes the reasons why VEs and immersive VEs in particular need to be used in conjunction with procedural training. VEs provide good spatial cues, and immersive VEs enhance these cues in a realistic way [66]. It has also been shown that higher levels of immersion lead to better spatial understanding and spatial memory [20, 64, 61]. Spatial memory can be used as a substitute for procedural memory; a person can remember a procedure by remembering the spatial locations of the objects or steps used in the procedure. This is similar to the "method of loci" used in classical times[22]. In this method, one memorizes a speech or set of items by associating each piece with a physical location in the mind [42]. Since higher levels of immersion provide enhanced spatial cues and better spatial memory, it can be concluded that they can also provide more effective procedural training, as long as the procedure can be mapped to spatial locations.

The first goal of this research would be to verify the claim that an immersive VE helps memorize a procedure. Therefore, the following hypotheses are:

1. *Immersive VEs help in memorizing a procedure.*
2. *Higher levels of immersion help in effective memorization of a procedure*

To test these hypotheses, a preliminary experiment was conducted. Participants were trained on two procedures, and their performances were compared at two different levels of immersion, the levels being lower and higher.

3.2. APPARATUS

The lower level of immersion used a typical laptop display with a resolution of 1024x768 pixels on a 15.4-inch screen. An XBox 360 game controller was used as the input device. The left analog stick was used to move forward, backward, strafe left and strafe right. The right analog stick was used to move up and down. The left and right keys on the directional pad were used to rotate left and right. Participants in experimental set-up sat in a chair in front of the display; the physical environment was quiet with dim lighting. The Irrlicht Game Engine [29] was used to render the environment in this condition.

The higher level of immersion (see **Figure 3.1**) made use of two VisBox-X3 displays, in an L-shaped configuration [31]. Each display had a 10'x7.5' screen with rear-projection, and is 7.5' deep. The projectors display SXGA+ resolution (1400x1050) on each screen. In our experiment, monoscopic graphics were rendered on each display. This condition made use of the same input device and interaction technique as in the lower level of immersion condition. Participants stood near the center of the L-shaped display, approximately eight feet from the seam between the two screens. The environment was rendered by the DIVERSE toolkit [28].

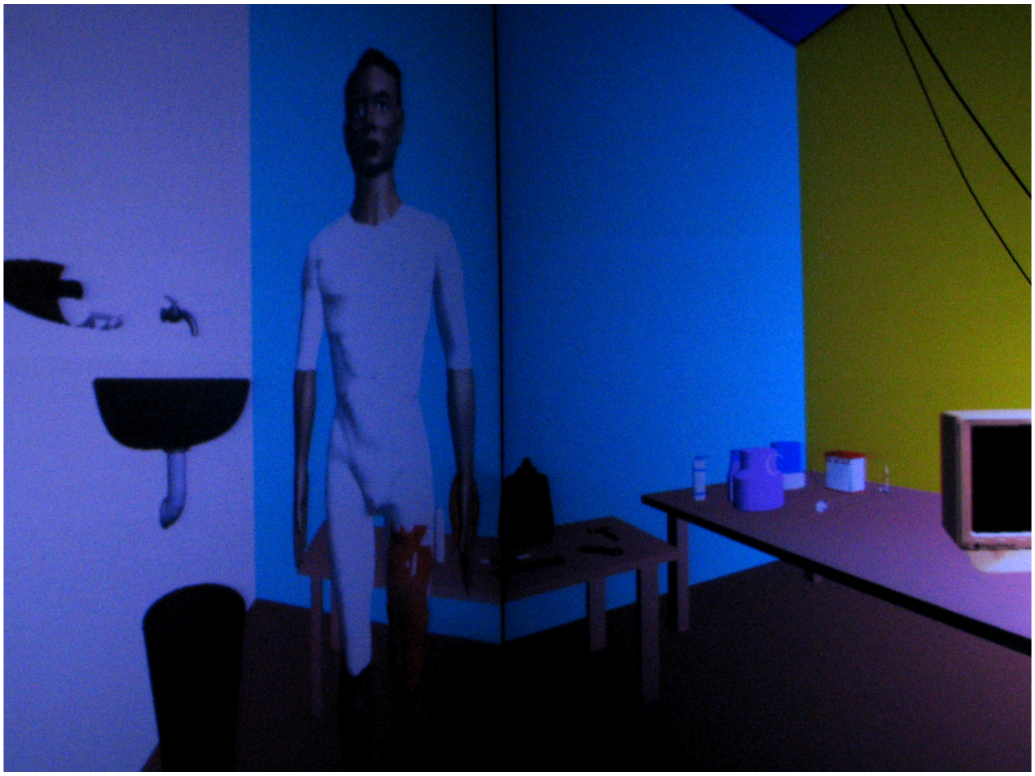

Figure 3.1. The display hardware used in the higher level of immersion

The physical Field Of View (FOV) of these two displays is obviously very different. In the low-immersion condition, the physical horizontal FOV was approximately 15 degrees, while the horizontal FOV for the high-immersion condition was nearly 180 degrees. In the high-immersion condition, the software FOV was set to match the physical FOV, so that the user's view of the environment was not distorted. For the low-immersion condition, however, software FOV of 72 degrees was employed, since it is well-known that users can adapt to the perspective distortions induced by larger software FOVs on desktop displays [52]. This value was chosen so that users were able to see the entire room at a glance on the laptop display and their performances in the low-immersion condition were not adversely affected by the requirement to navigate around the scene to see all the objects involved in the procedure.

The virtual environment consisted of a simulated emergency room containing a virtual patient, tables, a vital signs monitor, and various medicines, bandages, and surgical instruments **Figure 3.2** and **Figure 3.3** illustrate the contents of the virtual room for the simple and complex scenarios, respectively. The model was produced using Flux Studio [30].

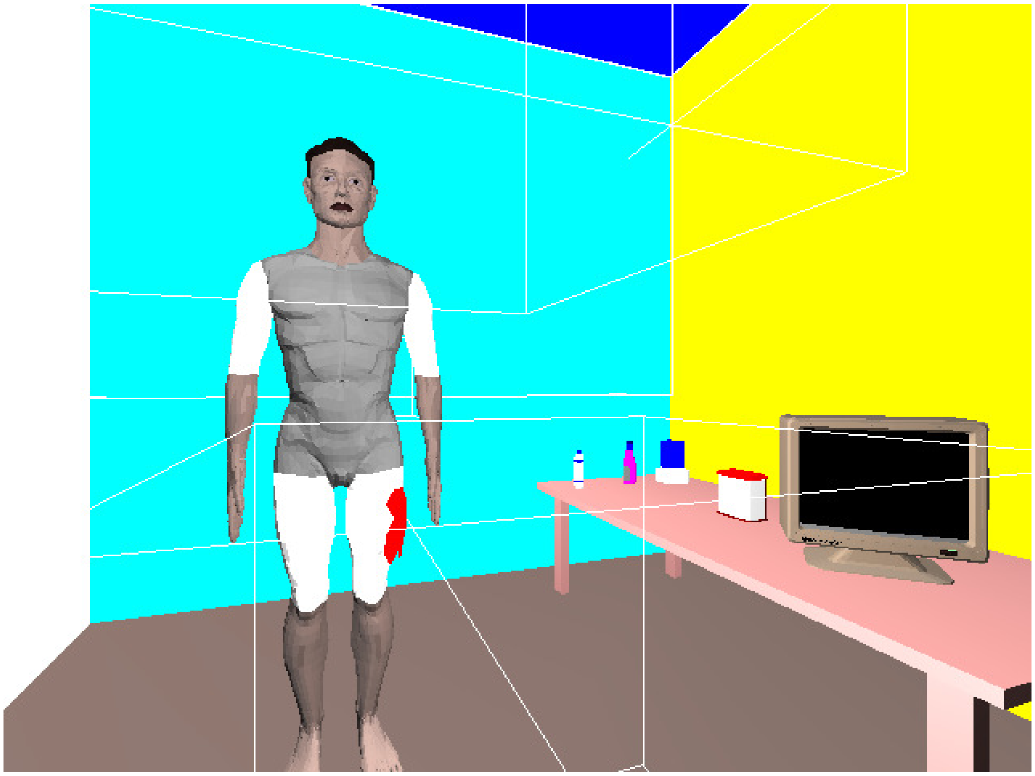

Figure 3.2. Virtual room used in the simple procedural learning task.

Figure 3.3. Room used in the complex procedural learning task.

3.3. EXPERIMENTAL DESIGN

While designing an experiment, the dependent and the independent variables under measurement needed to be considered. There was a single independent variable in the experiment: level of immersion. The low level of immersion made use of a typical laptop display, while the high level of immersion was implemented with a large L-shaped two-screen projection display. Other factors, such as the input device, navigation technique, environment design, and task, were held constant across both conditions.

The experiment used a between-subjects design. The 14 participants were divided randomly into two groups with three females in each group. The dependent variables in the experiment were the time taken to recall each learned procedure, and the number of errors in describing the procedure.

3.4. PROCEDURE

Before beginning the experiment, participants were asked to fill an informed consent form **(Appendix A.1)** and a user questionnaire **(Appendix A.2)**. The participants were given an instruction sheet (**Appendix A.3**) that debriefed them over the experiment. Then the participants practiced the navigation technique until they were satisfied that they could use it effectively to navigate the virtual room. The tasks in the experiment involved memorizing procedures in an environment loosely based on a hospital emergency room. The first task was a simple ten-step scenario involving four objects. The second task was more complex; it consisted of 31 steps involving 14 objects. For each task, the experiment was divided into three phases.

In the *Training phase* the experimenter first identified the objects that would be used in the procedure, and then explained each step of the procedure in detail. The participant was taught to describe the steps of the procedure using specific terms. For example, three steps might be described as: “pick up the purple bottle,” “apply it to the wound,” and “put it back.”

The *Practice phase* allowed participants to recall, with the experimenter’s assistance, the procedure from the training phase. In this phase, the participants were asked to verbally describe the procedure, following the protocol from the training phase. If a participant made a mistake or could not recall the next step, they were given help to remember the correct step in the procedure.

In the *Final Assessment phase*, participants were asked to recall the entire procedure without any assistance. Only when the participant provided the current step correctly did the scenario move on to the next step.

Both time and errors in the Practice and Final Assessment phases were measured along with the time taken to complete the Training phase for each task.

3.5. PARTICIPANTS

Fourteen voluntary, unpaid participants (eight men and six women) took part in the experiment. Their mean age was 23. All reported using computers daily. Two participants had used immersive VEs previously, while eight had video game experience.

3.6. RESULTS

The data was analyzed by performing a series of t-tests (assuming unequal variance) comparing the time taken in the low- and high-immersion conditions for each phase of each task, and comparing the number of errors made in the two conditions for the practice and assessment phases of each task. A complete summary of the results and the t-test can be found in **(Appendix B).**

No significant differences between the conditions for either of the metrics in task 1 (the simple task) were found **(Appendix B.12)**. **Figure 3.4** shows the time taken in each phase and condition for task 1. There were no errors in the practice or assessment phases for either of the conditions.

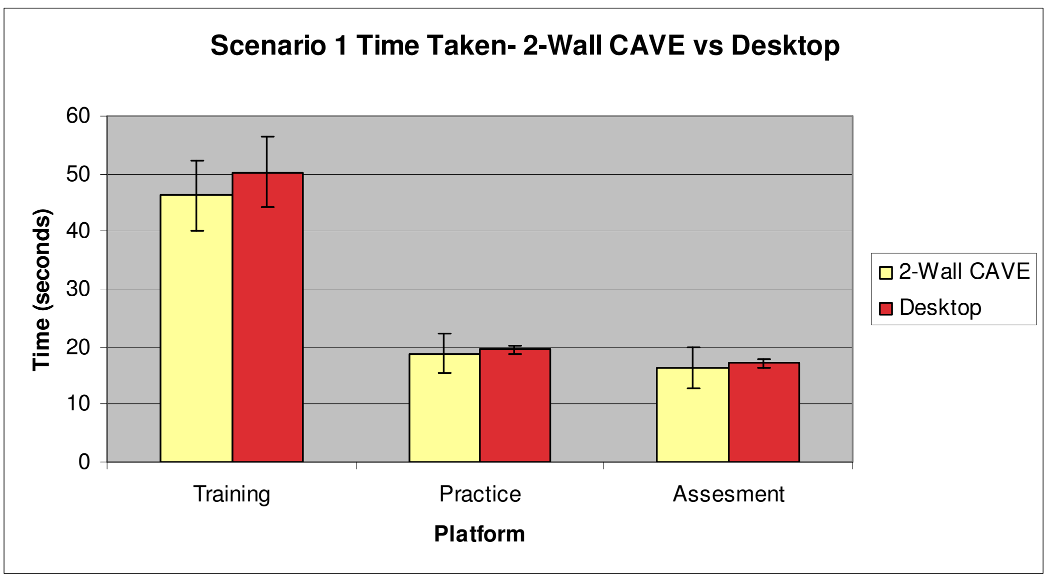

Figure 3.4. Average time for completion of each of the phases of the simple task in the low- and high-immersion conditions.

Significant differences were found between the two conditions in task 2 (complex task). The mean time to complete the assessment phase for task 2 was 110.2 seconds for the low-immersion condition and 77. 9 seconds for the high-immersion condition ($t = -2.72$, $p < 0.01$) **(Appendix B.7)**. The difference in time was not significant for the training and practice phases **(Appendix B.5 and B.6)** as shown in **Figure 3.5**.

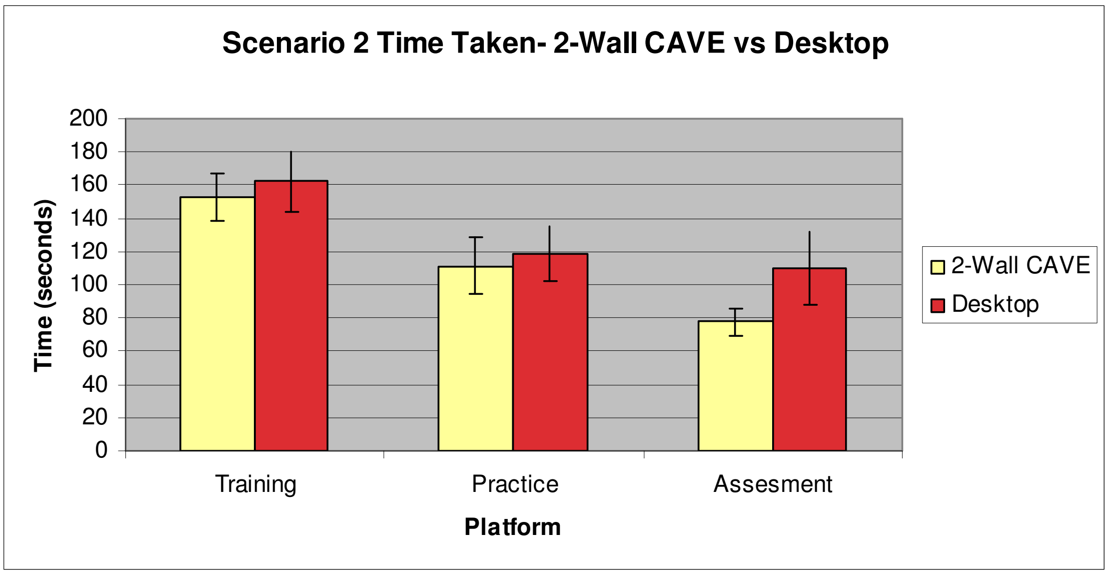

Figure 3.5. Average time for completion of each of the phases of the complex task in the low- and high-immersion conditions. The difference is significant for the assessment phase.

Figure 3.6 shows the average number of errors in the practice and assessment phases for the two conditions. Both of these differences were significant. In the practice phase, users in the low level of immersion made an average of 3.86 errors, while users in the high level of immersion made an average of 2.29 errors ($t = -2.69$, $p < 0.01$) **(Appendix B.8)**. In the assessment phase, these averages were 3.57 and 0.71 errors, respectively ($t = -2.96$, $p < 0.01$) **(Appendix B.9)**. In each case, where a significant difference was found, users performed better in the high-immersion condition. Thus, it can be concluded that an increased immersion resulted in higher levels of training effectiveness for the complex procedural learning task in this experiment.

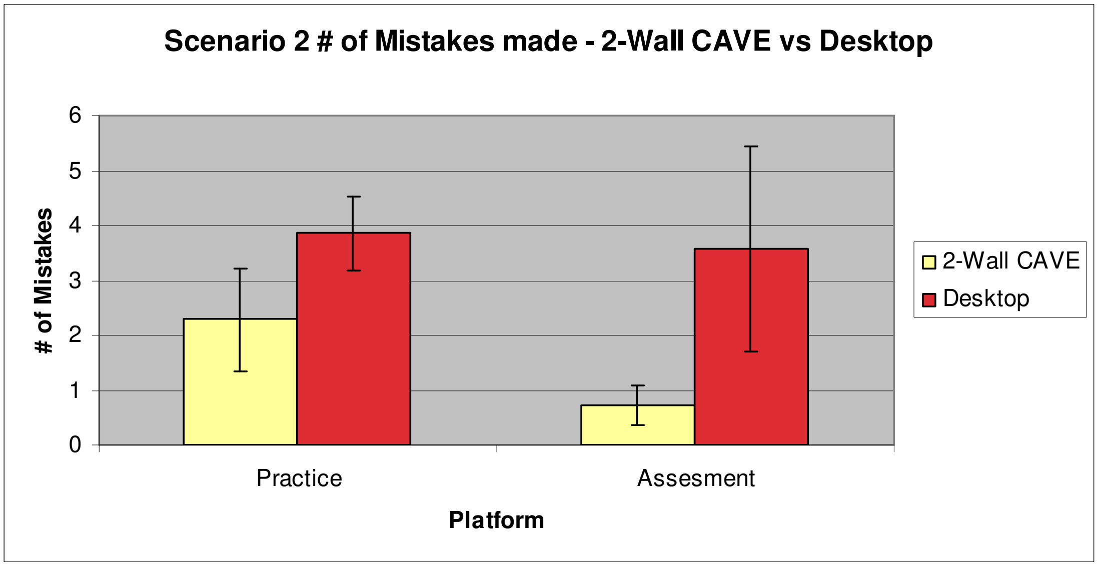

Figure 3.6. Average number of errors in the practice and assessment phases of the complex task in the low- and high-immersion conditions. Both differences are significant.

3.7. DISCUSSION

A key feature of the results is that increased immersion had no effect when the procedure was simple; most subjects were able to remember the procedure perfectly after training in either condition. But for the more complex procedures, increased immersion had a highly significant, positive effect on performance, particularly for the error metric. This suggests that with the amount of training provided, the higher level of immersion was needed in order to learn the procedure effectively. Finding a benefit of immersion only in complex tasks is consistent with our prior results for other task types. For example, in a study of spatial understanding in a visualization application, the same distinction between simple and complex tasks was found [64]. Experiments on single-user object manipulation showed no differences based on level of immersion [10], but a separate study on collaborative object manipulation (a more difficult task) indicated that stereo improved user performance [45]. The hypothesis in this experiment was supported.

It can be safely concluded that memorizing a procedure, with a higher level of immersion, was more effective because participants could make use of enhanced spatial cues as a memory aid. In the high-immersion condition, the objects in the environment were spread out spatially, affording the use of head turning and pointing, and could be remembered based their spatial location, while in the low-immersion condition, all of the objects were "squeezed" into a much smaller physical space. At this point, however, there is only circumstantial evidence for this theory. Seven of the eight participants in the high-immersion condition believed that the size of the display was partially responsible for their ability to memorize the procedure. Most of the participants in the low-immersion condition mentioned that their memorization strategy was based on object color (not on spatial position of the objects).

This experiment fails to indicate which component of immersion resulted in the observed difference between the two conditions. The conditions differed in at least the following ways: FOV, software FOV, field of regard, screen size, and screen shape. A follow-up experiment is needed to determine which component(s) have a positive effect on procedural learning.

It was demonstrated that a higher level of immersion can be more effective in the learning of complex procedures that reference spatial locations. The implication of this finding is that immersive VR systems may be suitable for procedural training in a wide variety of domains that require students or workers to memorize complex procedures.

Therefore, a follow-up experiment to examine the effects of individual components of immersion on memorizing an abstract procedure was planned. Using a CAVE system, the physical FOV, software FOV, and FOR (Field of Regard) in the training of a complex procedure involving objects in a 3D environment need to be varied independently. In addition, the results from this research will be further validated by assessing the effectiveness of the training not only in the virtual environment, but also in a real-world setting.

4. FORMAL EXPERIMENT

In the preliminary experiment it was found that an immersive virtual environment is indeed useful for procedural training. Furthermore, it was also found that, a higher level of immersion helps in better memorization as compared to a lower level of immersion. As mentioned before, it not possible to find out which component of immersion contributed to higher memorization capabilities in the virtual environment. Therefore the goal in the formal experiment is to identify those components of immersion that help in better understanding of the procedure. Another factor that will be investigated is if there is any transfer of learning from the virtual environment to the real environment.

4.1 GOALS AND HYPOTHESIS

The previous hypotheses, stating that, higher level of immersion helps in effective memorization of a procedure have been tested. Now in-order to define our goal and state the hypothesis in this section, the components of immersion that can have an impact on learning in VR need to be identified. VEs provide good spatial cues, and that immersive VEs enhance these cues in a realistic way [66]. It has also been shown that a higher level of immersion leads to better spatial understanding and spatial memory [20, 64, 61]. Since it has already been proved that higher levels of immersion results in effective procedural training, identifying those components of immersion that were responsible for better learning is the next step. A few components of immersion are:

1. Field of View: Field of view (FOV) is the area (measured in visual angle) that the user sees in the virtual world at any instant in time[9].

2. Field of Regard: The field of regard (FOR) is equivalent to the level of physical immersion, and can be defined as the visual angle surrounding the user within which the virtual world is displayed to the user[9].

3. Software Field of View: Software Field of view (FOV) is the area (measured in visual angle) that the computer graphic program camera sees in the virtual world at any instant in time[52].

Note that FOV is not the same as FOR. The FOV is the amount of world or the environment that the user sees at an instant of time. The FOV may vary through many VR display devices. In a tracked head-mounted display (HMD), the horizontal FOV may be 60 degrees (the user is able to see 60 degrees of his visual field of the virtual environment at a given instant), where as in a CAVE the user can see 180 degrees of the environment at any instant, limited only by the FOV of his own eyes. Coming to FOR, say the horizontal FOR is 360 degrees (for a Head Mounted Display, *HMD*), the user sees the virtual world no matter which direction he looks because the virtual world surrounds the user. With a non-head-tracked single large projection screen, the horizontal FOV might be 90 degrees; in this case the horizontal FOR would also be 90 degrees as shown in **Figure 4.1**, since the user can see the entirety of the display at a glance[55].

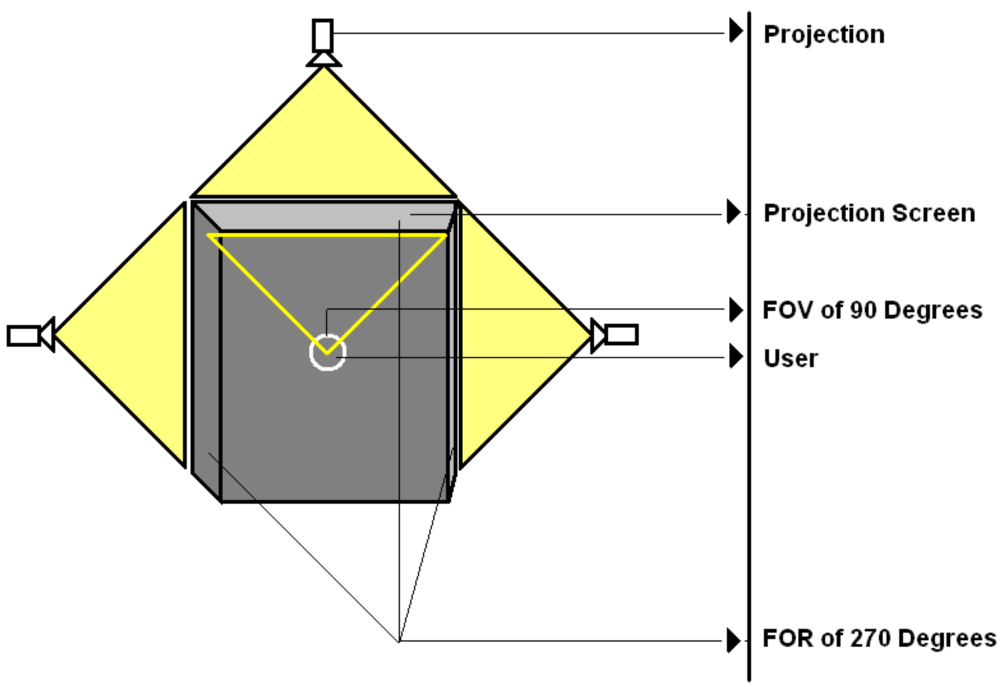

Figure 4.1. CAVE Display (Top view) with FOV and FOR components

The concept of proprioception[44] is possible only if we have a large Field Of Regard and wide Field Of View which can enable the user's head movement in the virtual environment to map the environment much better in the users head thereby increasing the spatial understanding of the environment. Therefore, with support of our detailed related work, we see that FOV and FOR can possibly have a significant effect on the learning process.

Other components like head tracking, head-based rendering and stereo were not considered for our experiment. Since in our experiment the user's position is fixed and the virtual environment is relatively fixed, head tracking and head based rendering will not have any effect on the final result. Currently most of the VR systems use Stereo display that has glasses which reduce the physical FOV for the user. Since, in the present experiment, FOV was a major factor, we decided to use monoscopic 3D graphics or in other words no stereo.

Software FOV is another component that was varied. Before hypothesizing about this component, it is necessary to analyze and understand the possible conditions available with this component. A matched software FOV would mean that the virtual world is scaled exactly to the same dimensions as the real world, meaning that spatial layout of the virtual environment would be very similar to that of the real world [75, 21]. But an unmatched Software FOV would mean that the spatial layout is either a cluttered world for that specified camera angle or it is very large. This leads to reduction of fidelity of the virtual environment, but we claim that it will affect the performance.

Considering the first experiment, the SFOV was in a matched state for the higher level of immersion condition. The SFOV for the low level of immersion was unmatched It is a general norm that on a desktop, a distorted SFOV is a norm. A simple reason being on a smaller screen large amount of information has to be deployed, for which a balance has to be achieved between SFOV and distortion. In the second experiment, since it is testing only the CAVE which is of higher level of immersion, the SFOV will be varied to find out its effect on the performance. An example of a distorted SFOV of 135 degrees is shown in **Figure 4.2** and a matched SFOV of 90 degrees is show in **Figure 4.3.**

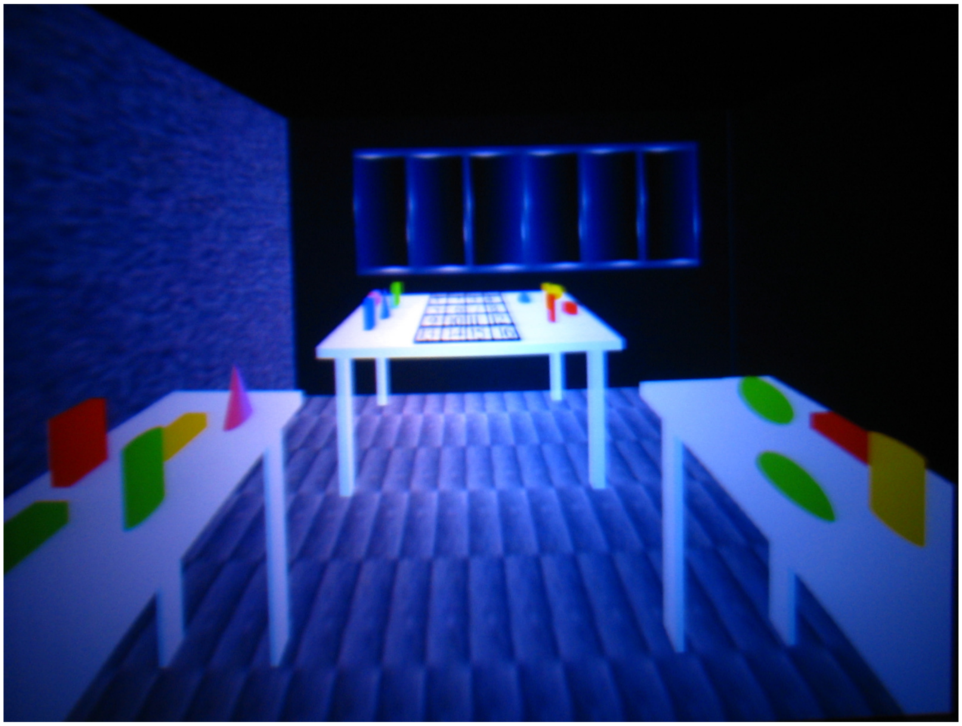

Figure 4.2. Distorted SFOV with 135 degrees in CAVE

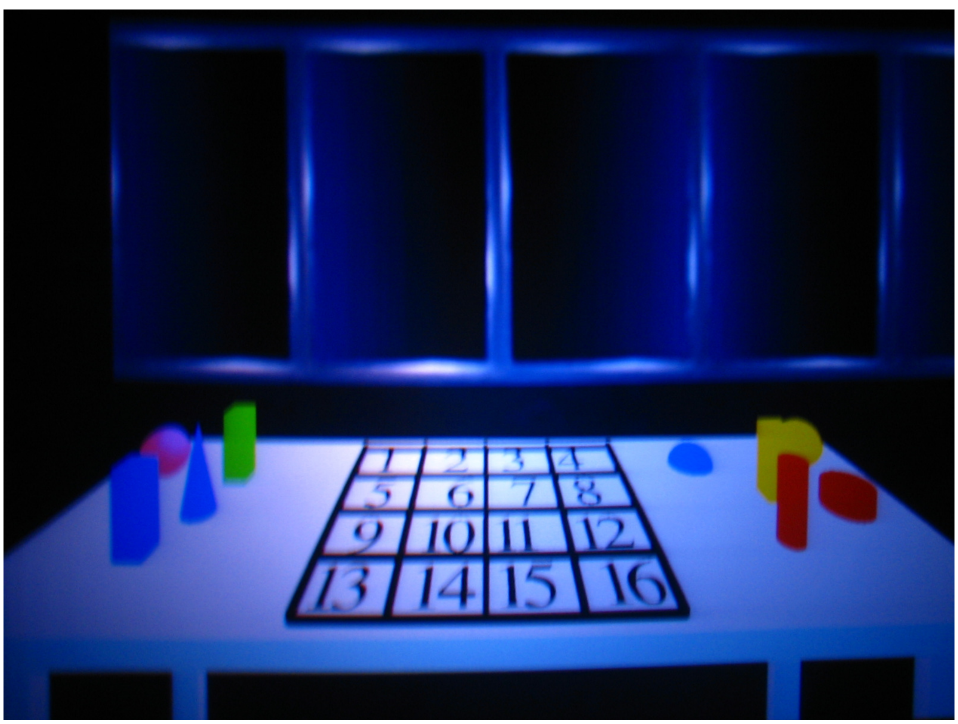

Figure 4.3. Matched SFOV with 90 degrees in CAVE

Thus it would be interesting to test and analyze if a person purely relays on visual cues for learning a procedure (i.e. Unmatched Software FOV condition) or visual cues supported with significant cognitive aid (i.e. Matched Software FOV condition).

Matched Software FOV condition would result in better memorization of a procedure because of better spatial understanding than the Unmatched Software FOV condition.

In the preliminary experiment, the final assessment was done in the virtual environment. The effectiveness of the training was never tested in the real world. Also, the spatial layout in the final assessment was not changed. Therefore in the final experiment, it was decided to do the final assessment either in the real world or in the virtual world, but keep objects either in the same location or different location and ask the user to recall the same procedure that they were trained on. VE training should transfer to the real world; it is not expected to be a difference in procedural memory between VE assessment and real world assessment. This leads to the claim that the environment would not have a significant impact on our results.

Therefore, performance in the real world is going to be similar to that of the mocked virtual world.

A similar argument can be applied to changing the spatial layout of the objects involved in the scene, like changing the location of the objects involved in the scene that will not affect the performance of learning the procedure. The goal of training is to increase the capability of the user to apply the knowledge learnt under any circumstances and in any given environment.

Therefore the goal would be to verify which components of immersion lead to higher performance in learning a procedure in VEs.

Therefore the hypotheses will be:

1. *Higher Field of View, Field of Regard and a matched software Field of Vision (as in when the image is the not distorted) leads to better performance in memorizing a procedure.*
2. *Environment (Virtual/Real) and spatial layout (Objects kept in Same Location/ Different Location) will not affect the performance in memorizing a procedure.*

To test these hypotheses, a controlled experiment was conducted. Participants were trained on four procedures, and compared performance with 6 different immersion conditions.

4.2 EXPERIMENTAL DESIGN

The experimental was designed, considering the dependent and the independent variable. There were three between-subject independent variables that described the level of immersion of the VE used in the training and practice phases in our experiment: FOR, FOV and Software FOV. Therefore totally eight conditions are possible. They are:

1. High FOR, High FOV, Matched Software FOV
2. Low FOR, High FOV, Matched Software FOV
3. High FOR, Low FOV, Matched Software FOV
4. Low FOR, Low FOV, Matched Software FOV
5. Low FOR, High FOV, UnMatched Software FOV
6. Low FOR, Low FOV, UnMatched Software FOV
7. High FOR, Low FOV, UnMatched Software FOV
8. High FOR, High FOV, UnMatched Software FOV

It was decided to maintain 135 degrees per screen for the unmatched Software FOV conditions. Maximum FOR that is possible in a virtual environment is 360 degrees, but when we have 135 degrees for three screens i.e. our high FOR condition, it exceeds 360 degrees. Therefore the last two conditions are not meaningful, so only the first six conditions were tested.

Every in-between subject condition had two with-in subject variables. The user can do his final assessment under every between subject condition in

1. Virtual World or in the Real World
2. Objects kept in Same Location or Different Location

Therefore we have four within subject conditions. They are:

1. Virtual World with objects kept in Same Location (V S)
2. Virtual World with objects kept in Different Location (V D)
3. Real World with objects kept in Same Location (R S)
4. Real World with objects kept in Different Location (R D)

The four within subject conditions were applied on four different procedures of the same level of complexity and difficulty. Procedures were not considered as variables. The procedures were randomized according to a latin square design[12] for every within subject condition. **Figure 4.4** below has all the six between-subject treatment conditions on the second column; the third column contains the order in which the within-subject conditions were executed; the fourth column was used to record the initial memory test data. The fifth column displayed a procedure column with lot of sub-columns. Every procedure had two major columns Virtual and Real. These two columns were further subdivided into Same and Different. Thus the four columns covered all the within-subject conditions. Each of the four columns was further subdivided into two response columns, one for time and the other for errors. There were totally four procedure columns. Every procedure column contained the same structure as mentioned above. Every subject would do four procedures and for every procedure only one of the within-subject conditions will be updated in other words the yellow colored box in every row represents the third column (Order) which is the order in which the within-subject condition will be executed.

Serial #	Condition	Order	Subject		Procedure 3								Procedure 4								Procedure 5								Procedure 6							
			Memory		Virtual				Real				Virtual				Real				Virtual				Real				Virtual				Real			
			Test		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different	
			Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
		VS, VD, RS, RD																																		
	Matched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
1	Low Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	Low FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD																																		
	Matched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
2	Low Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	High FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD																																		
	UnMatched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
3	Low Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	Low FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD																																		
	Matched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
4	High Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	Low FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD																																		
	Matched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
5	High Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	High FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD																																		
	UnMatched S/w	VD, RS, RD, VS																																		
	FOV	RS, RD, VS, VD																																		
6	High Physical	RD, VS, VD, RS																																		
	FOV	VS, RS, VD, RD																																		
	Low FOR	RS, VD, RD, VS																																		
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		

Figure 4.4. A table showing all the conditions

Every between subject condition had six participants that had to perform two practice procedures and four complex procedures. The dependent variables in the experiment were the time taken to recall each learned procedure, and the number of errors in describing the procedure.

4.3 APPARATUS

A room adjacent to the CAVE was used to setup the real world condition as show in **Figure 4.5**. It had three tables on which primitive shapes like cones, spheres, box, wide box, cylinder, wide cylinder and hemi-spheres as show in **Figure 4.5** and **Figure 4.6**. The primitive objects were of six different colors namely yellow, red, blue, pink, green and white. **Figure 4.6** illustrate the contents of the room for a scenario. A 4x4 target area with squares numbered from 1 to 16 as shown in **Figure 4.7** was kept at the center of the front table.

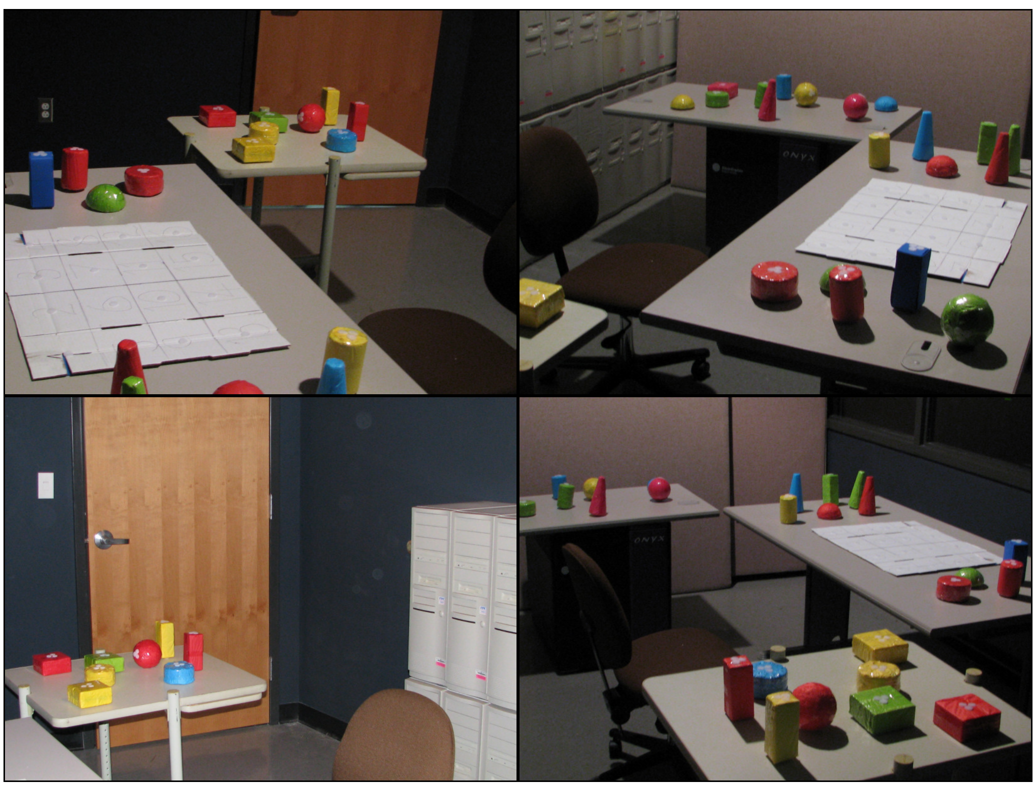

Figure 4.5. Real Environment setup in a room adjacent to CAVE

Figure 4.6. Arrangement of objects and tables in the Real Environment

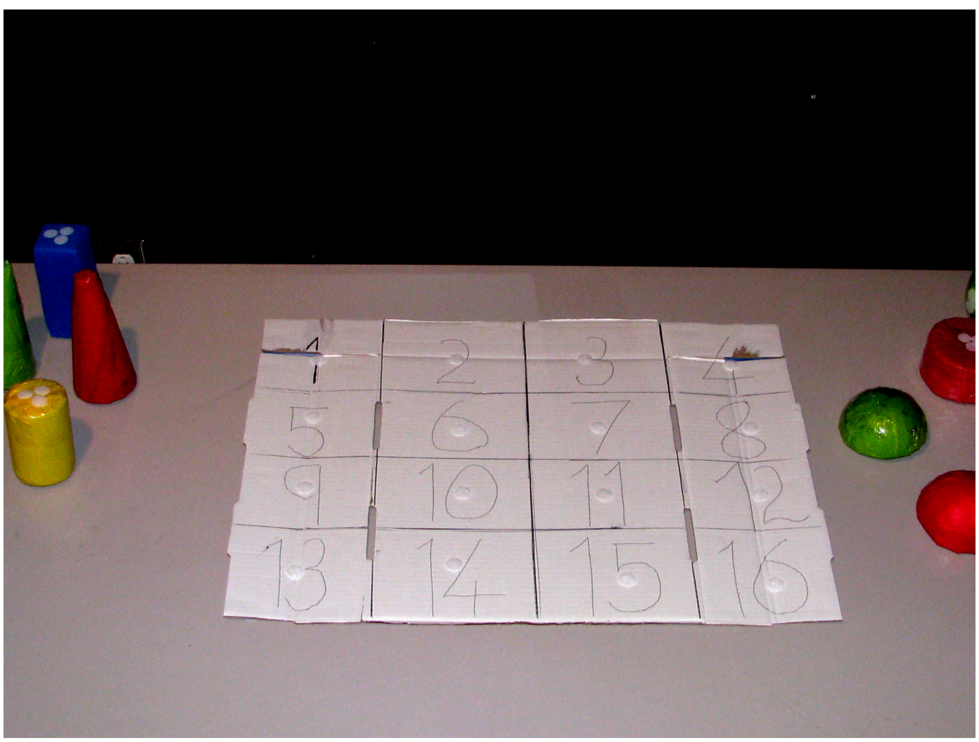

Figure 4.7. 4x4 Target square on the front table in Real Environment

CAVE[19], a four-screen display device arranged in configuration as shown in **Figure 4.8** and **Figure 4.9** was used. Each of the three sides of the display had a 10'x9' screen and a floor with 10'x10' projection surface. In the experiment the floor projector was not used. The projectors display SXGA+ resolution (1280x1024) on each screen. The CAVE provides a 270-degree horizontal field of regard (FOR). In addition to the CAVE, an Intersense IS-900 tracking system with a 6-DOF head tracker and a 6-DOF wand device with four buttons and a 2-DOF joystick as shown in **Figure 4.10** was used for navigation purpose. Participants sat in front of the front display of the CAVE, approximately five feet from the front screens. The environment was rendered by the DIVERSE toolkit [28, 36].

Figure 4.8. The display hardware used - CAVE[19]

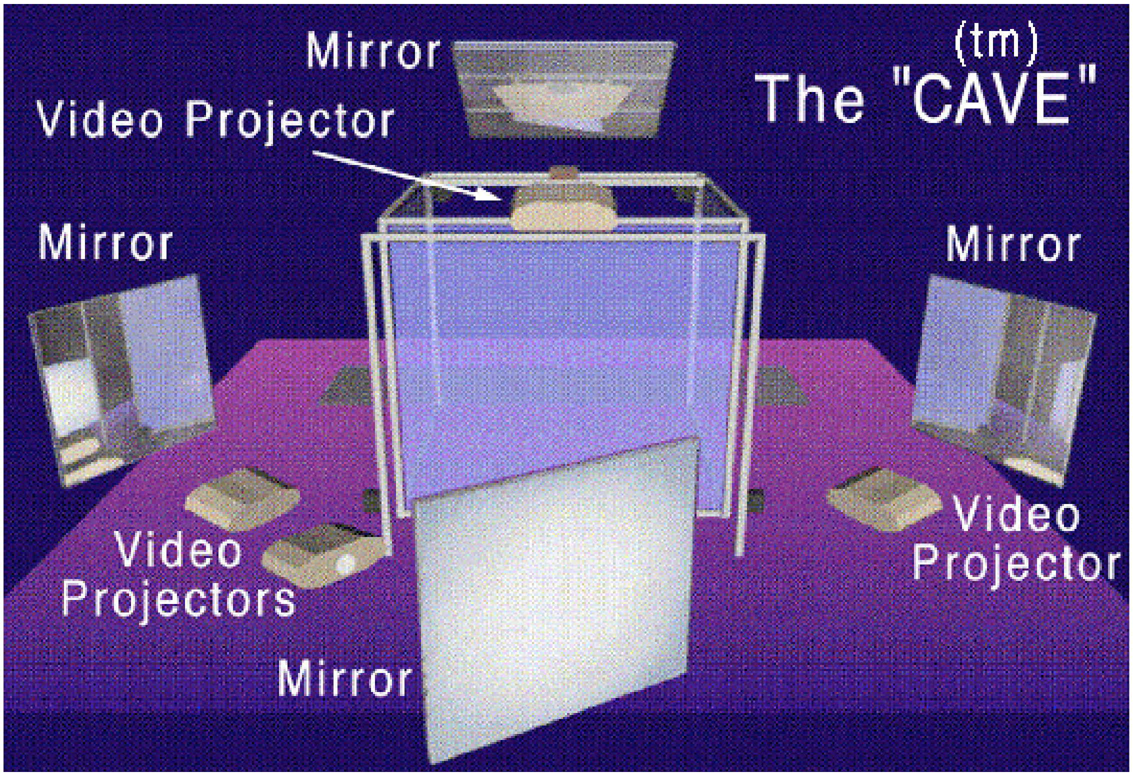

Figure 4.9. Components of the CAVE

Figure 4.10. 6-DOF wand device with four buttons and a 2-DOF joystick

The physical Field Of View (FOV) of the display was nearly 180 degrees in the high FOV condition and was changed to 60 degrees in the low FOV condition. A pair of lab glasses was used for both the conditions as shown in the **Figure 4.11**. For the Low FOV condition we used blinders to restrict the users view as shown in the **Figure 4.12**.

Figure 4.11. Glasses for High Physical FOV condition which support 180 degrees

Figure 4.12. Glasses for Low Physical FOV condition which support 60 degrees

The software FOV had two levels – matched and unmatched. In the matched condition the software FOV was 90 degrees per screen and in the unmatched condition it was 135 degrees per screen.

The FOR of the VE had two conditions. High FOR condition had three screens except the floor and the low FOR condition used just the center or front screen.

A virtual room containing the exact same configuration of the real room was built in the Virtual Environment. It contained three tables, primitive shapes like cones, spheres, box, wide box, cylinder, wide cylinder and hemi-sphere. We used the same six colors that were used in the real world. **Figure 4.13** illustrate the contents of the virtual room for scenarios. A 4x4 target area with squares numbered from 1 to 16 as shown in **Figure 4.14** was kept at the center of the front table. The model was produced using Flux Studio [30].

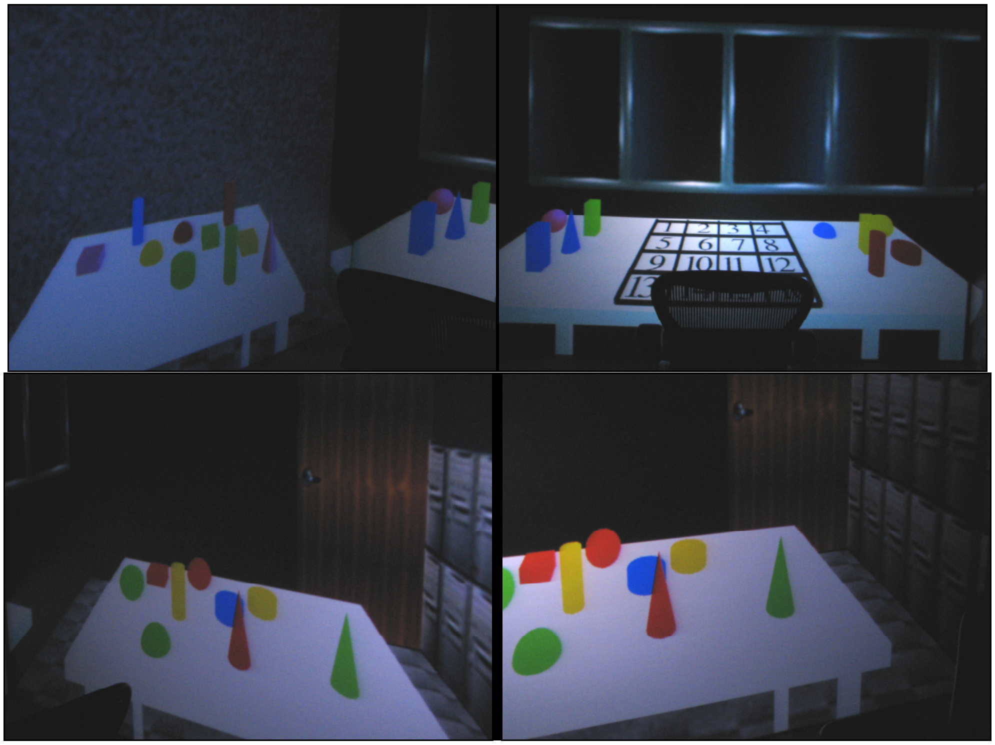

Figure 4.13. Scenario setup in Virtual Environment setup (CAVE)

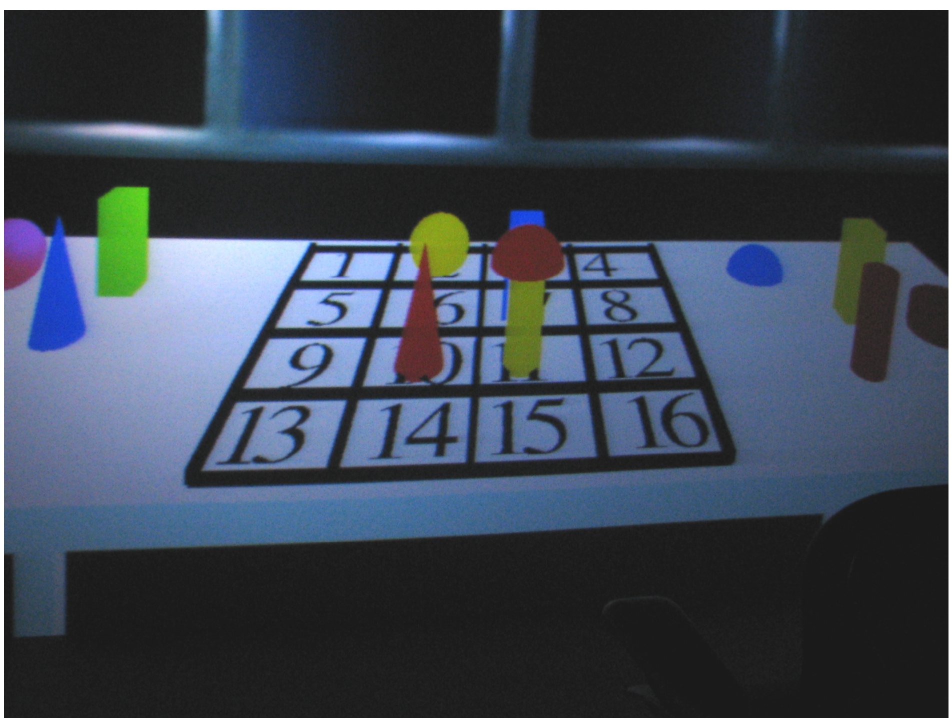

Figure 4.14. 4x4 Target square in the Virtual Environment

4.4 PROCEDURE

The experiment consists of four parts. Each part consisted of tasks that the participants were asked to memorize except the first part. The first part consisted of filling up forms and questionnaires. The second part consisted of a memory test which was conducted in the real world environment, to categorize the participants into the between-subject groups. The third part consisted of two simple practice tasks that had four steps each. These tasks were conducted in the CAVE and the motive of these tasks was to get the participant familiar with the CAVE setup and the experiment goals. The training and practice phases were performed in the CAVE, with the level of immersion (FOR, FOV, SFOV) set according to the subject's group. The assessment phase took place either in the CAVE or the real world, with the same or different spatial layout, based on the ordering defined in **Figure 4.4**. The final part consisted of four complex tasks that had eight steps in each of the tasks. Similar to the previous part, the training and practice phases were performed in the CAVE, with the level of immersion (FOR, FOV, SFOV) set according to the subject's group. The assessment phase took place either in the CAVE or the real world, with the same or different spatial layout, based on the ordering defined in **Figure 4.4**.

Now delving into the details of the tasks, every task contains three phases namely Training, Practice and Final Assessment. In the *Training phase* the experimenter initially identified the objects that would be used in the procedure, and then explained each step of the procedure in detail. The participant was taught to describe the steps of the procedure in specific terms. For example, a step might be described as: "Move the red hemisphere from the front table to position # 6".

The *Practice phase* allowed participants to recall, with the experimenter's assistance, the procedure from the training phase. In this phase participants were asked to verbally describe the procedure, following the protocol from the training phase. If a participant made a mistake or could not recall the next step, they were helped to remember the correct step in the procedure. The participant did not move the objects in the virtual world directly; it was done by the experimenter.

In the *Final Assessment phase*, participants were asked to recall the entire procedure without any assistance. Only when the participant provided the current step correctly did the scenario move on to the next step. Here again, the Participants did not move the objects directly; the experimenter moved the objects for the participant. The time taken by each of the participants and their errors were measured in the Final Assessment phases.

Before beginning the experiment, in the first part of the experiment, the participants were asked to complete an informed consent **(Appendix C.1)** form and take up a demo-graphic questionnaire **(Appendix C.2)**. Participants were given an instruction sheet **(Appendix C.3)** and a reference sheet **(Appendix C.4)** which would explain the type of objects and the colors available in the experiment.

In the second part, the participants took an initial memory test n which all three phases took place in the real world environment. They were then asked to sit in a chair. The task was to memorize a procedure that involved multiple steps, with each step consisting of taking one of the objects that was spread over in the environment and placing it at a particular location on the 4x4 grid as shown in **Figure 4.14**. The memory test consisted of eight steps. The Participants' performance time and errors were measured in the Final assessment phase of the task. These data were used to categorize the participants into various between-subject groups.

To categorize the participants, initially five pilot subjects were assessed and an average time of completion for the initial memory task was found. Two groups were defined using the average time; forty seconds below to the average time was set as the lower bound and forty seconds above than the average time was set as upper bound. The Participants' performance time was compared with the two groups that we had defined. If the performance time fell in either of the groups defined above, they were put into one of the between-subject condition groups. The distributions of the participants into the group was made even so that three from lower bound group and three from the upper bound group were selected for every between-subject condition group. Some participants were not able to memorize the tasks and were treated as outliers and did not perform the experiment.

After the initial memory test the participants were moved into the CAVE environment for the third and fourth part. The participants were made to sit in a chair placed in the center of the CAVE. They performed two practice tasks **(Appendix C.5)** and four experimental **(Appendix C.6)** tasks. The tasks in the experiments involved memorizing procedures involving objects kept on tables spread over in the environment.

The third part consisted of simple practice tasks that were four-step procedures. This part differed from part two in that, the *Training phase* and *Practice phase* were always done in the Virtual Environment under one of the between-subject conditions. For example if a participant got a low FOV, low FOR and matched Software FOV condition, the participant will be asked to wear glasses with blinders and they would do the *Training* and *Practice phase* for all the tasks in this condition. The *Final Assessment phase* was done in done either in a fully Immersive Virtual Environment or in Real Environment. By fully Immersive Virtual Environment we mean High FOR, High Physical FOV and Matched SFOV condition in this experiment.

The fourth part consisted of complex tasks that were more difficult than the tasks in part three; it consisted of eight steps. All the rules discussed in part three were applicable in this part too. The performance time and errors of the participants' performance were recorded in the final assessment of each complex task in this part.

In parts three and four, there was no time gap between any of the phases. The participants were discouraged from talking when they did the experiment, especially when they did all the three phases for a procedure. The real world simulation room was adjacent to the CAVE, thereby avoiding the time gap between the training, practice and final assessment phase. The participants were informed as to in which within-subject condition they would be performing their final assessment before the start of the task. There was a navigational constraint imposed upon the user in the experiment. Only rotation was allowed; translation and flying ability were curbed inside the virtual environment. Since it was a controlled experiment, it was believed that navigational traits may divert the user's attention from the main task[23].

4.5 PARTICIPANTS

Forty-one voluntary, unpaid participants (twenty five men and sixteen women) took part in the experiment. Their mean age was 22. All of them reported that they use computers daily. Eight of them had used immersive VEs previously, while eighteen had video game experience. Every participant was asked to take the initial memory test. Their performance was compared to the average performance of the initial memory test, if their performance were below the average, they were not considered for the experiment. Five out of these forty-one participants did not clear the initial memory test; therefore they were treated as outliers.

4.6 RESULTS

ANOVA analysis on the data table **(Appendix C.7 and C.8)** was used on the results, comparing the time taken and the errors, for the final assessment phase of each procedure. One more important fact is that although the number of errors was not a continuous dependent variable, ANOVA was still used for the analysis of this variable. This is a common practice adopted in the HCI community [12, 20, 33]. Here, a discussion of the with-in subject conditions will be undertaken before discussing the between-subject conditions.

It was hypothesized that the environment would not play a significant role in the performance of learning a procedure. It was found that there was no significant difference for the environment factor on the set of tasks. The mean time spent **(Appendix C.9)** on a *Final Assessment* done in a real environment was 65.415 (Standard deviation 19.782) and in virtual was 65.626 (Standard deviation 22.526). It had a confidence level of $p<0.849$. Similarly, the mean error **(Appendix C.10)** for a *Final Assessment* done in a real environment was 3.347 (Standard deviation 3.742) and in virtual was 3.611 (Standard deviation 4.234). It had a confidence level of $p<0.355$. Since *'p'* values for both performance time and error are greater than 0.05, it can be argued that the VE training did transfer to the real world.

It was also hypothesized that the spatial location of the objects will not play a significant role in learning a procedure. It was found that it did not have a significant difference on the set of tasks. The mean performance time **(Appendix C.9)** of a task done in the final assessment phase with the same spatial layout as the practice and training phase was 65.519 (Standard deviation 21.269) and that with different spatial location was 65.521 (Standard deviation 21.129). It had a confidence level of $p<0.634$. The mean error **(Appendix C.10)** of a task done in the final assessment phase with the same spatial layout as the practice and training phase was observed to be 3.277 (Standard deviation 4.018) and that with different spatial location was 3.680 (Standard deviation 3.967). It had a confidence level of $p<0.547$. Since *'p'* value is greater than 0.05, it can be argued that participants learned the procedure, and not just the spatial location of the objects in the procedure.

Thus from the above results the claim can be made that training is independent of the environment in which the user is assessed and it is also independent of the spatial arrangement of the objects inside the environment. In other words, it can be understood that learning does transfer to the real world and to different situation and scenarios.

Next, it is necessary to outline the between-subject variables namely the Software FOV (SFOV), Physical FOV and FOR. After a detailed analysis on these three between-subject variables we found that SFOV was independent of everything else. A matched SFOV was a very important factor for all the tasks. There was a main effect of SFOV for time spent in *Final Assessment* ($p<0.0004$) **(Appendix C.9)**, with matched SFOV (Mean = 59.988, Standard Deviation = 18.676) resulting in better times than unmatched SFOV (Mean = 71.053, Standard Deviation = 22.088). There was also a main effect of SFOV for error in *Final Assessment* ($p<0.0001$) **(Appendix C.10)**, with matched SFOV (Mean = 1.555, Standard Deviation = 2.181) resulting in fewer errors than unmatched SFOV (Mean = 5.402, Standard Deviation = 4.439).

There was a main effect of FOR for time spent in *Final Assessment* ($p<0.0003$) **(Appendix C.9)**, with High FOR (Mean = 58.347 and Standard Deviation = 19.740) resulting in better times than Low FOR (Mean = 72.694 and Standard Deviation = 20.119). There was also a main effect of FOR for error in *Final Assessment* ($p<0.001$) **(Appendix C.10)**, with High FOR (Mean = 2.097 and Standard Deviation = 3.340) resulting in fewer errors than Low FOR (Mean = 4.861 and Standard Deviation = 4.115).

There was a no main effect of Physical FOV for time spent in *Final Assessment* ($p<0.4487$) **(Appendix C.9)**, with high Physical FOV (Mean = 60.056 and Standard Deviation = 20.88275992) resulting in better times than low Physical FOV (Mean = 70.985 and Standard Deviation = 20.054). But there was a main effect of Physical FOV for error in *Final Assessment* ($p<0.0466$) **(Appendix C.10)**, with High Physical FOV (Mean = 2.722 and Standard Deviation = 3.620) resulting in fewer errors than Low Physical FOV (Mean = 4.236 and Standard Deviation = 4.207).

The motive of this experiment was to determine how well a person learns a procedure after training in different settings; therefore the correctness is more important than how quickly the user does the task. As can be seen from the above three results, though Physical FOV is not significant for time, it is significant for errors, which implies that it does have a significant impact on the training. An interesting result to consider would be the interaction that Physical FOV had with SFOV and FOR with time and errors. The interaction between Physical FOV and SFOV was significant for time ($p<0.013$) but not significant for errors ($p<0.4607$). A Least Square Mean table on time as shown in **Table 4.1** gives the mean and standard deviation values for various combinations of conditions.

Level(SFOV, Physical FOV)	Least Sq Mean	Std Error
Matched,Low	64.149792	3.1146139
Matched,High	49.129792	3.1146139
UnMatched,Low	70.049375	5.3946696
UnMatched,High	78.307292	5.3946696

Table 4.1. Interaction between SFOV and Physical FOV for Time

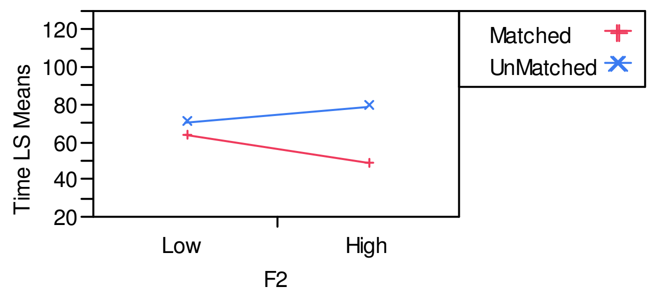

Figure 4.15. Interaction plot between SFOV and Physical FOV for Time

The Least Square means was also plotted as shown in **Figure 4.15** and a Post HOC Test – Tukey HSD on time was conducted and the results were tabulated in **Table 4.2**.

Level(SFOV, Physical FOV)			Least Sq Mean
UnMatched,High	A		78.307292
UnMatched,Low	A		70.049375
Matched,Low	A		64.149792
Matched,High		B	49.129792

Table 4.2. Tukey HSD on Time for SFOV and Physical FOV for Time

It can be observed from the Tukey HSD that a Matched SFOV and High Physical FOV form a separate group and perform much better when compared to the other three conditions with a mean of 49.13 seconds and standard deviation of 3.115. From the figure it can be observed that when there is a Matched SFOV, an increasing Physical FOV increase from Low to High helps in better performance, but for Unmatched SFOV it does not seem to help.

A Least Square Mean table on error as shown in **Table 4.3** gives the mean and standard deviation values for various combinations of conditions though the interaction on errors was insignificant.

Level(SFOV, Physical FOV)	**Least Sq Mean**	**Std Error**
Matched,Low	2.0208333	0.35481966
Matched,High	0.6041667	0.35481966
UnMatched,Low	7.2291667	0.61456568
UnMatched,High	6.5625000	0.61456568

Table 4.3. Interaction between SFOV and Physical FOV for Errors

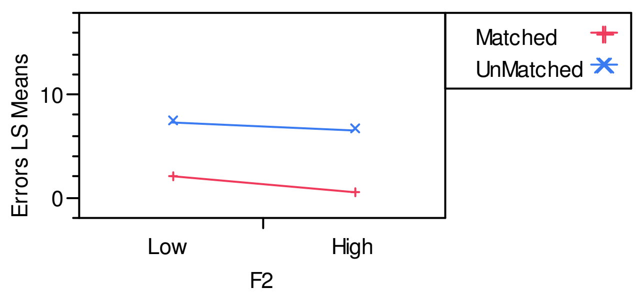

Figure 4.16. Interaction plot between SFOV and Physical FOV for Errors

The Least Square means was also plotted as shown in **Figure 4.16** and a Post HOC Test – Tukey HSD on error was conducted and the results were tabulated in **Table 4.4**.

Level(SFOV, Physical FOV)				Least Sq Mean
UnMatched,Low	A			7.2291667
UnMatched,High	A			6.5625000
Matched,Low		B		2.0208333
Matched,High			C	0.6041667

Table 4.4. Tukey HSD on Time for SFOV and Physical FOV for Errors

It can be observed that here similar results were found as for the time factor. Matched SFOV and a High Physical FOV form a separate group that perform better when compared to the other group with a mean of 0.604 and standard deviation of 0.355. Since the interaction is not significant we find that the two lines in the Least Square mean plot is nearly parallel.

There is an interaction between Physical FOV and FOR was significant with time ($p<0.0182$) and errors ($p<0.0466$). A Least Square Mean table on time as shown in **Table 4.5** gives the mean and standard deviation values for various combinations of conditions.

Level(Physical FOV, FOR)	Least Sq Mean	Std Error
Low,Low	81.706042	3.1146139
Low,High	52.493125	5.3946696
High,Low	67.321667	3.1146139
High,High	60.115417	5.3946696

Table 4.5. Interaction between Physical FOV and FOR for Time

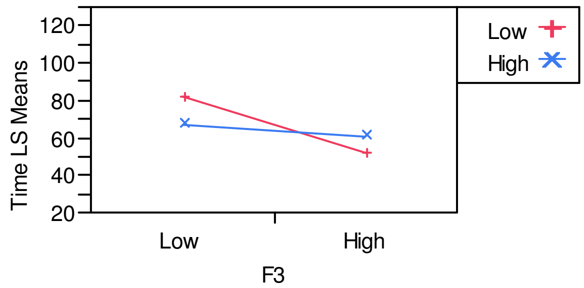

Figure 4.17. Interaction plot between Physical FOV and FOR for Time

A plot for the Least Square means was done as shown in **Figure 4.17** and conducted a Post HOC Test – Tukey HSD on time was conducted and the results were tabulated in **Table 4.6**.

Level(Physical FOV, FOR)			**Least Sq Mean**
Low,Low	A		81.706042
High,Low		B	67.321667
High,High		B	60.115417
Low,High		B	52.493125

Table 4.6. Tukey HSD on Time for Physical FOV and FOR for Time

It can be observed from the Tukey HSD that a Low FOR and Low Physical FOV form a separate group and their performance is bad when compared to the other three conditions with a mean of 81.706 seconds and standard deviation of 3.115. From the figure it can be observed that when there is a High FOV, an increasing FOR does not help in better performance, but for Low FOV it does help.

A Least Square Mean table on error as shown in **Table 4.7** gives the mean and standard deviation values for various combinations of conditions.

Level(Physical FOV, FOR)	Least Sq Mean	Std Error
Low,Low	6.0625000	0.35481966
Low,High	3.1875000	0.61456568
High,Low	3.9791667	0.35481966
High,High	3.1875000	0.61456568

Table 4.7. Interaction between Physical FOV and FOR for Errors

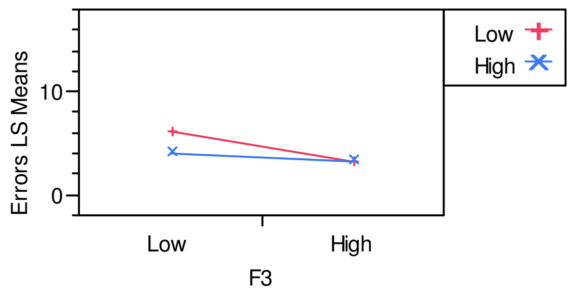

Figure 4.18. Interaction plot between Physical FOV and FOR for Errors

There can also be a plot for the Least Square means as shown in **Figure 4.18** and conducted a Post HOC Test – Tukey HSD on error was conducted and the results were tabulated in **Table 4.8**.

Level(Physical FOV, FOR)			Least Sq Mean
Low,Low	A		6.0625000
High,Low		B	3.9791667
Low,High		B	3.1875000
High,High		B	3.1875000

Table 4.8. Tukey HSD on Time for Physical FOV and FOR for Errors

It can be observed from the Tukey HSD that a Low FOR and Low Physical FOV form a separate group and perform badly when compared to the other three conditions with a mean of 6.0625 seconds and standard deviation of 0.355. From the figure it can be observed that when there is a High FOV, an increasing FOR does not help in better performance, but for Low FOV it does help. From the above graphs and Tukey HSD data it is observed that you need either a High FOR or a High FOV or both for better performance in learning. A summary of all the results can be found in **Appendix C.9 and C.10**.

4.7 DISCUSSION

A key feature of the results is that in this experiment the best condition with regards to performance time and error were those that paired Matched Software FOV with either High FOR or High FOV or both. Therefore, a distorted virtual world had a significant reduction in performance with mean time 70.049 and 78.307 and approximately 6 to 7 errors. As discussed in the experiment design, there were six different treatments. Post HOC Test – Tukey HSD was conducted on treatments with time and error as response as shown in **Table 4.9** and **Table 4.10** respectively. A compilation of the result can be found in **Appendix C.11 and C.12**.

Treatment (SFOV, Physical FOV, FOR)			Least Sq Mean
3 (Unmatched, Low, Low)	A		84.655833
6 (Unmatched, High, Low)	A		81.910417
1 (Matched, Low, Low)	A		78.756250
4 (Matched, High, Low)		B	52.732917
2 (Matched, Low, High)		B	49.543333
5 (Matched, High, High)		B	45.526667

Table 4.9. Tukey HSD on Time for between-subject treatments for Time

Treatment (SFOV, Physical FOV, FOR)				Least Sq Mean
3 (Unmatched, Low, Low)	A			8.6666667
6 (Unmatched, High, Low)	A			6.9583333
1 (Matched, Low, Low)		B		3.4583333
4 (Matched, High, Low)			C	1.0000000
2 (Matched, Low, High)			C	0.5833333
5 (Matched, High, High)			C	0.2083333

Table 4.10. Tukey HSD on Time for between-subject treatments for Errors

Treatment 4, 2 and 5 forms a group that has a Matched SFOV. The group reports a better performance both in terms of time and errors as response. Among the three treatments, treatment 5, with Matched SFOV, High Physical FOV and High FOR, reports the best performance in learning. Treatment 5 replicates a VR system that can be compared to the CAVE. Treatment 2 can possibly mimic a Head Mounted Display VR system (High FOR and Low FOV). But a very interesting finding has been reported in treatment 4. Treatment 4 replicates a VR system that can be compared to just a single large screen projection based display system. It is a notable fact that VR system that mimics treatment 4 is highly cost efficient when compared to a CAVE or HMD. Therefore for a procedural training application a cost efficient VR system can be built.

The other group did not perform well and had a significant performance debasement. From this group we can infer that Software FOV is a very important component for memorizing a procedure using a VR system.

Considering individual components, it has been identified that FOR is highly significant for time ($p<0.0003$) and errors ($p<0.0010$). SFOV is also highly significant for time ($p<0.0004$) and error ($p<0.0001$). The results confirm that SFOV is the most important component among the three components which is also confirmed in **Table 4.9** and **Table 4.10**. A Matched SFOV is very essential for learning a procedure using a VR system. Results also show that FOR is a very important component. Larger the FOR better the learning performance becomes. From **Table 4.9** and **Table 4.10** we can see that High FOR conditions have the best performance.

The motive for this experiment is to evaluate the correctness of learning than how quickly a person learns. It was found that the significance in error was given more importance than time. Results revealed that Physical FOV was not significant for time ($p<0.4487$) but it was found to be significant for errors ($p<0.0466$). Though it was found that Physical FOV was not significant for time, it was found to have significant interaction with SFOV and FOR. Therefore it is very important to consider the interaction of the Physical FOV with SFOV and FOR. One of the conditions that support this statement is treatment 4 when we have a Low FOR only a Higher Physical FOV can help in better learning performance. Thus these results reveal the importance of these three components and the interaction that bounds them.

Thus all hypotheses were tested and verified. It can be concluded that components of immersion that are essential for a memorizing a procedure are SFOV, Physical FOV, FOR and the interaction between these components. It can also be concluded that a cost efficient VR system can be built for a procedural training purpose.

5. CONCLUSIONS AND FUTURE WORK

5.1 SUMMARY

Training in VR has been a very popular research direction that has existed over decades. Military and medical VR training have been very popular in particular. Various advantages of VR have been identified in Chapter one which have made it popular for training involving motor skills, spatial awareness or a training involving both. But there has not been enough evidence about training involving mental activities in VR.

A trauma room project that was built in Virginia Tech helped the doctors in decision making, given a trauma scenario. It was observed that a VR system helped in decision making. But a decision making process is based on information from two sources namely external cues supplied by the environment to the user so that he can filter out the unwanted cues with selective attention and long-term memory which helps in contemplating the various possible hypotheses of system states and its correctness. Thus to verify these we first had to identify if virtual environments can be used to memorizing a procedure and understanding the spatial layout of the training environment. This perennially leads to the research questions, as stated below:

1. *Does immersive VE technology help in memorizing a procedure?*
2. *Does a higher level of immersion help in effective memorization of the procedure?*
3. *What components of immersion lead to higher performance in memorizing a procedure in VEs?*

To test the validity of these questions two experiments were conducted that observed the following results.

1. A preliminary study with a medical procedure was conducted to show that an immersive VE technology helps in memorizing a procedure much better when

compared to a non-immersive technology. But it did not show which components of immersion helped in better memorization.

2. Therefore a formal experiment was conducted to verify the impact of FOR, FOV and Software FOV on memorizing a procedure. It was found that a High FOR, High FOV and a Matched Software FOV condition significantly helped them to memorize the procedure more effectively.

But we did not verify if the cues found in the virtual environment did help the user in better spatial understanding of the environment. Also our results do not provide evidence that higher levels of immersion support better decision-making training, but only that higher level of immersion support better memorization of procedure.

5.2 CONTRIBUTION

The results of this experiment are targeted towards two research communities: VE and Education and Training. The learning community can definitely identify VR as one of the potential tools for memorizing instruction and procedures with specific immersive conditions suggested by our thesis.

Secondly, we believe our results have contributed significantly to the VR community and knowledge base of the benefits of immersion. The validity of our hypothesis was tested for domain specificity (Preliminary study) and generic procedures (Formal experiment). Therefore any procedural learning task, irrespective of the domain, can employ our findings as a baseline to start training subjects on memorizing a procedure.

Another notable contribution is defining hardware specifications for a memorization of procedure in VR. The motive behind identifying the benefits of immersion is not only to help the researchers in the VR community but to also identify the cost of setting up a VR system for a particular task. For example [34, 40] laparoscopic surgery in VR requires a system that can deliver precise tactile feedback than a fully fledged CAVE to train the doctors. This reduces cost of building a VR system for that particular task.

5.3 FUTURE WORK

Having got our motivation from the Trauma room project, it would be ideal to test if a higher level of immersion would help in effective decision making. Since only the validity of memorizing the procedure was verified, it would be essential for us to verify if the user is able to take decision in the virtual environment training that involves the procedure that they learnt in the memorization phase. Before an experiment can be run for decision making process we would have to empirically prove that spatial understanding helps in understanding the spatial layout of the environment and in memorizing a procedure in VR.

In the literature review, it was identified how some kind of perceptual motor activity can help in learning a procedure. The review illustrated that learning is possible only through good spatial understanding of the environment. Therefore, it was believed that a VR system could possibly help a user process his spatial understanding ability and convert it into long-term memory. To verify the above claim studies can follow up with the same formal experiment and add a spatial questionnaire to the user and test if the user understood the spatial layout of the environment better.

After verifying the validity of using virtual environments for both memorization and spatial understanding, a formal experiment to verify decision-making can be designed to identify the components of virtual environments that will helps in effective decision making capabilities. These results will help us quantifying benefits of immersion for an abstract VR training procedure.

Further studies can investigate how other components of immersion like head tracking, stereo, and resolution could help in a procedural learning task in VR. Future experiments could be more controlled, varying these components for a either specific conditions of FOV, FOR and Software FOV, or we can also vary all the components to indentify how they all interact between each other.

It has already been identified that IVEs are highly beneficial for training. A possible research direction could investigate how IVEs is beneficial for other types of mental activities like problem solving and teaching.

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Appendix A – Preliminary Experiment Forms

A.1 Informed Consent

Informed Consent for Participant of Investigative Project

Virginia Polytechnic Institute and State University

Title of Project: **Quantifying the Benefits of Immersive Virtual Environment in Decision-Making Training**

Principal Investigator: Dr. Doug A. Bowman

I. THE PURPOSE OF THIS RESEARCH/PROJECT

You are invited to participate in a study of quantifying the benefits of immersive virtual environment in decision-making training. This research studies how people perform decision making task in virtual environment on different platforms. This study involves experimentation for the purpose of evaluating the benefits of immersive virtual environment in decision-making training compared with non-immersive virtual environment.

II. PROCEDURES

You will be asked to perform a set of tasks using a virtual environment system. There are four sessions involved in our study. First session is navigation training session, in which you will learn how to navigation the virtual environment using mouse or joystick. The second session is task traning session, in which you will be presented two trauma cases on the screen and learn how to deal with them step by step. The two trauma cases are both trauma on left leg of virtual patient. The wound looks larger and deeper in one case than in the other. In our experiment, we design a standard procedure to deal with each trauma cases using different medicine and equipments shown on the virtual trauma room. You are expected to learn the procedure by heart. The third session is practice session, in which you will practice how to deal with the trauma cases trained in the previous session. Experimenters will help you if needed. The final session is assessment session, in which you will deal with the cases without help. The performance time and correct steps you make will be recorded. At the end of final session, you might also be interviewed about how you feel about the platforms. The total time commitment will be about 60 minutes. You may also be asked to fill out a questionnaire relating to your background with such systems, and to take a short test of spatial ability.

The whole sessions will last about one hour. The tasks are not very tiring, but you are welcome to take rest breaks as needed. One scheduled rest break will be given to you about half-way through the experiment. You may also terminate your participation at any time, for any reason. You will be given full instructions before every task and every session. It is important that you understand the instructions before beginning each task. If anything is unclear, be sure to ask us questions.

III. RISKS

The proposed experiments are straightforward tests of performance using standard virtual environments displays, trackers, and input devices. Participation involves standing on the floor (while using the CAVE or VisWall) or using desktop and performing simple tasks. The physical components of these tasks are not stressful, and include head and body turning and pointing. All light and sound intensities are well within normal ranges. There are no known mental risks. If you feel upset because of the trauma scenario graphic, or experience any eye strain, dizziness, or nausea during a session, then between tasks step away from the CAVE or VisWall and take a rest break. The experimenter will explain when you can take such rest breaks. If you are having trouble with any task, please tell us. If dizziness or nausea becomes uncomfortable, you will be allowed to leave with no penalty.

IV. BENEFITS OF THIS PROJECT

Your participation in this project will provide information that may be used to evaluate the benefits of immersive virtual environment. No guarantee of benefits has been made to encourage you to participate. You may receive a synopsis summarizing this research when completed. Please leave a self-addressed envelope with the experimenter and a copy of the results will be sent to you. You are requested to refrain from discussing the evaluation with other people who might be in the candidate pool from which other participants might be drawn.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

VI. COMPENSATION

Your participation is voluntary and unpaid.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project

____

Signature Date

Name (please print) Contact: phone or address or

email address (OPTIONAL)

Signature Date

Should I have any questions about this research or its conduct, I may contact:

Investigator: Dr. Doug A. Bowman Phone (540) 231-2058

Professor, Computer Science Department (231-6931)

email: bowman@vt.edu

Rongrong Wang wangr06@vt.edu

Ajith Sowndararajan ajiths@vt.edu

cc: the participant, Dr. Bowman

A.2 Preliminary Experiment – User Questionnaire

User Questionnaire

Please help us to categorize our user population by completing the following items.

Gender (circle one): Male Female

Age: _____________

Do you wear glasses or contact lenses (circle one)?

No Glasses Contact Lenses

Occupation (if student, indicate graduate or undergraduate):

____

Major / Area of specialization (if student): _________________________________

Rate your familiarity with computers: (circle one)

•----------------------•----------------------•----------------------•----------------------•

not at all familiar not very familiar somewhat familiar fairly familiar very familiar

Briefly describe your 3D video games experience? (i.e. how often do you play and how many games you play)

____

____

Have you ever used a virtual reality (VR) system? If so, please describe it (what type of display was used, what kind of application (e.g. game, architectural walk-through) was running, how did you interact with the system, etc.).

A.3 Preliminary Experiment – Instruction

Instructions

Thank you for participating in our study. The study will require you to memorize the steps in couple of medical procedures. Each trial involves memorizing a medical procedure of several steps. We will measure how fast you do the task and the number of errors that you make while performing the task. Please try to memorize and recall each medical step as accurately as possible.

Each trial is split into 3 phases:

1. **Training phase**
2. **Practice phase**
3. **Assessment phase**

Training phase: In this phase the experimenter will identify the objects that would be used in the medical procedure, and then explain each step of the procedure in detail. You will be taught to describe the steps of the procedure in specific terms. For example, three steps might be described as: "pick up the purple bottle," "apply it to the wound," and "put it back."

Practice phase: In this phase you are allowed to recall the medical procedure that you learnt in the previous phase, with the experimenter's assistance. In this phase we will ask you to verbally describe the procedure, following the protocol from the training phase. If a participant made a mistake or could not recall the next step, we helped him/her to remember the correct step in the medical procedure.

Assessment phase: In the Final Assessment phase, you will be asked to recall the entire procedure that you learnt in the practice and training phase without any assistance. Only when you provided the current step correctly will the scenario move on to the next step. If you are confused, please feel free to ask the experimenter for more clarifications and examples. Use the same type of verbal instructions to tell the experimenter how to complete the procedure.

Before beginning the experimental trials, the experimenter will run you through simple practice trials to help familiarize you with the system, the navigational capabilities and the task. You will then perform one simple and one complex experimental trial as described above.

IMPORTANT: Please remember that we are evaluating our virtual reality system; we are not evaluating you. Please do your best in each trial to memorize and recall the procedures as accurately as you can.

P.S. If you have any questions please feel free to ask the experimenter at any point of the experiment (except the assessment phase)

Appendix B - Preliminary Experiment Results

B.1 Preliminary Experiment – Simple procedure - Time

		VisWalls - 2-Wall CAVE				**Desktop**	
		Scenario 1				**Scenario 1**	
	Training	**Practice**	**Assesment**		**Training**	**Practice**	**Assesment**
	56	19	20		60	20	19
	55	25	20		57	20	16
	50	20	22		47	18	18
	45	23	14		36	20	17
	40	11	11		45	19	16
	33	15	10		52	21	17
	45	19	17		55	19	17
AVG	**46.2857**	**18.857142**	**16.28571**	**AVG**	**50.28571**	**19.57143**	**17.14286**
CONF	6.074447	3.4859078	3.493396		6.104487	0.7229436	0.791945

B.2 Preliminary Experiment – Simple procedure - Errors

		VisWalls - 2-Wall CAVE				**Desktop**	
		Scenario 1				**Scenario 1**	
	Training	**Practice**	**Assesment**		**Training**	**Practice**	**Assesment**
	0	0	0		0	0	0
	0	0	0		0	0	0
	0	0	0		0	0	0

	0	0	0		0	0	0
	0	0	0		0	0	0
	0	0	0		0	0	0
	0	0	0		0	0	0
AVG	**0**	**0**	**0**	**AVG**	**0**	**0**	**0**

B.3 Preliminary Experiment – Complex procedure – VisWalls –Time and Errors

		Scenario 2	VisWalls - 2-Wall CAVE		
	Training	**Practice**	**Mistakes**	**Assesment**	**Mistakes**
	180	131	4	90	1
	140	105	2	69	1
	140	135	2	97	1
	138	140	3	72	0
	140	95	0	76	0
	150	84	3	70	1
	180	90	2	71	1
AVG	**152.571**	**111.43**	**2.28571**	**77.85714**	**0.71429**
CONFIDENCE	14.177807	17.31446165	0.928637877	8.2206031	0.3614718

B.4 Preliminary Experiment – Complex procedure – Desktop –Time and Errors

		Scenario 2	**Desktop**		
	150	107	3	91	2
	149	120	3	114	2
	210	137	5	127	6
	154	92	5	83	1
	150	124	3	103	3
	143	97	4	87	3
	180	154	4	167	8
AVG	**162.2857**	**118.7142857**	**3.857143**	**110.2857**	**3.571429**
CONFIDENCE	17.916024	16.37431361	0.666521072	21.853354	1.8572757

B.5 t-Test: Two-Sample Assuming Equal Variances - Complex procedure –Time - Training

180	150	t-Test: Two-Sample Assuming Equal Variances
140	149	

140	210		*Variable 1*	*Variable 2*
138	154	Mean	152.5714286	162.285714
140	150	Variance	366.2857143	584.904762
150	143	Observations	7	7
180	180	Pooled Variance	475.5952381	
		Hypothesized Mean Difference	0	
		df	12	
			-	
		t Stat	0.833347518	
		P(T<=t) one-tail	0.210463342	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.420926684	
		t Critical two-tail	2.178812827	

B.6 t-Test: Two-Sample Assuming Equal Variances - Complex procedure –Time - Practice

131	107	t-Test: Two-Sample Assuming Equal Variances		
105	120			
135	137		*Variable 1*	*Variable 2*
140	92	Mean	111.4285714	118.714286
95	124	Variance	546.2857143	488.571429
84	97	Observations	7	7
90	154	Pooled Variance	517.4285714	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-0.599212625	
		P(T<=t) one-tail	0.280087049	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.560174097	
		t Critical two-tail	2.178812827	

B.7 t-Test: Two-Sample Assuming Equal Variances - Complex procedure –Time – Final Assessment

90	91	t-Test: Two-Sample Assuming Equal Variances		
69	114			
97	127		*Variable 1*	*Variable 2*
72	83	Mean	77.85714286	110.285714
76	103	Variance	123.1428571	870.238095
70	87	Observations	7	7
71	167	Pooled Variance	496.6904762	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-2.722193064	
		P(T<=t) one-tail	0.009266209	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.018532418	
		t Critical two-tail	2.178812827	

B.8 t-Test: Two-Sample Assuming Equal Variances - Complex procedure –Error – Practice

4	3	t-Test: Two-Sample Assuming Equal Variances		
2	3			
2	5		*Variable 1*	*Variable 2*
3	5	Mean	2.285714286	3.85714286
0	3	Variance	1.571428571	0.80952381
3	4	Observations	7	7
2	4	Pooled Variance	1.19047619	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-2.694438717	
		P(T<=t) one-tail	0.009754515	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.019509031	
		t Critical two-tail	2.178812827	

B.9 t-Test: Two-Sample Assuming Equal Variances - Complex procedure –Error – Final Assessment

1	2	t-Test: Two-Sample Assuming Equal Variances		
1	2			
1	6		*Variable 1*	*Variable 2*
0	1	Mean	0.714285714	3.57142857
0	3	Variance	0.238095238	6.28571429
1	3	Observations	7	7
1	8	Pooled Variance	3.261904762	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-2.959581742	
		P(T<=t) one-tail	0.00596496	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.01192992	
		t Critical two-tail	2.178812827	

B.10 t-Test: Two-Sample Assuming Equal Variances - Simple procedure –Time – Training

20	19	t-Test: Two-Sample Assuming Equal Variances		
20	16			
22	18		*Variable 1*	*Variable 2*
14	17	Mean	16.28571429	17.1428571
11	16	Variance	22.23809524	1.14285714
10	17	Observations	7	7
17	17	Pooled Variance	11.69047619	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-0.468998152	
		P(T<=t) one-tail	0.323738449	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.647476897	
		t Critical two-tail	2.178812827	

B.11 t-Test: Two-Sample Assuming Equal Variances - Simple procedure –Time – Practice

19	20	t-Test: Two-Sample Assuming Equal Variances		
25	20			
20	18		*Variable 1*	*Variable 2*
23	20	Mean	18.85714286	19.5714286
11	19	Variance	22.14285714	0.95238095
15	21	Observations	7	7
19	19	Pooled Variance	11.54761905	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-0.393241879	
		P(T<=t) one-tail	0.350518887	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.701037774	
		t Critical two-tail	2.178812827	

B.12 t-Test: Two-Sample Assuming Equal Variances - Simple procedure –Time – Final Assessment

56	60	t-Test: Two-Sample Assuming Equal Variances		
55	57			
50	47		*Variable 1*	*Variable 2*
45	36	Mean	46.28571429	50.2857143
40	45	Variance	67.23809524	67.9047619
33	52	Observations	7	7
45	55	Pooled Variance	67.57142857	
		Hypothesized Mean Difference	0	
		df	12	
		t Stat	-0.910358524	
		P(T<=t) one-tail	0.190278086	
		t Critical one-tail	1.782287548	
		P(T<=t) two-tail	0.380556172	
		t Critical two-tail	2.178812827	

Appendix C - Final Experiment Forms

C.1 Informed Consent

Informed Consent for Participant of Investigative Project

Virginia Polytechnic Institute and State University

Title of Project: **Quantifying the Benefits of Immersion for Procedural Training in Virtual Environment**

Principal Investigator: Dr. Doug A. Bowman

I. THE PURPOSE OF THIS RESEARCH/PROJECT

You are invited to participate in our study by which we would try to quantifying the benefits of immersion for a procedural training task. This research studies how effective is virtual environments, as a tool to memorize an abstract procedure. This study involves experimentation for the purpose of evaluating the benefits of immersive virtual environment in decision-making training compared with non-immersive virtual environment.

II. PROCEDURES

You will be asked to perform a set of tasks in real world and virtual world. There are three phases for every task that you perform. The first phase in a task is a traning session, in which you will be presented with set of primitive-colored objects on 3 tables in a room. You will be taught a procedure using the primitive-colored objects. The second phase will allow you to practice the procedure you learnt with some assisstance from the experimentor If you get stuck in completing the task. The third phase is the final phase where you would be asked to repeat the procedure that you learnt either in virtual world or real world. In this phase you wont receive any assistance from the experimenter. The performance time and number of errors that you make will be recorded. At the end of experiment, the experimenter might ask you few questions about the system and experiment. You may also be asked to fill out a questionnaire relating to your background with such systems, and to take a short memory tests. The whole sessions will last about one hour. The tasks are not very tiring, but you are welcome to take rest breaks as needed. One scheduled rest break will be given to you about half-way through the experiment. You may also terminate your participation at any time, for any reason. You will be given full instructions before every task and every session. It is important that you understand the instructions before beginning each task. If anything is unclear, be sure to ask questions.

III. RISKS

The proposed experiments are straightforward tests of performance using standard virtual environments displays, trackers, and input devices. Participation would involve sitting in a chair (while using the CAVE) and performing the tasks that is given to you. The physical components of these tasks are not stressful, and include head and body turning and pointing. All light and sound intensities are well within normal ranges. There are no known mental risks.

If you feel upset because of the graphic, or experience any eye strain, dizziness, or nausea during a session, then between tasks step away from the CAVE and take a rest break. The experimenter will explain when you can take such rest breaks. If you are having trouble with any task, please tell the experimenter. If dizziness or nausea becomes uncomfortable, you will be allowed to leave with no penalty.

IV. BENEFITS OF THIS PROJECT

Your participation in this project will provide information that may be used to evaluate the benefits of immersive virtual environment. No guarantee of benefits has been made to encourage you to participate. You may receive a synopsis summarizing this research when completed. Please leave a self-addressed envelope with the experimenter and a copy of the results will be sent to you. You are requested to refrain from discussing the evaluation with other people who might be in the candidate pool from which other participants might be drawn.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

VI. COMPENSATION

Your participation is voluntary and unpaid.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Computer Science.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project

---

Signature Date

Name (please print) Contact: phone or address or

email address (OPTIONAL)

Signature Date

Should I have any questions about this research or its conduct, I may contact:

Investigator: Dr. Doug A. Bowman Phone (540) 231-2058

Professor, Computer Science Department (231-6931)

email: bowman@vt.edu

Ajith Sowndararajan ajiths@vt.edu

Rongrong Wang wangr06@vt.edu

cc: the participant, Dr. Bowman

C.2 Final Experiment – User Questionnaire

User Questionnaire

Please help us to categorize our user population by completing the following items.

Gender (circle one): Male Female

Age: _____________

Do you wear glasses or contact lenses (circle one)?

No Glasses Contact Lenses

Occupation (if student, indicate graduate or undergraduate):

____

Major / Area of specialization (if student): _________________________________

Rate your familiarity with computers: (circle one)

•----------------------•----------------------•----------------------•----------------------•

not at all familiar not very familiar somewhat familiar fairly familiar very familiar

Briefly describe your 3D video games experience? (i.e. how often do you play and how many games you play)

____

____

Have you ever used a virtual reality (VR) system? If so, please describe it (what type of display was used, what kind of application (e.g. game, architectural walk-through) was running, how did you interact with the system, etc.).

C.3 Final Experiment – Instructions

Instructions

Thank you for participating in our study. The study will require you to memorize the steps in several procedures. Each trial involves memorizing a procedure of several steps. We will measure how fast you do the task and the number of errors that you make while performing the task. Please try to memorize and recall each procedure as accurately as possible.

Each trial is split into 3 phases:

4. **Training phase**
5. **Practice phase**
6. **Assessment phase**

Training phase: The experimenter will teach you a procedure in a virtual reality system. The procedure involves finding colored objects (e.g., red hemisphere, yellow box) in a 3D environment and placing them at the correct locations in a particular order. Objects will be found and placed on tables in the environment. The experimenter will first state the name of the object. Once you have found the object, the experimenter will move it to its final location. In this phase you will be seated in a chair and will wear a pair of glasses that the experimenter will give you. You will be able to use a handheld joystick to rotate the virtual world around yourself if necessary. If you have questions about the procedure, please ask the experimenter during this phase.

Practice phase: In this phase you will be asked to recall the same procedure that you learned in the *Training phase*. In this phase the experimenter will help you to complete the procedure if you forget one of the steps. To complete the procedure, you will tell the experimenter verbally what should happen next. For example, you might say, “Move the red sphere from the left table to position #4” or “Move the green cube from the front table on top of the blue cylinder.” You will again wear a pair of glasses that the experimenter will give you, and you will again have the joystick to rotate the world if necessary.

Assessment phase: In this phase you will be asked to recall the same procedure that you learned in the *Training phase* and practiced in the *Practice phase*. The assessment will either take place in the virtual reality system or in a real room. In some trials, the objects will be in the same location as they were during training, and in other trials the objects will be in different locations. During this phase you will not receive any kind of assistance from the experimenter. If you make a mistake, keep trying until you remember the correct next step in the procedure. You will get a maximum of 10 chances. A chance may be either naming the correct object or the correct position. The experimenter will let you know if you get either of the chance correctly, (if you are confused, please feel free to ask the experimenter for more clarifications and examples). Use the same type of verbal instructions to tell the experimenter how to complete the procedure. In this phase you will not wear any glasses.

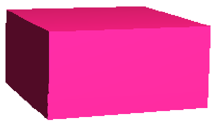
Before beginning the experimental trials, the experimenter will run you through 2 simple practice trials to help familiarize you with the system and the task. You will then perform 4 experimental trials as described above.

IMPORTANT: Please remember that we are evaluating our virtual reality system; we are not evaluating you. Please do your best in each trial to memorize and recall the procedures as accurately as you can.

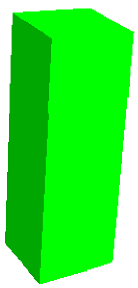
P.S. If you have any questions please feel free to ask the experimenter at any point of the experiment (except the assessment phase).

C.4 Final Experiment –Object Reference Sheet for the Participant

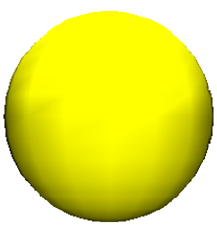
Objects



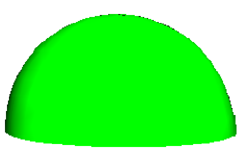
Box



Tall Box

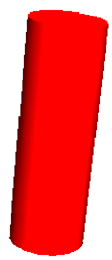


Sphere



Hemi-sphere

Cone



Tall Cylinder

Wide Cylinder

Available Colors:

Red	**Green**	**Blue**	**Yellow**	**Pink**

C.5 Final Experiment –Object Position - Reference Sheet for the Experimenter – Simple Trials

trialSet_memoryTest_6Steps

1. Move the **tall yellow box** from the **right** table to position # 16
2. Move the **red box** from the **right** table to position # 2
3. Move the **green hemisphere** from the **front** table to position # 3
4. Move the **wide yellow cylinder** in the **left** table to position # 5
5. Move the **red hemisphere** in the **front** table and place it on top of the red box position #2
6. Move the **green sphere** in the **left** table to position #9
7. Move the **yellow box** in the **right** table to position #8
8. Move the **red cone** in the **left** table to position #12

Set_1_virtualWorld_6_Steps

9. Move the **red hemisphere** from the **front** table to position # 6
10. Move the **wide red cylinder** from the **right** table to position # 12
11. Move the **red cone** from the **left** table to position # 3
12. Move the **pink box** in the **front** table to position # 9

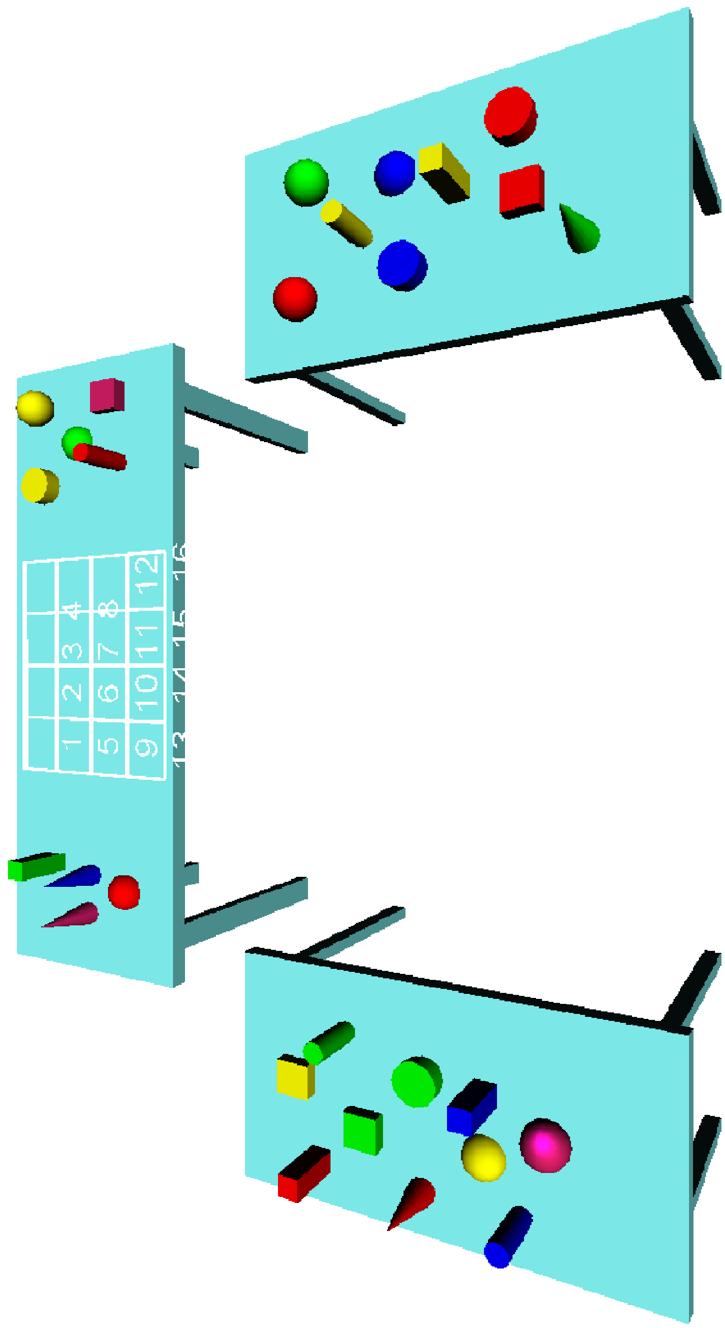
Set_1_virtualWorld_differentLocation_6_Steps

1. Move the **red hemisphere** from the **left** table to position # 6
2. Move the **wide red cylinder** from the **front** table to position # 12
3. Move the **red cone** from the **right** table to position # 3
4. Move the **pink box** in the **left** table to position # 9

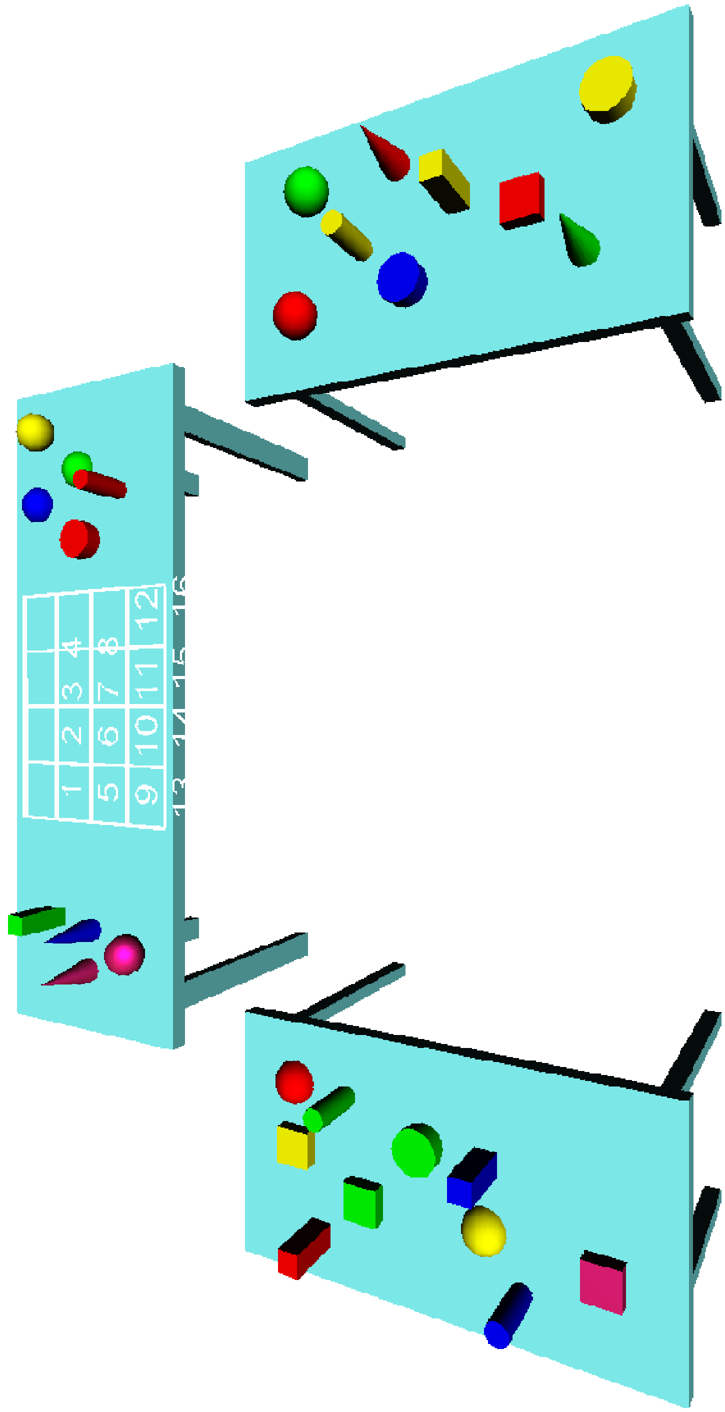
Set_2_realWorld_sameLocation_6_Steps

1. Move the **pink sphere** from the **front** table to position # 10
2. Move the **blue tall cylinder** from the **left** table to position # 7

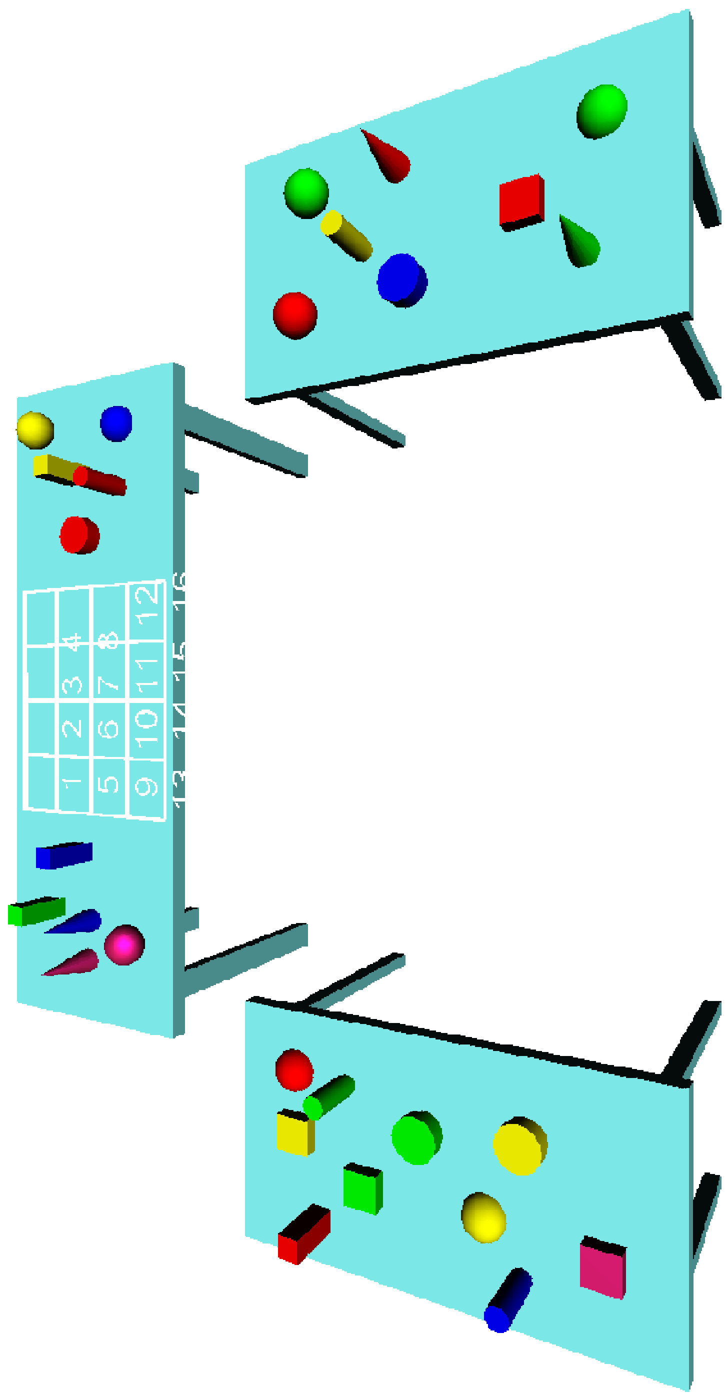
3. Move the **yellow hemisphere** from the **left** table and place it on top of the blue tall cylinder at position # 7
4. Move the **wide blue cylinder** from the **right** table to position # 1



Set_1_virtualWorld_6_Steps



Set_1_virtualWorld_differentLocation_6_Steps



Set_2_realWorld_sameLocation_6_Steps

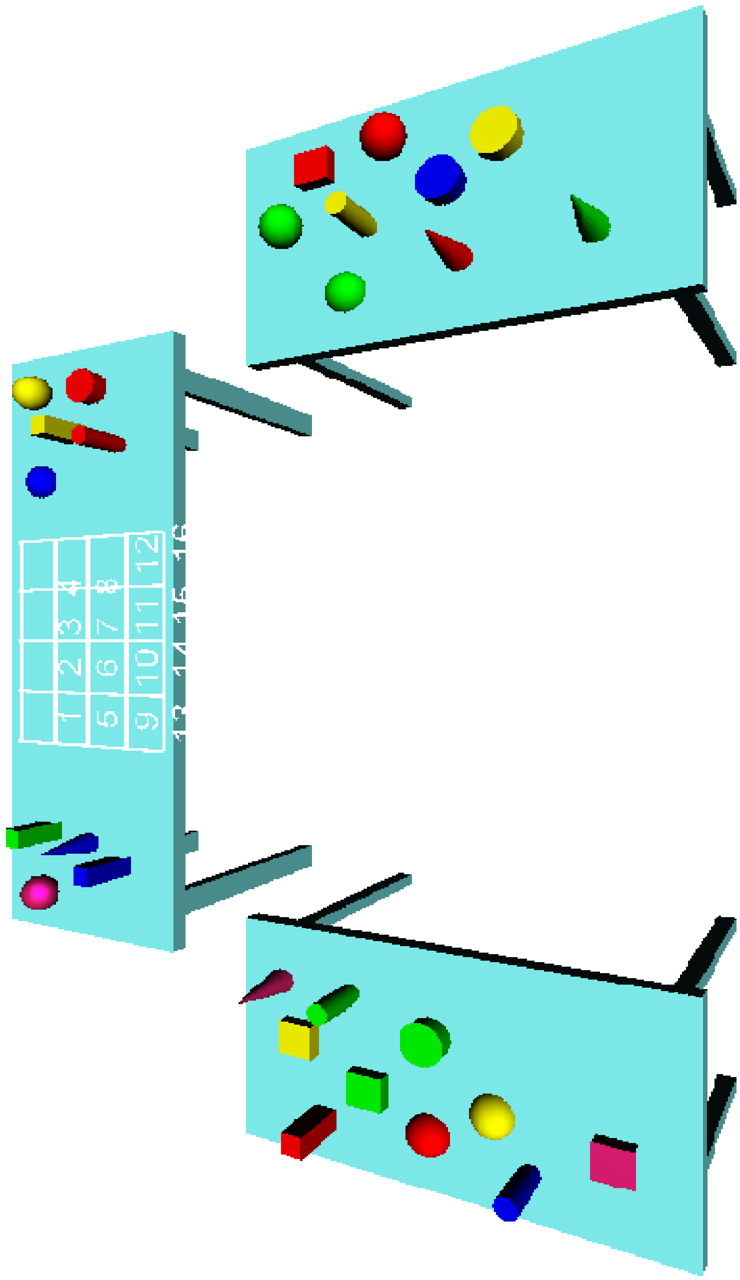
C.6 Final Experiment –Object Position - Reference Sheet for the Experimenter – Complex Trials

<u>Set3_16Steps</u>

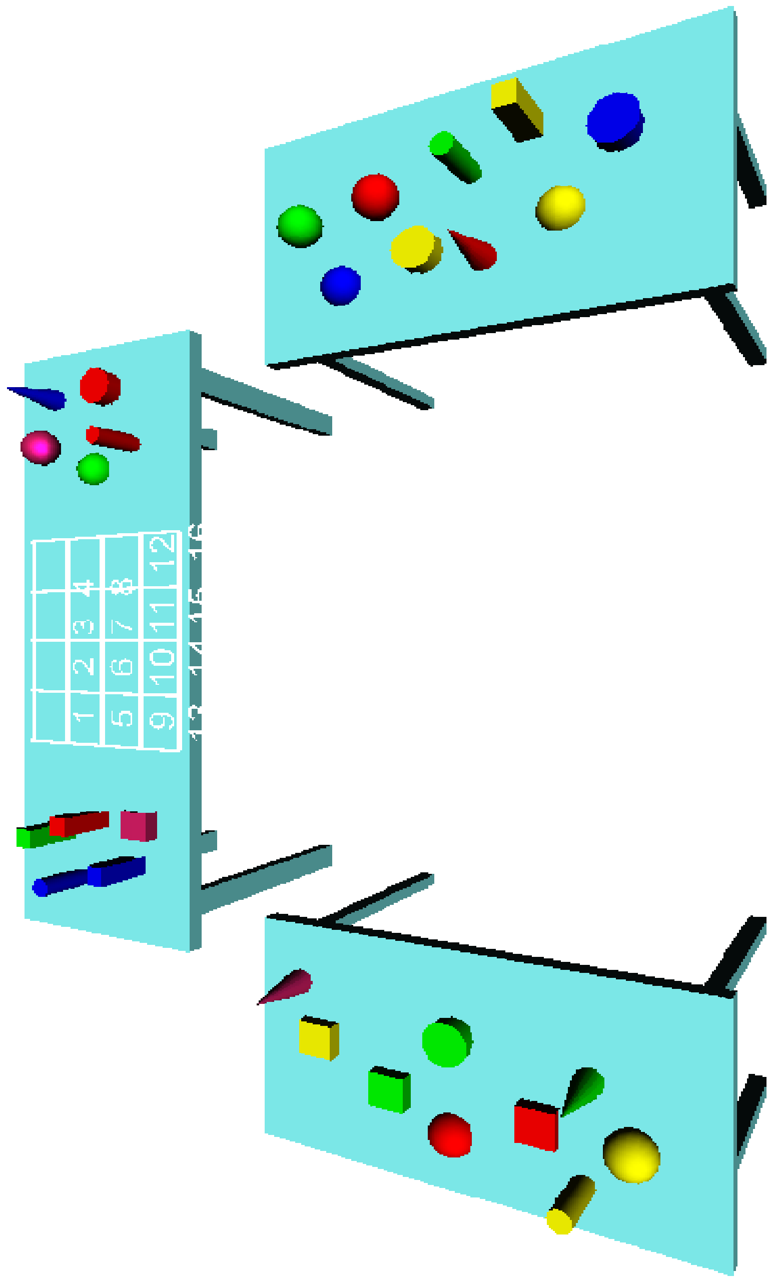
1. Move the **red cone** from the **right** table to position # 10
2. Move the **yellow sphere** from the **front** table to position # 2
3. Move the **blue tall box** from the **front** table to position # 7
4. Move the **tall yellow cylinder** from the **right** table to position # 11
5. Move the **red hemisphere** from the **left** table and place it on top of the tall yellow cylinder at position # 11
6. Move the **green box** from the **left** to position # 8
7. Move the **pink sphere** in the **front** table and place it on top of green box at position # 8
8. Move the **wide yellow** cylinder from the **right** table to position # 13

<u>Set3_finalAssessment_16Steps</u>

1. Move the **red cone** from the **right** table to position # 10
2. Move the **yellow sphere** from the **left** table to position # 2
3. Move the **tall blue box** from the **front** table to position # 7
4. Move the **tall yellow cylinder** from the **left** table to position # 11
5. Move the **red hemisphere** from the **left** table and place it on top of the tall yellow cylinder at position # 11
6. Move the **green box** from the **left** table to position # 8
7. Move the **pink sphere** in the **front** table and place it on top of green box at position # 8
8. Move the **wide yellow** cylinder from the **right** table to position # 13



Set3_16Steps



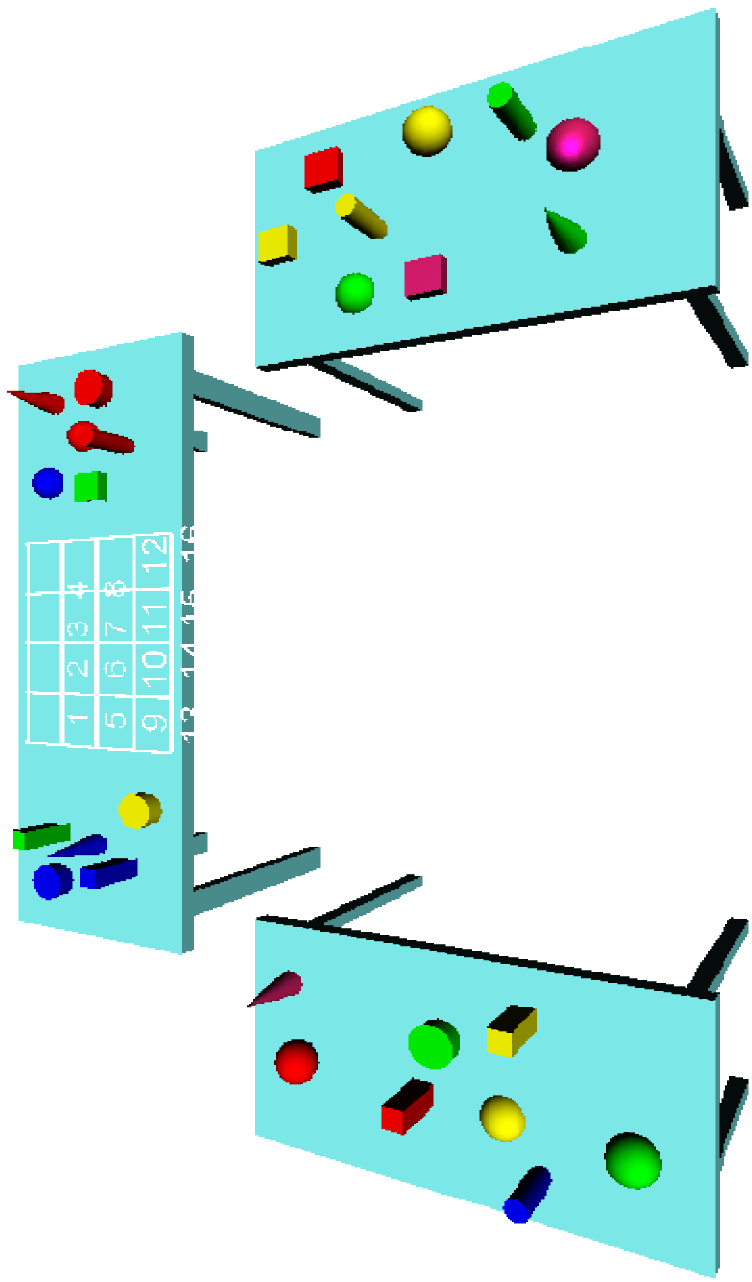
<u>Set3_finalAssessment_16Steps</u>

Set4 _16Steps

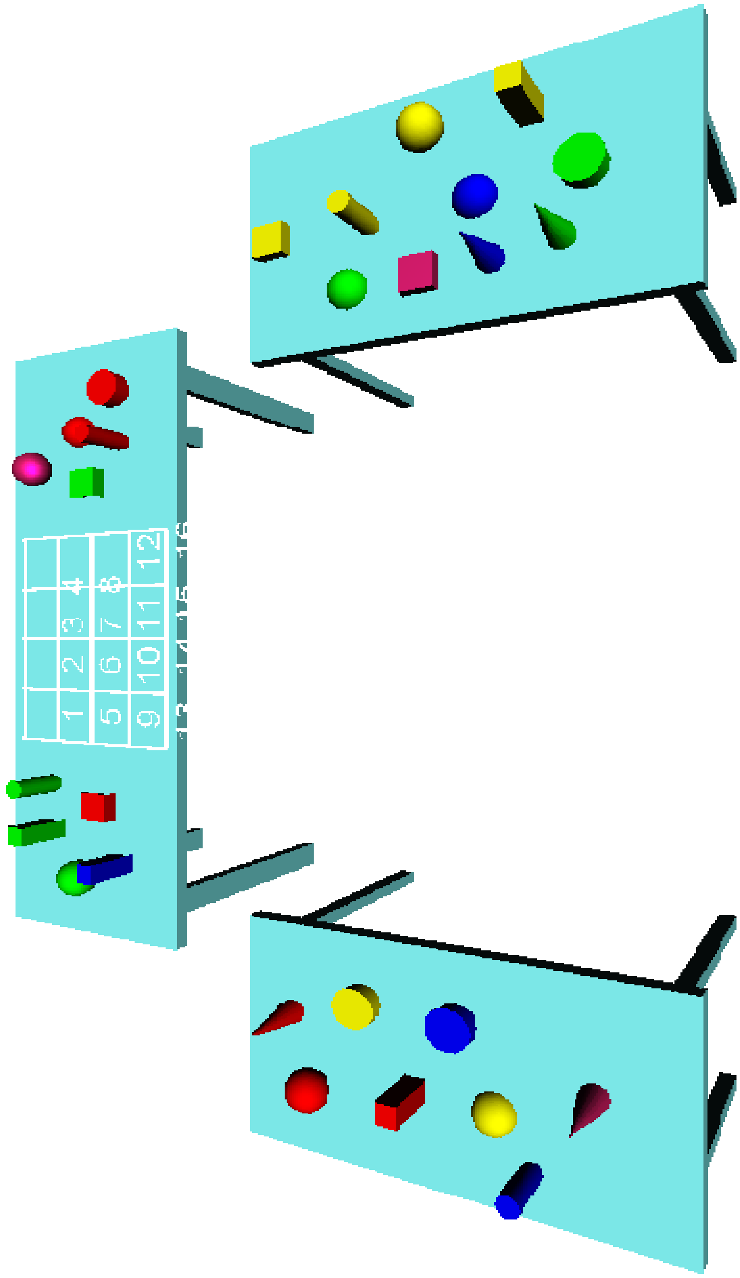
1. Move the **wide green cylinder** from the **left** table to position # 16
2. Move the **wide yellow cylinder** from the **front** table to position # 6
3. Move the **blue hemisphere** from the **front** table to position # 11
4. Move the **green cone** from the **right** table and place it on top of wide green cylinder at position # 16
5. Move the **yellow hemisphere** from the **left** table to position # 9
6. Move the **tall green cylinder** from the **right** table to position # 8
7. Move the **tall green box** from the **front** table to position # 7
8. Move the **pink cone** from the **left** table to position # 1

Set4_ finalAssessment_16Steps

1. Move the **wide green cylinder** from the **right** table to position # 16
2. Move the **wide yellow cylinder** from the **left** table to position # 6
3. Move the **blue hemisphere** from the **right** table to position # 11
4. Move the **green cone** from the **right** table and place it on top of wide green cylinder at position # 16
5. Move the **yellow hemisphere** from the **right** table to position # 9
6. Move the **tall green cylinder** from the **front** table to position # 8
7. Move the **tall green box** from the **front** table to position # 7
8. Move the **pink cone** from the **left** table to position # 1



Set4 _16Steps



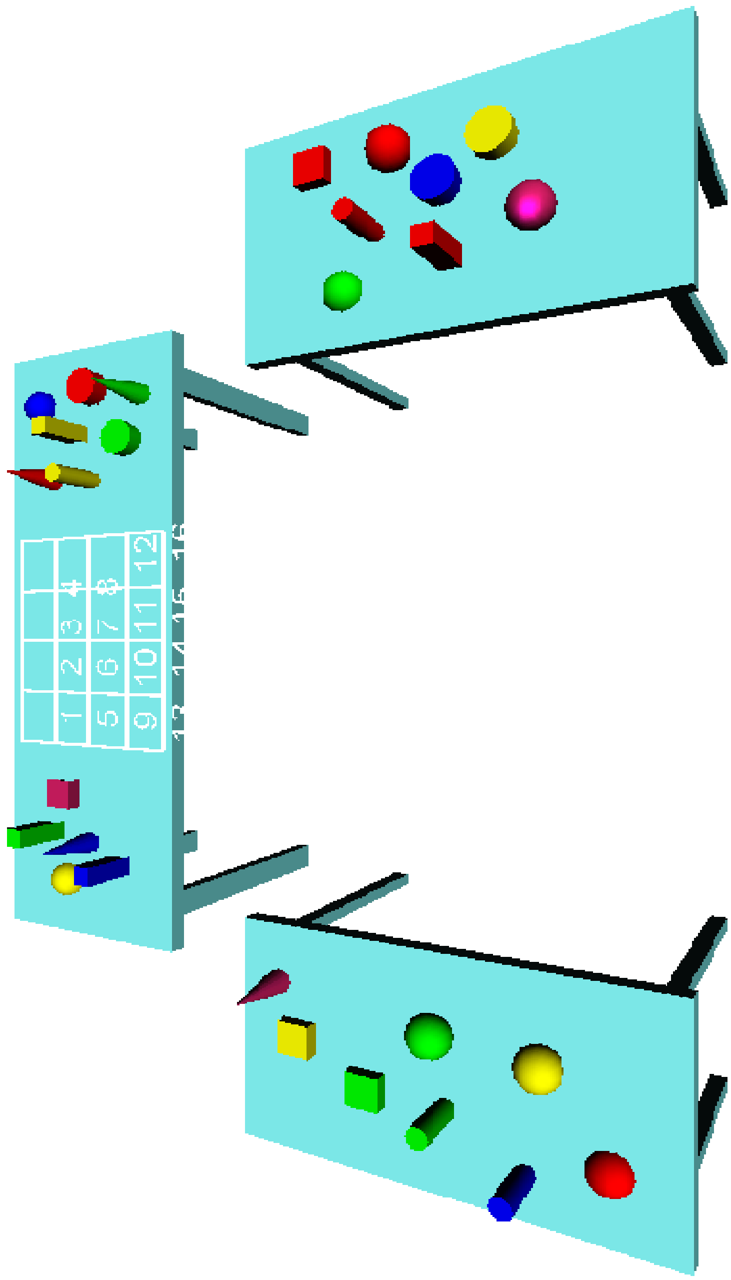
Set4_ finalAssessment_16Steps

Set5_ 16Steps

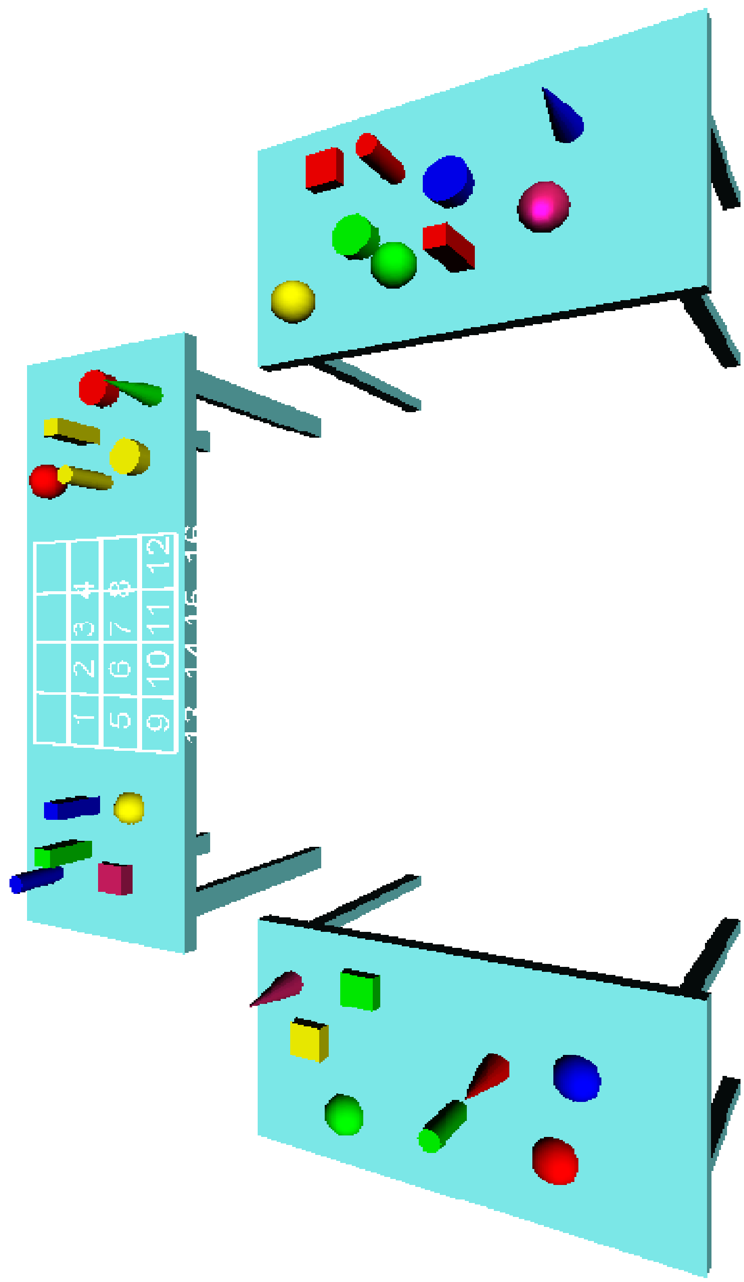
1. Move the **green sphere** from the **left** table to position # 2
2. Move the **yellow hemisphere** from the **front** table to position # 3
3. Move the **wide yellow cylinder** from the **right** table to position # 13
4. Move the **tall red box** from the **right** table to position # 12
5. Move the **blue hemisphere** from the **front** table to position # 10
6. Move the **red hemisphere** from the **left** table and place it on top of wide yellow cylinder at position # 13
7. Move the **green box** from the **left** table to position # 8
8. Move the **blue cone** from the **front** table to position # 12

Set5_finalAssessment_16Steps

1. Move the **green sphere** from the **right** table to position # 2
2. Move the **yellow hemisphere** from the **front** table to position # 3
3. Move the **wide yellow cylinder** from the **front** table to position # 13
4. Move the **tall red box** from the **right** table to position # 12
5. Move the **blue hemisphere** from the **left** table to position # 10
6. Move the **red hemisphere** from the **left** table and place it on top of wide yellow cylinder at position # 13
7. Move the **green box** from the **left** table to position # 8
8. Move the **blue cone** from the **right** table and place it on top of the tall red box at position # 12



Set5_ 16Steps



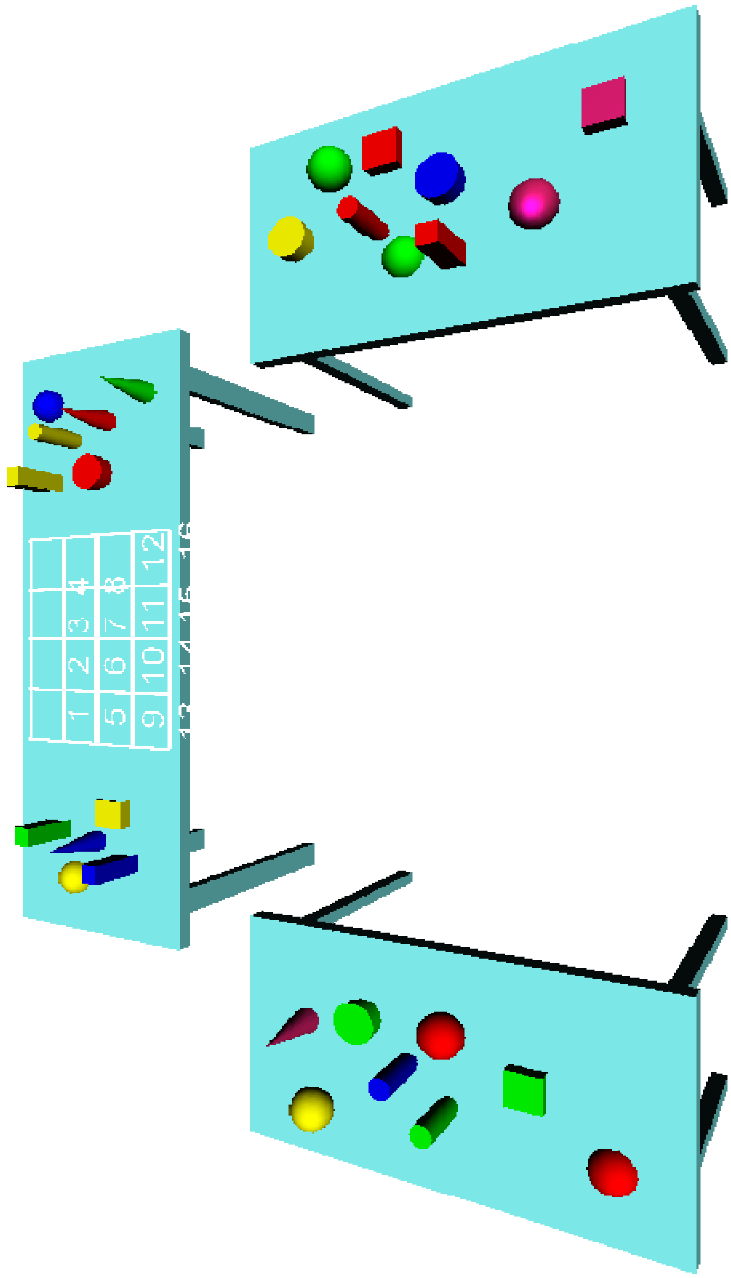
Set5_finalAssessment_16Steps

Set6_16Steps

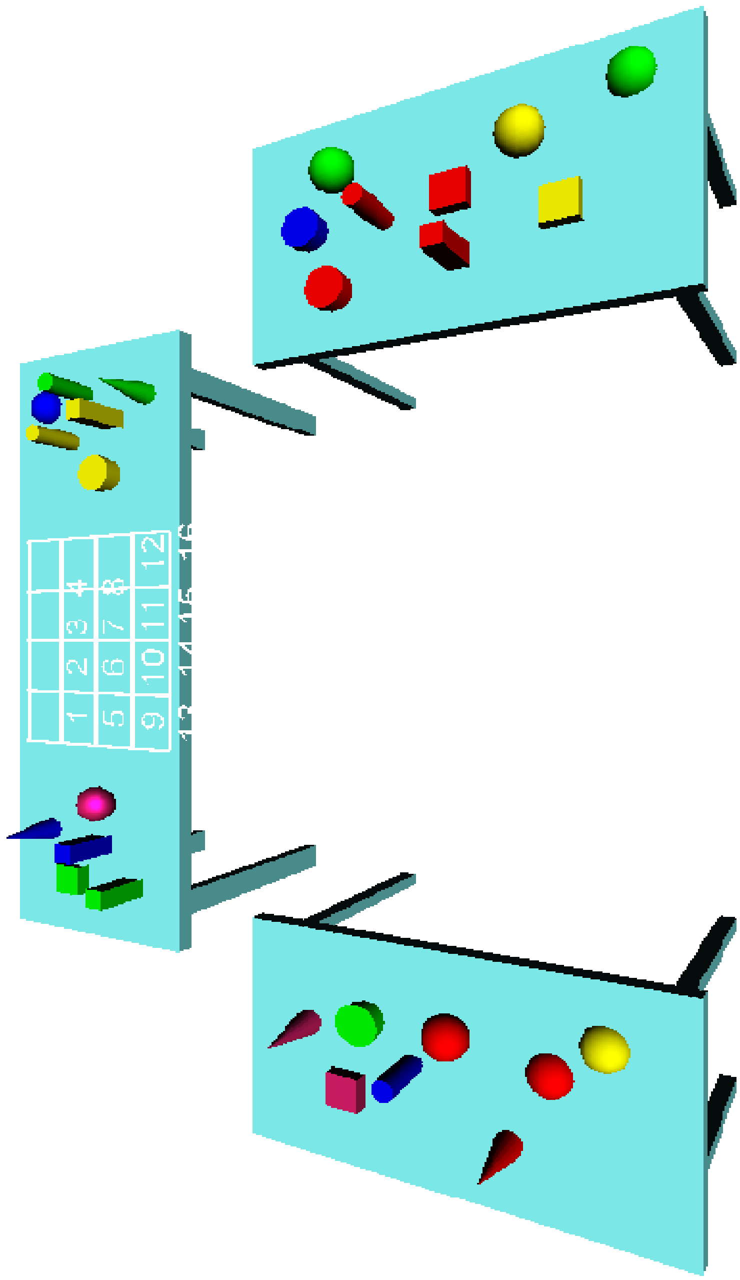
1. Move the **tall blue box** from the **front** table to position # 6
2. Move the **yellow box** from the **front** table to position # 11
3. Move the **red cone** from the **front** table to position # 4
4. Move the **green sphere** from the **right** table to position # 1
5. Move the **pink sphere** from the **right** table and place it on top of yellow box at position # 11
6. Move the **red box** from the **right** table to position # 3
7. Move the **tall green cylinder** from the **left** table to position # 9
8. Move the **yellow hemisphere** from the **front** table and place it on top of tall green cylinder at position # 9

Set6_finalAssessment_16Steps

1. Move the **tall blue box** from the **front** table to position # 6
2. Move the **yellow box** from the **right** table to position # 11
3. Move the **red cone** from the **left** table to position # 4
4. Move the **green sphere** from the **right** table to position # 1
5. Move the **pink sphere** from the **front** table and place it on top of yellow box at position # 11
6. Move the **red box** from the **right** table to position # 3
7. Move the **tall green cylinder** from the **front** table to position # 9
8. Move the **yellow hemisphere** from the **left** table and place it on top of tall green cylinder at position # 9



Set6_16Steps



Set6_finalAssessment_16Steps

C.7 Data Recorded for Final Experiment

Serial #	Condition	Order	Subject Memory Test		Procedure 3								Procedure 4								Procedure 5								Procedure 6							
					Virtual				Real				Virtual				Real				Virtual				Real				Virtual				Real			
					Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different		Same		Different	
			Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error	Time	Error
		VS, VD, RS, RD	125.56	3	110.45	2									80.71	2									90.45	5									105.63	8
	Matched S/w	VD, RS, RD, VS	50.23	1			68.78	2									55.67	0									69.56	2	74.85	3						
	FOV	RS, RD, VS, VD	65.01	2					74.89	1									65.22	1	79.56	5									82.33	6				
1	Low Physical	RD, VS, VD, RS	60.43	1							78.33	4	55.83	0									85.67	3									89.78	7		
	FOV	VS, RS, VD, RD	95.39	2	78.57	2											69.78	1					99.39	9											78.12	10
	Low FOR	RS, VD, RD, VS	66.97	3					73.01	1					78.19	3											70.04	2	75.34	4						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD	120.85	3	78.45	1									65.87	0									73.89	1									74.55	3
	Matched S/w	VD, RS, RD, VS	64.74	1			56.54	1									40.23	0									51.81	2	52.11	0						
	FOV	RS, RD, VS, VD	90.42	2					43.86	0									33.07	0	52.7	2									48.67	1				
2	Low Physical	RD, VS, VD, RS	55.67	0							46.77	0	34.86	0									44.65	1									42.34	0		
	FOV	VS, RS, VD, RD	74.56	2	51.34	0											38.02	0					48.98	1											47.92	0
	High FOR	RS, VD, RD, VS	50.34	1					43.34	0					31.23	0											43.08	1	44.76	0						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD	127.85	4	85.99	12									77.39	6									98.11	11									97.98	14
	UnMatched S/w	VD, RS, RD, VS	73.44	2			94.47	11									82.44	8									101.43	10	110.17	16						
	FOV	RS, RD, VS, VD	60.31	1					85.81	8									76.44	5	99.15	13									96.78	10				
3	Low Physical	RD, VS, VD, RS	49.67	2							72.29	5	64.98	3									74.31	7									78.73	8		
	FOV	VS, RS, VD, RD	55.15	2	76.9	7											62.34	4					92.19	12											97.83	10
	Low FOR	RS, VD, RD, VS	56.34	2					75.88	6					65.82	5											83.76	9	80.55	8						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD	93.45	2	41.04	0									38.96	0									77.65	2									61.96	1
	Matched S/w	VD, RS, RD, VS	49.71	1			35.99	0									32.67	0									39.09	1	38.98	1						
	FOV	RS, RD, VS, VD	65.01	2					74.08	2									55.5	0	65.01	1									68.12	2				
4	High Physical	RD, VS, VD, RS	65.84	2							51.01	1	44.49	1									45.67	2									49.7	1		
	FOV	VS, RS, VD, RD	105.56	3	55.09	1											52.34	1					61.44	2											63.83	1
	Low FOR	RS, VD, RD, VS	70.45	3					73.98	2					43.72	0											51.68	1	43.59	1						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD	114.45	6	51.74	0									34.33	0									57.79	0									56.33	0
	Matched S/w	VD, RS, RD, VS	94.47	3			57.56	1									48.41	0									63.45	1	67.17	0						
	FOV	RS, RD, VS, VD	49.01	2					40.02	0									31.07	0	39.57	0									43.71	0				
5	High Physical	RD, VS, VD, RS	68.44	3							51.37	0	43.44	0									55.62	2									59.07	1		
	FOV	VS, RS, VD, RD	67.2	1	31.15	0											29.35	0					37.89	0											38.05	0
	High FOR	RS, VD, RD, VS	57.14	1					44.56	0					32.89	0											37.03	0	41.07	0						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		
		VS, VD, RS, RD	57.85	0	65.89	6									61.39	3									78.11	9									77.98	12
	UnMatched S/w	VD, RS, RD, VS	123.44	2			104.87	9									86.65	4									94.33	8	120.12	14						
	FOV	RS, RD, VS, VD	90.31	3					95.31	7									70.44	4	97.15	9									98.18	9				
6	High Physical	RD, VS, VD, RS	54.67	1							62.22	3	58.98	1									72.71	6									74.73	8		
	FOV	VS, RS, VD, RD	65.15	2	96.97	8											62.34	3					92.19	12											97.83	9
	Low FOR	RS, VD, RD, VS	60.98	1					71.34	5					57.16	2											86.21	7	82.75	9						
		VD, RD, VS, RS																																		
		RD, VS, RS, VD																																		

C.8 Data from Final Experiment formatted for ANOVA

Subject	S/w FOV	FOV	FOR	Procedure	Virtual/Real	Same/Different	Time	Error
1	Matched	Low	Low	1	Virtual	Same	110	2
1	Matched	Low	Low	2	Virtual	Different	80.7	2
1	Matched	Low	Low	3	Real	Same	90.5	5
1	Matched	Low	Low	4	Real	Different	106	8
2	Matched	Low	Low	1	Virtual	Different	68.8	2
2	Matched	Low	Low	2	Real	Same	55.7	0
2	Matched	Low	Low	3	Real	Different	69.6	2
2	Matched	Low	Low	4	Virtual	Same	74.9	3
3	Matched	Low	Low	1	Real	Same	74.9	1
3	Matched	Low	Low	2	Real	Different	65.2	1
3	Matched	Low	Low	3	Virtual	Same	79.6	5
3	Matched	Low	Low	4	Virtual	Different	82.3	6
4	Matched	Low	Low	1	Real	Different	78.3	4
4	Matched	Low	Low	2	Virtual	Same	55.8	0
4	Matched	Low	Low	3	Virtual	Different	85.7	3
4	Matched	Low	Low	4	Real	Same	89.8	7
5	Matched	Low	Low	1	Virtual	Same	78.6	2
5	Matched	Low	Low	2	Real	Same	69.8	1
5	Matched	Low	Low	3	Virtual	Different	99.4	9
5	Matched	Low	Low	4	Real	Different	78.1	10
6	Matched	Low	Low	1	Real	Same	73	1
6	Matched	Low	Low	2	Virtual	Different	78.2	3
6	Matched	Low	Low	3	Real	Different	70	2
6	Matched	Low	Low	4	Virtual	Same	75.3	4
7	Matched	Low	High	1	Virtual	Same	78.5	1
7	Matched	Low	High	2	Virtual	Different	65.9	0
7	Matched	Low	High	3	Real	Same	73.9	1
7	Matched	Low	High	4	Real	Different	74.6	3
8	Matched	Low	High	1	Virtual	Different	56.5	1
8	Matched	Low	High	2	Real	Same	40.2	0
8	Matched	Low	High	3	Real	Different	51.8	2
8	Matched	Low	High	4	Virtual	Same	52.1	0
9	Matched	Low	High	1	Real	Same	43.9	0
9	Matched	Low	High	2	Real	Different	33.1	0

9	Matched	Low	High	3	Virtual	Same	52.7	2
9	Matched	Low	High	4	Virtual	Different	48.7	1
10	Matched	Low	High	1	Real	Different	46.8	0
10	Matched	Low	High	2	Virtual	Same	34.9	0
10	Matched	Low	High	3	Virtual	Different	44.7	1
10	Matched	Low	High	4	Real	Same	42.3	0
11	Matched	Low	High	1	Virtual	Same	51.3	0
11	Matched	Low	High	2	Real	Same	38	0
11	Matched	Low	High	3	Virtual	Different	49	1
11	Matched	Low	High	4	Real	Different	47.9	0
12	Matched	Low	High	1	Real	Same	43.3	0
12	Matched	Low	High	2	Virtual	Different	31.2	0
12	Matched	Low	High	3	Real	Different	43.1	1
12	Matched	Low	High	4	Virtual	Same	44.8	0
13	UnMatched	Low	Low	1	Virtual	Same	86	12
13	UnMatched	Low	Low	2	Virtual	Different	77.4	6
13	UnMatched	Low	Low	3	Real	Same	98.1	11
13	UnMatched	Low	Low	4	Real	Different	98	14
14	UnMatched	Low	Low	1	Virtual	Different	94.5	11
14	UnMatched	Low	Low	2	Real	Same	82.4	8
14	UnMatched	Low	Low	3	Real	Different	101	10
14	UnMatched	Low	Low	4	Virtual	Same	110	16
15	UnMatched	Low	Low	1	Real	Same	85.8	8
15	UnMatched	Low	Low	2	Real	Different	76.4	5
15	UnMatched	Low	Low	3	Virtual	Same	99.2	13
15	UnMatched	Low	Low	4	Virtual	Different	96.8	10
16	UnMatched	Low	Low	1	Real	Different	72.3	5
16	UnMatched	Low	Low	2	Virtual	Same	65	3
16	UnMatched	Low	Low	3	Virtual	Different	74.3	7
16	UnMatched	Low	Low	4	Real	Same	78.7	8
17	UnMatched	Low	Low	1	Virtual	Same	76.9	7
17	UnMatched	Low	Low	2	Real	Same	62.3	4
17	UnMatched	Low	Low	3	Virtual	Different	92.2	12
17	UnMatched	Low	Low	4	Real	Different	97.8	10
18	UnMatched	Low	Low	1	Real	Same	75.9	6
18	UnMatched	Low	Low	2	Virtual	Different	65.8	5
18	UnMatched	Low	Low	3	Real	Different	83.8	9
18	UnMatched	Low	Low	4	Virtual	Same	80.6	8
19	Matched	High	Low	1	Virtual	Same	41	0

19	Matched	High	Low	2	Virtual	Different	39	0
19	Matched	High	Low	3	Real	Same	77.7	2
19	Matched	High	Low	4	Real	Different	62	1
20	Matched	High	Low	1	Virtual	Different	36	0
20	Matched	High	Low	2	Real	Same	32.7	0
20	Matched	High	Low	3	Real	Different	39.1	1
20	Matched	High	Low	4	Virtual	Same	39	1
21	Matched	High	Low	1	Real	Same	74.1	2
21	Matched	High	Low	2	Real	Different	55.5	0
21	Matched	High	Low	3	Virtual	Same	65	1
21	Matched	High	Low	4	Virtual	Different	68.1	2
22	Matched	High	Low	1	Real	Different	51	1
22	Matched	High	Low	2	Virtual	Same	44.5	1
22	Matched	High	Low	3	Virtual	Different	45.7	2
22	Matched	High	Low	4	Real	Same	49.7	1
23	Matched	High	Low	1	Virtual	Same	55.1	1
23	Matched	High	Low	2	Real	Same	52.3	1
23	Matched	High	Low	3	Virtual	Different	61.4	2
23	Matched	High	Low	4	Real	Different	63.8	1
24	Matched	High	Low	1	Real	Same	74	2
24	Matched	High	Low	2	Virtual	Different	43.7	0
24	Matched	High	Low	3	Real	Different	51.7	1
24	Matched	High	Low	4	Virtual	Same	43.6	1
25	Matched	High	High	1	Virtual	Same	51.7	0
25	Matched	High	High	2	Virtual	Different	34.3	0
25	Matched	High	High	3	Real	Same	57.8	0
25	Matched	High	High	4	Real	Different	56.3	0
26	Matched	High	High	1	Virtual	Different	57.6	1
26	Matched	High	High	2	Real	Same	48.4	0
26	Matched	High	High	3	Real	Different	63.5	1
26	Matched	High	High	4	Virtual	Same	67.2	0
27	Matched	High	High	1	Real	Same	40	0
27	Matched	High	High	2	Real	Different	31.1	0
27	Matched	High	High	3	Virtual	Same	39.6	0
27	Matched	High	High	4	Virtual	Different	43.7	0
28	Matched	High	High	1	Real	Different	51.4	0
28	Matched	High	High	2	Virtual	Same	43.4	0
28	Matched	High	High	3	Virtual	Different	55.6	2
28	Matched	High	High	4	Real	Same	59.1	1

29	Matched	High	High	1	Virtual	Same	31.2	0
29	Matched	High	High	2	Real	Same	29.4	0
29	Matched	High	High	3	Virtual	Different	37.9	0
29	Matched	High	High	4	Real	Different	38.1	0
30	Matched	High	High	1	Real	Same	44.6	0
30	Matched	High	High	2	Virtual	Different	32.9	0
30	Matched	High	High	3	Real	Different	37	0
30	Matched	High	High	4	Virtual	Same	41.1	0
31	UnMatched	High	Low	1	Virtual	Same	65.9	6
31	UnMatched	High	Low	2	Virtual	Different	61.4	3
31	UnMatched	High	Low	3	Real	Same	78.1	9
31	UnMatched	High	Low	4	Real	Different	78	12
32	UnMatched	High	Low	1	Virtual	Different	105	9
32	UnMatched	High	Low	2	Real	Same	86.7	4
32	UnMatched	High	Low	3	Real	Different	94.3	8
32	UnMatched	High	Low	4	Virtual	Same	120	14
33	UnMatched	High	Low	1	Real	Same	95.3	7
33	UnMatched	High	Low	2	Real	Different	70.4	4
33	UnMatched	High	Low	3	Virtual	Same	97.2	9
33	UnMatched	High	Low	4	Virtual	Different	98.2	9
34	UnMatched	High	Low	1	Real	Different	62.2	3
34	UnMatched	High	Low	2	Virtual	Same	59	1
34	UnMatched	High	Low	3	Virtual	Different	72.7	6
34	UnMatched	High	Low	4	Real	Same	74.7	8
35	UnMatched	High	Low	1	Virtual	Same	97	8
35	UnMatched	High	Low	2	Real	Same	62.3	3
35	UnMatched	High	Low	3	Virtual	Different	92.2	12
35	UnMatched	High	Low	4	Real	Different	97.8	9
36	UnMatched	High	Low	1	Real	Same	71.3	5
36	UnMatched	High	Low	2	Virtual	Different	57.2	2
36	UnMatched	High	Low	3	Real	Different	86.2	7
36	UnMatched	High	Low	4	Virtual	Same	82.8	9

	Time				Error	
	Real	Virtual			Real	Virtual
Mean	65.415	65.62681		Mean	3.347222	3.611111

S.D	19.78216	22.5269		S.D	3.742259	4.234518

	Time				Error	
	Different	Same			Different	Same
Mean	65.52194	65.51986		Mean	3.680556	3.277778
S.D	21.12906	21.26924		S.D	3.967567	4.018346

	Time				Error	
SFOV	Matched	UnMatched		SFOV	Matched	UnMatched
Mean	59.98861	71.05319444		Mean	1.555556	5.402778
S.D	18.67675	22.08896001		S.D	2.181154	4.439451

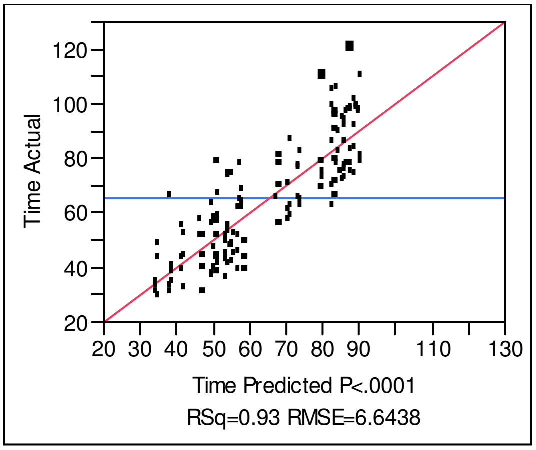
	Time				Error	
FOV	High	Low		FOV	High	Low
Mean	60.05667	70.98514		Mean	2.722222	4.236111
S.D	20.88276	20.05421		S.D	3.620062	4.207616

	Time				Error	
FOR	High	Low		FOR	High	Low
Mean	58.34736	72.69444		Mean	2.097222	4.861111
S.D	19.74002	20.11915		S.D	3.340573	4.115603

C.9 Fit Least Squares for the within-subjects and between-subjects variables and interaction between between-subject variables with Time as Response

Response Time

Actual by Predicted Plot



Summary of Fit

RSquare	0.926791
RSquare Adj	0.921287
Root Mean Square Error	6.64375
Mean of Response	65.5209
Observations (or Sum Wgts)	144

Parameter Estimates

Term	**Estimate**	**Std Error**	**DFDen**	**t Ratio**	**Prob>|t|**
Intercept	65.409062	2.202365	30	29.70	<.0001
F1[Matched]	-8.769271	2.202365	30	-3.98	0.0004
F2[Low]	1.6905208	2.202365	30	0.77	0.4487
F3[Low]	9.1047917	2.202365	30	4.13	0.0003
Procedure[1]	1.0511806	0.977565	103	1.08	0.2848
Procedure[2]	-11.01479	0.958943	103	-11.49	<.0001
Procedure[3]	4.3286806	0.977565	103	4.43	<.0001
Environment[Real]	-0.105903	0.553646	103	-0.19	0.8487
Position[Different]	-0.272083	0.569697	103	-0.48	0.6340
F2[Low]*F3[Low]	5.5016667	2.202365	30	2.50	0.0182

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
F1[Matched]*F2[Low]	5.8194792	2.202365	30	2.64	0.0130

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Subject[F1,F2,F3]	2.3873216	105.37498	30.096198	46.386437	164.36353	70.478
Residual		44.139417	6.1506778	34.189666	59.190764	29.522
Total		149.5144				100.00

-2 LogLikelihood = 1002.629074

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
F1	1	1	30	15.8544	0.0004
F2	1	1	30	0.5892	0.4487
F3	1	1	30	17.0908	0.0003
Procedure	3	3	103	46.9301	<.0001
Environment	1	1	103	0.0366	0.8487
Position	1	1	103	0.2281	0.6340
F2*F3	1	1	30	6.2404	0.0182
F1*F2	1	1	30	6.9822	0.0130

Effect Details

F1

Least Squares Means Table

Level	Least Sq Mean	Std Error
Matched	56.639792	2.2023646
UnMatched	74.178333	3.8146074

F2

Least Squares Means Table

Level	Least Sq Mean	Std Error

Level	Least Sq Mean	Std Error
Low	67.099583	3.1146139
High	63.718542	3.1146139

F3

Least Squares Means Table

Level	Least Sq Mean	Std Error
Low	74.513854	2.2023646
High	56.304271	3.8146074

Procedure

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	66.460243	2.4095731
2	54.394271	2.4020785
3	69.737743	2.4095731
4	71.043993	2.4020785

Environment

Least Squares Means Table

Level	Least Sq Mean	Std Error
Real	65.303160	2.2708883
Virtual	65.514965	2.2708883

Position

Least Squares Means Table

Level	Least Sq Mean	Std Error
Different	65.136979	2.2748548
Same	65.681146	2.2748548

Subject[F1,F2,F3]

F2*F3

Least Squares Means Table

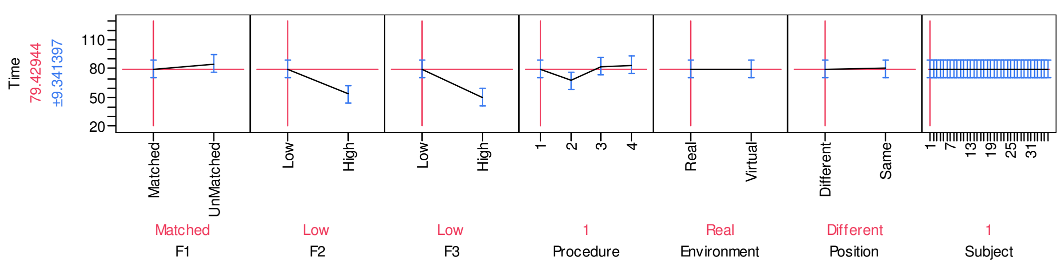
Level	Least Sq Mean	Std Error
Low,Low	81.706042	3.1146139
Low,High	52.493125	5.3946696
High,Low	67.321667	3.1146139
High,High	60.115417	5.3946696

F1*F2

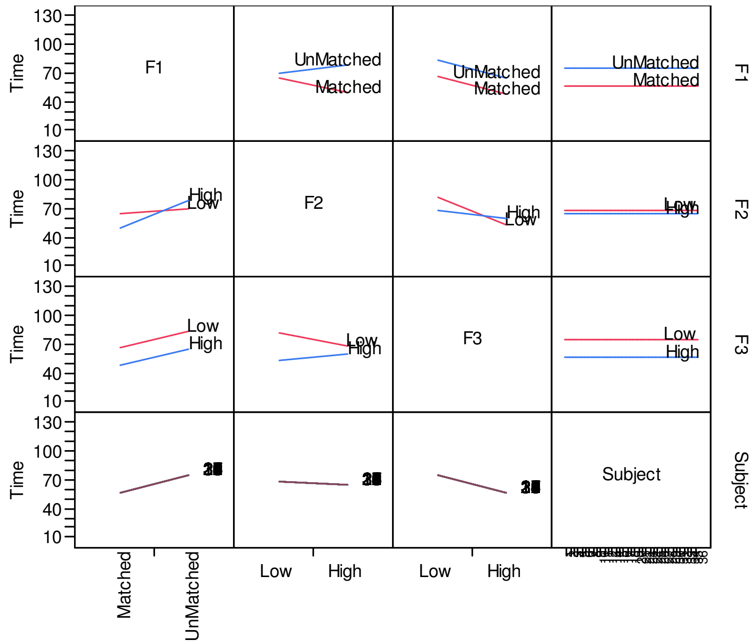
Least Squares Means Table

Level	Least Sq Mean	Std Error
Matched,Low	64.149792	3.1146139
Matched,High	49.129792	3.1146139
UnMatched,Low	70.049375	5.3946696
UnMatched,High	78.307292	5.3946696

Prediction Profiler



Interaction Profiles

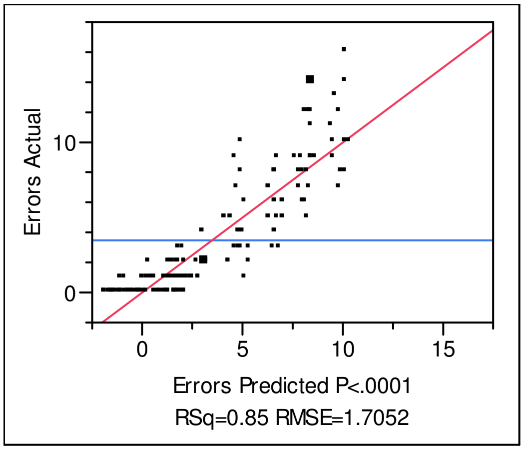


Time
130
100
70
40
10
F1
F2
F3
Subject
UnMatched
Matched
High
Low
Low
High
Matched
UnMatched
Low
High
Low
High

C.10 Fit Least Squares for the within-subjects and between-subjects variables and interaction between between-subject variables with Error as Response

Response Errors

Actual by Predicted Plot



Summary of Fit

RSquare	0.849568
RSquare Adj	0.838258
Root Mean Square Error	1.705208
Mean of Response	3.479167
Observations (or Sum Wgts)	144

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	4.1041667	0.250895	30	16.36	<.0001
F1[Matched]	-2.791667	0.250895	30	-11.13	<.0001
F2[Low]	0.5208333	0.250895	30	2.08	0.0466
F3[Low]	0.9166667	0.250895	30	3.65	0.0010
Procedure[1]	-0.449755	0.250905	103	-1.79	0.0760
Procedure[2]	-1.895833	0.246126	103	-7.70	<.0001
Procedure[3]	0.9080882	0.250905	103	3.62	0.0005
Environment[Real]	-0.131944	0.142101	103	-0.93	0.3553
Position[Different]	0.0882353	0.14622	103	0.60	0.5475

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
F2[Low]*F3[Low]	0.5208333	0.250895	30	2.08	0.0466
F1[Matched]*F2[Low]	0.1875	0.250895	30	0.75	0.4607

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Subject[F1,F2,F3]	0.2695672	0.7838301	0.4030153	-0.00608	1.5737401	21.233
Residual		2.9077353	0.405183	2.2522839	3.8992602	78.767
Total		3.6915653				100.00

-2 LogLikelihood = 592.13622116

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
F1	1	1	30	123.8060	<.0001
F2	1	1	30	4.3094	0.0466
F3	1	1	30	13.3487	0.0010
Procedure	3	3	103	27.3874	<.0001
Environment	1	1	103	0.8622	0.3553
Position	1	1	103	0.3641	0.5475
F2*F3	1	1	30	4.3094	0.0466
F1*F2	1	1	30	0.5585	0.4607

Effect Details

F1

Least Squares Means Table

Level	Least Sq Mean	Std Error
Matched	1.3125000	0.25089539
UnMatched	6.8958333	0.43456356

F2

Least Squares Means Table

Level	Least Sq Mean	Std Error
Low	4.6250000	0.35481966
High	3.5833333	0.35481966

F3

Least Squares Means Table

Level	Least Sq Mean	Std Error
Low	5.0208333	0.25089539
High	3.1875000	0.43456356

Procedure

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	3.6544118	0.35482660
2	2.2083333	0.35146310
3	5.0122549	0.35482660
4	5.5416667	0.35146310

Environment

Least Squares Means Table

Level	Least Sq Mean	Std Error
Real	3.9722222	0.28834199
Virtual	4.2361111	0.28834199

Position

Least Squares Means Table

Level	Least Sq Mean	Std Error
Different	4.1924020	0.29039439
Same	4.0159314	0.29039439

Subject[F1,F2,F3]

F2*F3

Least Squares Means Table

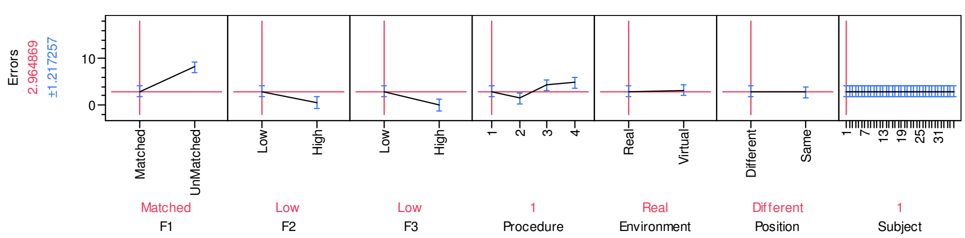
Level	Least Sq Mean	Std Error
Low,Low	6.0625000	0.35481966
Low,High	3.1875000	0.61456568
High,Low	3.9791667	0.35481966
High,High	3.1875000	0.61456568

F1*F2

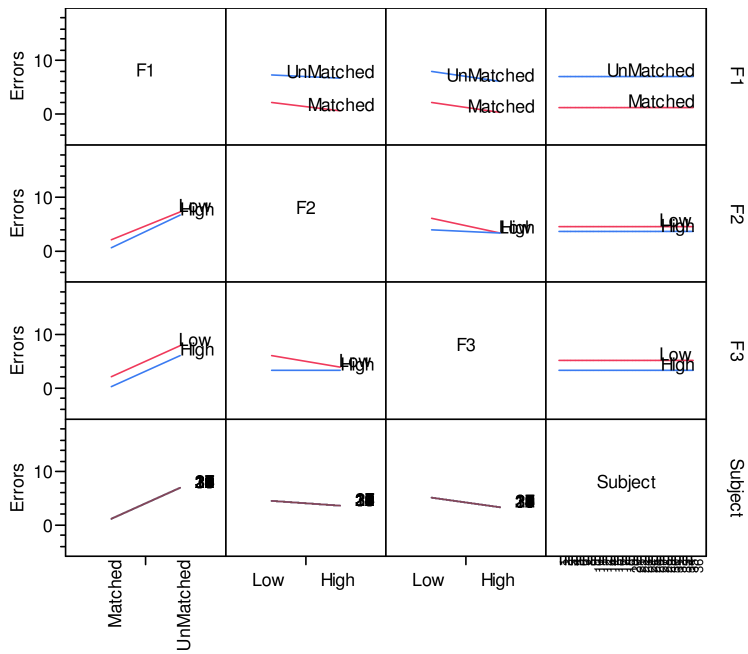
Least Squares Means Table

Level	Least Sq Mean	Std Error
Matched,Low	2.0208333	0.35481966
Matched,High	0.6041667	0.35481966
UnMatched,Low	7.2291667	0.61456568
UnMatched,High	6.5625000	0.61456568

Prediction Profiler



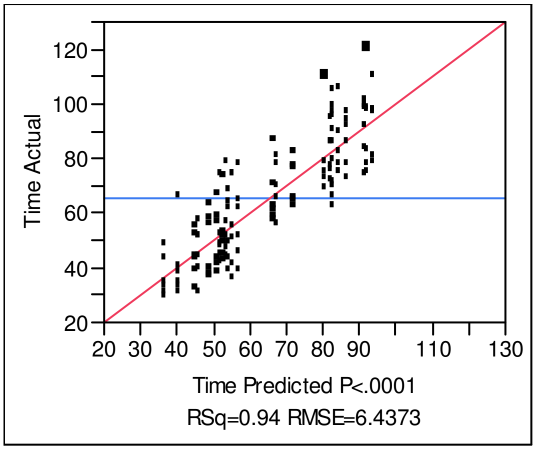
Interaction Profiles



C.11 Fit Least Squares for various combination of between-subjects variables with Time as Response

Response Time

Actual by Predicted Plot



Summary of Fit

RSquare	0.939826
RSquare Adj	0.928292
Root Mean Square Error	6.437258
Mean of Response	65.5209
Observations (or Sum Wgts)	144

Parameter Estimates

Term	**Estimate**	**Std Error**	**DFDen**	**t Ratio**	**Prob>|t|**
Intercept	65.520903	1.798223	30	36.44	<.0001
Procedure[1]	1.141875	0.929138	90	1.23	0.2223
Procedure[2]	-11.01479	0.929138	90	-11.85	<.0001
Procedure[3]	4.2379861	0.929138	90	4.56	<.0001
A[1]	13.235347	4.020949	30	3.29	0.0026
A[2]	-15.97757	4.020949	30	-3.97	0.0004
A[3]	19.134931	4.020949	30	4.76	<.0001
A[4]	-12.78799	4.020949	30	-3.18	0.0034

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
A[5]	-19.99424	4.020949	30	-4.97	<.0001
Procedure[1]*A[1]	0.7735417	2.077616	90	0.37	0.7105
Procedure[1]*A[2]	2.698125	2.077616	90	1.30	0.1974
Procedure[1]*A[3]	-3.907708	2.077616	90	-1.88	0.0632
Procedure[1]*A[4]	1.3235417	2.077616	90	0.64	0.5257
Procedure[1]*A[5]	-0.601875	2.077616	90	-0.29	0.7727
Procedure[2]*A[1]	-0.174792	2.077616	90	-0.08	0.9331
Procedure[2]*A[2]	2.018125	2.077616	90	0.97	0.3340
Procedure[2]*A[3]	-2.072708	2.077616	90	-1.00	0.3211
Procedure[2]*A[4]	2.8952083	2.077616	90	1.39	0.1669
Procedure[2]*A[5]	2.0697917	2.077616	90	1.00	0.3218
Procedure[3]*A[1]	-0.549236	2.077616	90	-0.26	0.7921
Procedure[3]*A[2]	-1.262986	2.077616	90	-0.61	0.5448
Procedure[3]*A[3]	2.5978472	2.077616	90	1.25	0.2144
Procedure[3]*A[4]	-0.214236	2.077616	90	-0.10	0.9181
Procedure[3]*A[5]	-1.206319	2.077616	90	-0.58	0.5629

Random Effect Predictions

Term	BLUP	Std Error	DFDen	t Ratio	Prob>|t|
A[1]:Subject[1]	16.447106	5.053687	46.99	3.25	0.0021
A[1]:Subject[2]	-10.51417	5.053687	46.99	-2.08	0.0430
A[1]:Subject[3]	-2.966469	5.053687	46.99	-0.59	0.5600
A[1]:Subject[4]	-1.233277	5.053687	46.99	-0.24	0.8083
A[1]:Subject[5]	2.4676922	5.053687	46.99	0.49	0.6276
A[1]:Subject[6]	-4.200884	5.053687	46.99	-0.83	0.4100
A[2]:Subject[7]	21.542297	5.053687	46.99	4.26	<.0001
A[2]:Subject[8]	0.5731757	5.053687	46.99	0.11	0.9102
A[2]:Subject[9]	-4.52619	5.053687	46.99	-0.90	0.3750
A[2]:Subject[10]	-6.730829	5.053687	46.99	-1.33	0.1893
A[2]:Subject[11]	-2.713285	5.053687	46.99	-0.54	0.5939
A[2]:Subject[12]	-8.145168	5.053687	46.99	-1.61	0.1137
A[3]:Subject[13]	4.7478687	5.053687	46.99	0.94	0.3523
A[3]:Subject[14]	11.361785	5.053687	46.99	2.25	0.0293
A[3]:Subject[15]	4.4540687	5.053687	46.99	0.88	0.3826
A[3]:Subject[16]	-11.00346	5.053687	46.99	-2.18	0.0345

Term	BLUP	Std Error	DFDen	t Ratio	Prob>|t|
A[3]:Subject[17]	-2.132517	5.053687	46.99	-0.42	0.6750
A[3]:Subject[18]	-7.42775	5.053687	46.99	-1.47	0.1483
A[4]:Subject[19]	1.9765072	5.053687	46.99	0.39	0.6975
A[4]:Subject[20]	-14.62205	5.053687	46.99	-2.89	0.0058
A[4]:Subject[21]	11.792616	5.053687	46.99	2.33	0.0240
A[4]:Subject[22]	-4.569083	5.053687	46.99	-0.90	0.3705
A[4]:Subject[23]	4.9577801	5.053687	46.99	0.98	0.3316
A[4]:Subject[24]	0.4642344	5.053687	46.99	0.09	0.9272
A[5]:Subject[25]	4.1185142	5.053687	46.99	0.81	0.4192
A[5]:Subject[26]	12.408685	5.053687	46.99	2.46	0.0178
A[5]:Subject[27]	-6.31708	5.053687	46.99	-1.25	0.2175
A[5]:Subject[28]	6.2388847	5.053687	46.99	1.23	0.2231
A[5]:Subject[29]	-10.40067	5.053687	46.99	-2.06	0.0452
A[5]:Subject[30]	-6.048332	5.053687	46.99	-1.20	0.2374
A[6]:Subject[31]	-10.08296	5.053687	46.99	-2.00	0.0518
A[6]:Subject[32]	17.83943	5.053687	46.99	3.53	0.0009
A[6]:Subject[33]	7.6156452	5.053687	46.99	1.51	0.1385
A[6]:Subject[34]	-13.43774	5.053687	46.99	-2.66	0.0107
A[6]:Subject[35]	4.9395599	5.053687	46.99	0.98	0.3334
A[6]:Subject[36]	-6.873933	5.053687	46.99	-1.36	0.1803

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Subject[A]	2.5592334	106.05027	30.096538	47.06105	165.03948	71.904
Residual		41.438294	6.1772562	31.569123	56.810947	28.096
Total		147.48856				100.000

-2 LogLikelihood = 933.99791562

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Procedure	3	3	90	49.9082	<.0001
A	5	5	30	16.7875	<.0001
Procedure*A	15	15	90	1.3331	0.1996

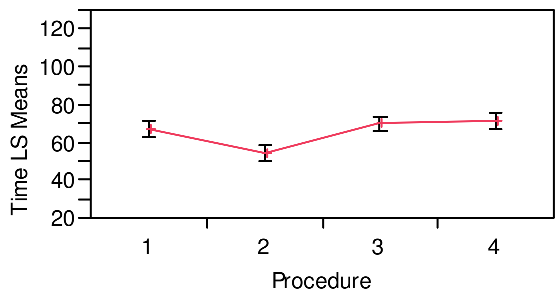
Effect Details

Procedure

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	66.662778	2.0240811
2	54.506111	2.0240811
3	69.758889	2.0240811
4	71.155833	2.0240811

LS Means Plot



LSMeans Differences Tukey HSD

α=0.050

LSMean[i] By LSMean[j]

Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	1	2	3	4
1	0 0 0 0	12.1567 1.51728 8.18491 16.1284	-3.0961 1.51728 -7.0679 0.87565	-4.4931 1.51728 -8.4648 -0.5213
2	-12.157 1.51728 -16.128 -8.1849	0 0 0 0	-15.253 1.51728 -19.225 -11.281	-16.65 1.51728 -20.621 -12.678
3	3.09611 1.51728	15.2528 1.51728	0 0	-1.3969 1.51728

	-0.8756 7.06787	11.281 19.2245	0 0	-5.3687 2.57481
4	4.49306 1.51728 0.5213 8.46481	16.6497 1.51728 12.678 20.6215	1.39694 1.51728 -2.5748 5.3687	0 0 0 0

Level				Least Sq Mean
4	A			71.155833
3	A	B		69.758889
1		B		66.662778
2			C	54.506111

Levels not connected by same letter are significantly different.

A

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	78.756250	4.4047293
2	49.543333	4.4047293
3	84.655833	4.4047293
4	52.732917	4.4047293
5	45.526667	4.4047293
6	81.910417	4.4047293

LSMeans Differences Tukey HSD

α=0.050

LSMean[i] By LSMean[j]

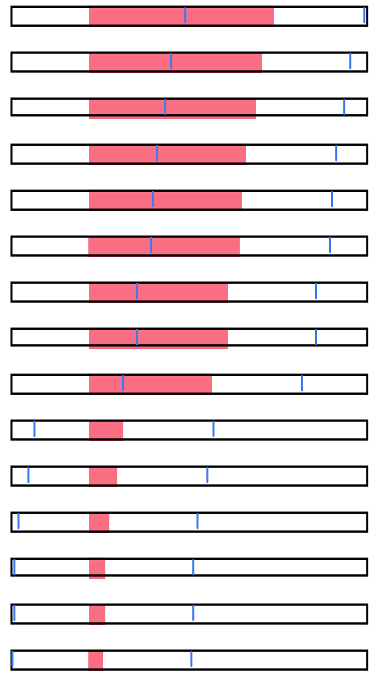
Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	1	2	3	4	5	6
1	0	29.2129	-5.8996	26.0233	33.2296	-3.1542

	0	6.22923	6.22923	6.22923	6.22923	6.22923
	0	10.2661	-24.846	7.07653	14.2828	-22.101
	0	48.1597	13.0472	44.9701	52.1764	15.7926
2	-29.213	0	-35.113	-3.1896	4.01667	-32.367
	6.22923	0	6.22923	6.22923	6.22923	6.22923
	-48.16	0	-54.059	-22.136	-14.93	-51.314
	-10.266	0	-16.166	15.7572	22.9635	-13.42
3	5.89958	35.1125	0	31.9229	39.1292	2.74542
	6.22923	6.22923	0	6.22923	6.22923	6.22923
	-13.047	16.1657	0	12.9761	20.1824	-16.201
	24.8464	54.0593	0	50.8697	58.076	21.6922
4	-26.023	3.18958	-31.923	0	7.20625	-29.178
	6.22923	6.22923	6.22923	0	6.22923	6.22923
	-44.97	-15.757	-50.87	0	-11.741	-48.124
	-7.0765	22.1364	-12.976	0	26.1531	-10.231
5	-33.23	-4.0167	-39.129	-7.2063	0	-36.384
	6.22923	6.22923	6.22923	6.22923	0	6.22923
	-52.176	-22.963	-58.076	-26.153	0	-55.331
	-14.283	14.9301	-20.182	11.7406	0	-17.437
6	3.15417	32.3671	-2.7454	29.1775	36.3838	0
	6.22923	6.22923	6.22923	6.22923	6.22923	0
	-15.793	13.4203	-21.692	10.2307	17.4369	0
	22.101	51.3139	16.2014	48.1243	55.3306	0

Level			**Least Sq Mean**
3	A		84.655833
6	A		81.910417
1	A		78.756250
4		B	52.732917
2		B	49.543333
5		B	45.526667

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	Difference
3	5	39.12917	20.1824	58.07597	
6	5	36.38375	17.4369	55.33056	
3	2	35.11250	16.1657	54.05931	
1	5	33.22958	14.2828	52.17639	
6	2	32.36708	13.4203	51.31389	
3	4	31.92292	12.9761	50.86972	
1	2	29.21292	10.2661	48.15972	
6	4	29.17750	10.2307	48.12431	
1	4	26.02333	7.0765	44.97014	
4	5	7.20625	-11.7406	26.15306	
3	1	5.89958	-13.0472	24.84639	
2	5	4.01667	-14.9301	22.96347	
4	2	3.18958	-15.7572	22.13639	
6	1	3.15417	-15.7926	22.10097	
3	6	2.74542	-16.2014	21.69222	



Contrast

Test Detail

1	0	0
2	0.5	0
3	0	0
4	-1	0
5	0.5	0
6	0	0
Estimate	-5.198	0
Std Error	5.3947	0
t Ratio	-0.964	0
Prob>|t|	0.343	1

Numerator DF	2
Denominator DF	79.299445129
F Ratio	0.4603301785

Prob > F 0.632750883

Subject[A]

Least Squares Means Table

Level	**Least Sq Mean**	**Std Error**
[1]1	95.203356	3.0969833
[1]2	68.242082	3.0969833
[1]3	75.789781	3.0969833
[1]4	77.522973	3.0969833
[1]5	81.223942	3.0969833
[1]6	74.555366	3.0969833
[2]7	71.085630	3.0969833
[2]8	50.116509	3.0969833
[2]9	45.017143	3.0969833
[2]10	42.812504	3.0969833
[2]11	46.830049	3.0969833
[2]12	41.398165	3.0969833
[3]13	89.403702	3.0969833
[3]14	96.017618	3.0969833
[3]15	89.109902	3.0969833
[3]16	73.652378	3.0969833
[3]17	82.523316	3.0969833
[3]18	77.228083	3.0969833
[4]19	54.709424	3.0969833
[4]20	38.110863	3.0969833
[4]21	64.525532	3.0969833
[4]22	48.163833	3.0969833
[4]23	57.690697	3.0969833
[4]24	53.197151	3.0969833
[5]25	49.645181	3.0969833
[5]26	57.935351	3.0969833
[5]27	39.209587	3.0969833
[5]28	51.765551	3.0969833

Level	Least Mean	Sq	Std Error
[5]29	35.125995		3.0969833
[5]30	39.478334		3.0969833
[6]31	71.827459		3.0969833
[6]32	99.749846		3.0969833
[6]33	89.526062		3.0969833
[6]34	68.472673		3.0969833
[6]35	86.849977		3.0969833
[6]36	75.036484		3.0969833

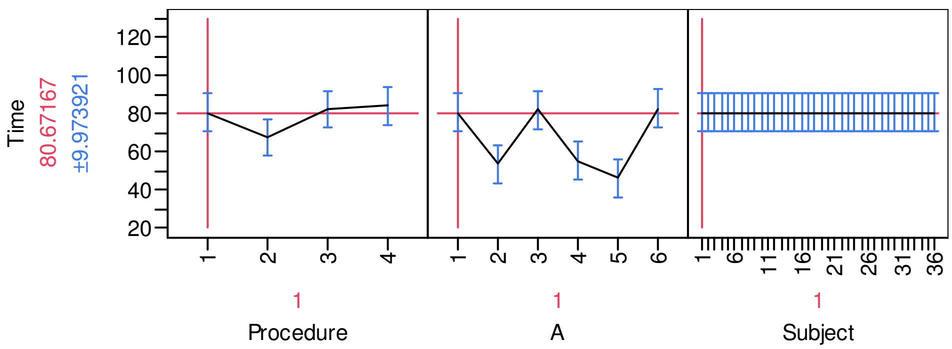
Procedure*A

Least Squares Means Table

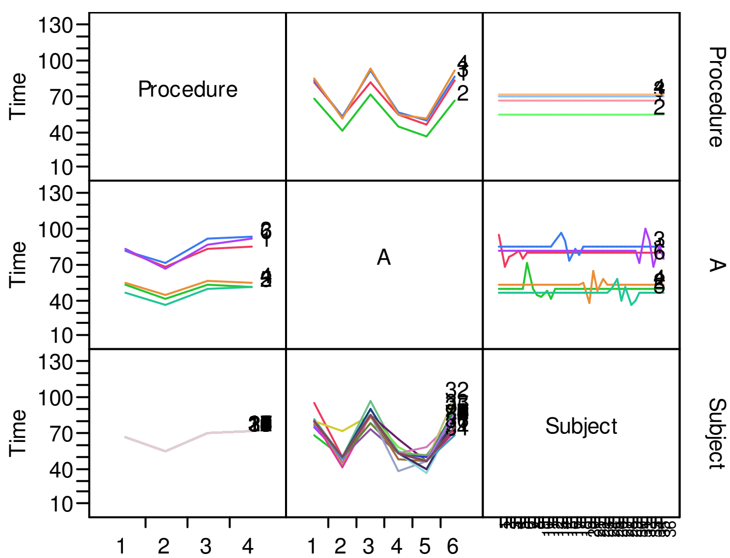
Level	Least Mean	Sq	Std Error
1,1	80.671667		4.9579660
1,2	53.383333		4.9579660
1,3	81.890000		4.9579660
1,4	55.198333		4.9579660
1,5	46.066667		4.9579660
1,6	82.766667		4.9579660
2,1	67.566667		4.9579660
2,2	40.546667		4.9579660
2,3	71.568333		4.9579660
2,4	44.613333		4.9579660
2,5	36.581667		4.9579660
2,6	66.160000		4.9579660
3,1	82.445000		4.9579660
3,2	52.518333		4.9579660
3,3	91.491667		4.9579660
3,4	56.756667		4.9579660
3,5	48.558333		4.9579660
3,6	86.783333		4.9579660
4,1	84.341667		4.9579660
4,2	51.725000		4.9579660
4,3	93.673333		4.9579660

Level	Least Sq Mean	Std Error
4,4	54.363333	4.9579660
4,5	50.900000	4.9579660
4,6	91.931667	4.9579660

Prediction Profiler



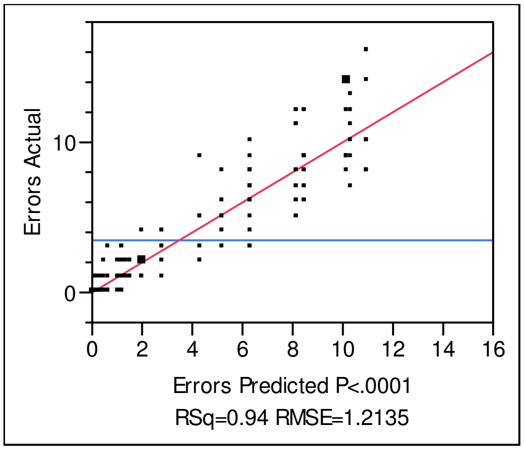
Interaction Profiles



C.12 Fit Least Squares for various combination of between-subjects variables with Error as Response

Response Errors

Actual by Predicted Plot



Summary of Fit

RSquare	0.936867
RSquare Adj	0.924766
Root Mean Square Error	1.213542
Mean of Response	3.479167
Observations (or Sum Wgts)	144

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	3.4791667	0.204855	30	16.98	<.0001
Procedure[1]	-0.479167	0.17516	90	-2.74	0.0075
Procedure[2]	-1.895833	0.17516	90	-10.82	<.0001
Procedure[3]	0.9375	0.17516	90	5.35	<.0001
A[1]	-0.020833	0.45807	30	-0.05	0.9640
A[2]	-2.895833	0.45807	30	-6.32	<.0001
A[3]	5.1875	0.45807	30	11.32	<.0001
A[4]	-2.479167	0.45807	30	-5.41	<.0001
A[5]	-3.270833	0.45807	30	-7.14	<.0001

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Procedure[1]*A[1]	-0.979167	0.391669	90	-2.50	0.0142
Procedure[1]*A[2]	0.2291667	0.391669	90	0.59	0.5599
Procedure[1]*A[3]	-0.020833	0.391669	90	-0.05	0.9577
Procedure[1]*A[4]	0.4791667	0.391669	90	1.22	0.2244
Procedure[1]*A[5]	0.4375	0.391669	90	1.12	0.2670
Procedure[2]*A[1]	-0.395833	0.391669	90	-1.01	0.3149
Procedure[2]*A[2]	1.3125	0.391669	90	3.35	0.0012
Procedure[2]*A[3]	-1.604167	0.391669	90	-4.10	<.0001
Procedure[2]*A[4]	1.2291667	0.391669	90	3.14	0.0023
Procedure[2]*A[5]	1.6875	0.391669	90	4.31	<.0001
Procedure[3]*A[1]	-0.0625	0.391669	90	-0.16	0.8736
Procedure[3]*A[2]	-0.1875	0.391669	90	-0.48	0.6333
Procedure[3]*A[3]	0.7291667	0.391669	90	1.86	0.0659
Procedure[3]*A[4]	-0.4375	0.391669	90	-1.12	0.2670
Procedure[3]*A[5]	-0.645833	0.391669	90	-1.65	0.1026

Random Effect Predictions

Term	BLUP	Std Error	DFDen	t Ratio	Prob>|t|
A[1]:Subject[1]	0.5987385	0.649979	48.81	0.92	0.3615
A[1]:Subject[2]	-1.292015	0.649979	48.81	-1.99	0.0525
A[1]:Subject[3]	-0.157563	0.649979	48.81	-0.24	0.8095
A[1]:Subject[4]	0.0315126	0.649979	48.81	0.05	0.9615
A[1]:Subject[5]	1.544115	0.649979	48.81	2.38	0.0215
A[1]:Subject[6]	-0.724789	0.649979	48.81	-1.12	0.2703
A[2]:Subject[7]	0.5042008	0.649979	48.81	0.78	0.4417
A[2]:Subject[8]	0.1260502	0.649979	48.81	0.19	0.8470
A[2]:Subject[9]	0.1260502	0.649979	48.81	0.19	0.8470
A[2]:Subject[10]	-0.2521	0.649979	48.81	-0.39	0.6998
A[2]:Subject[11]	-0.2521	0.649979	48.81	-0.39	0.6998
A[2]:Subject[12]	-0.2521	0.649979	48.81	-0.39	0.6998
A[3]:Subject[13]	1.5756276	0.649979	48.81	2.42	0.0191
A[3]:Subject[14]	1.9537782	0.649979	48.81	3.01	0.0042
A[3]:Subject[15]	0.2521004	0.649979	48.81	0.39	0.6998
A[3]:Subject[16]	-2.205879	0.649979	48.81	-3.39	0.0014
A[3]:Subject[17]	-0.315126	0.649979	48.81	-0.48	0.6300

Term	BLUP	Std Error	DFDen	t Ratio	Prob>|t|
A[3]:Subject[18]	-1.260502	0.649979	48.81	-1.94	0.0583
A[4]:Subject[19]	-0.189075	0.649979	48.81	-0.29	0.7724
A[4]:Subject[20]	-0.378151	0.649979	48.81	-0.58	0.5634
A[4]:Subject[21]	0.1890753	0.649979	48.81	0.29	0.7724
A[4]:Subject[22]	0.1890753	0.649979	48.81	0.29	0.7724
A[4]:Subject[23]	0.1890753	0.649979	48.81	0.29	0.7724
A[4]:Subject[24]	3.185e-17	0.649979	48.81	0.00	1.0000
A[5]:Subject[25]	-0.157563	0.649979	48.81	-0.24	0.8095
A[5]:Subject[26]	0.2205879	0.649979	48.81	0.34	0.7358
A[5]:Subject[27]	-0.157563	0.649979	48.81	-0.24	0.8095
A[5]:Subject[28]	0.4096632	0.649979	48.81	0.63	0.5315
A[5]:Subject[29]	-0.157563	0.649979	48.81	-0.24	0.8095
A[5]:Subject[30]	-0.157563	0.649979	48.81	-0.24	0.8095
A[6]:Subject[31]	0.4096632	0.649979	48.81	0.63	0.5315
A[6]:Subject[32]	1.3550397	0.649979	48.81	2.08	0.0423
A[6]:Subject[33]	0.2205879	0.649979	48.81	0.34	0.7358
A[6]:Subject[34]	-1.859241	0.649979	48.81	-2.86	0.0062
A[6]:Subject[35]	0.7878138	0.649979	48.81	1.21	0.2313
A[6]:Subject[36]	-0.913864	0.649979	48.81	-1.41	0.1661

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Subject[A]	0.7758566	1.1425926	0.3939197	0.37051	1.9146752	43.689
Residual		1.4726852	0.2195349	1.1219424	2.0190175	56.311
Total		2.6152778				100.000

-2 LogLikelihood = 503.32224164

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Procedure	3	3	90	55.1572	<.0001
A	5	5	30	51.0303	<.0001
Procedure*A	15	15	90	7.7193	<.0001

Effect Details

Procedure

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	3.0000000	0.26953034
2	1.5833333	0.26953034
3	4.4166667	0.26953034
4	4.9166667	0.26953034

A

Least Squares Means Table

Level	Least Sq Mean	Std Error
1	3.4583333	0.50179077
2	0.5833333	0.50179077
3	8.6666667	0.50179077
4	1.0000000	0.50179077
5	0.2083333	0.50179077
6	6.9583333	0.50179077

Subject[A]

Least Squares Means Table

Level	Least Sq Mean	Std Error
[1]1	4.057072	0.54166615
[1]2	2.166319	0.54166615
[1]3	3.300771	0.54166615
[1]4	3.489846	0.54166615
[1]5	5.002448	0.54166615
[1]6	2.733545	0.54166615
[2]7	1.087534	0.54166615
[2]8	0.709384	0.54166615
[2]9	0.709384	0.54166615
[2]10	0.331233	0.54166615
[2]11	0.331233	0.54166615

Level	Least Mean	Sq	Std Error
[2]12	0.331233		0.54166615
[3]13	10.242294		0.54166615
[3]14	10.620445		0.54166615
[3]15	8.918767		0.54166615
[3]16	6.460788		0.54166615
[3]17	8.351541		0.54166615
[3]18	7.406165		0.54166615
[4]19	0.810925		0.54166615
[4]20	0.621849		0.54166615
[4]21	1.189075		0.54166615
[4]22	1.189075		0.54166615
[4]23	1.189075		0.54166615
[4]24	1.000000		0.54166615
[5]25	0.050771		0.54166615
[5]26	0.428921		0.54166615
[5]27	0.050771		0.54166615
[5]28	0.617997		0.54166615
[5]29	0.050771		0.54166615
[5]30	0.050771		0.54166615
[6]31	7.367997		0.54166615
[6]32	8.313373		0.54166615
[6]33	7.178921		0.54166615
[6]34	5.099093		0.54166615
[6]35	7.746147		0.54166615
[6]36	6.044469		0.54166615

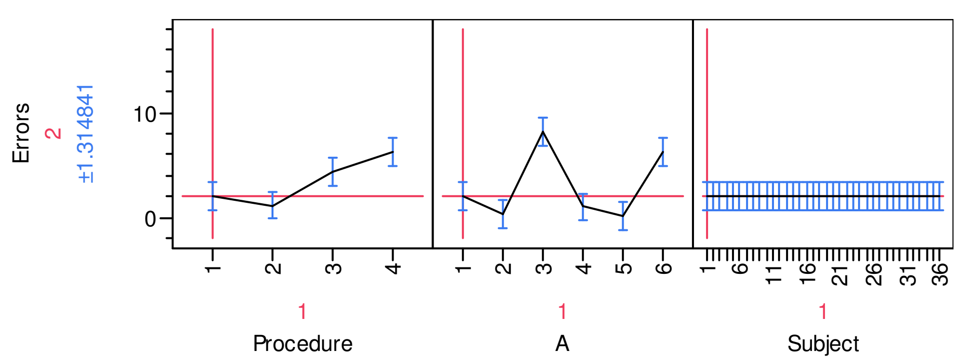
Procedure*A

Least Squares Means Table

Level	Least Mean	Sq	Std Error
1,1	2.000000		0.66021181
1,2	0.333333		0.66021181
1,3	8.166667		0.66021181
1,4	1.000000		0.66021181

Level	Least Sq Mean	Std Error
1,5	0.166667	0.66021181
1,6	6.333333	0.66021181
2,1	1.166667	0.66021181
2,2	1.1102e-14	0.66021181
2,3	5.166667	0.66021181
2,4	0.333333	0.66021181
2,5	2.0206e-14	0.66021181
2,6	2.833333	0.66021181
3,1	4.333333	0.66021181
3,2	1.333333	0.66021181
3,3	10.333333	0.66021181
3,4	1.500000	0.66021181
3,5	0.500000	0.66021181
3,6	8.500000	0.66021181
4,1	6.333333	0.66021181
4,2	0.666667	0.66021181
4,3	11.000000	0.66021181
4,4	1.166667	0.66021181
4,5	0.166667	0.66021181
4,6	10.166667	0.66021181

Prediction Profiler



Interaction Profiles