USING GRAPHICAL CONTEXT TO REDUCE THE EFFECTS OF REGISTRATION ERROR IN AUGMENTED REALITY

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Cindy M. Robertson

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USING GRAPHICAL CONTEXT TO REDUCE THE EFFECTS OF REGISTRATION ERROR IN AUGMENTED REALITY

Approved by:

Dr. Blair MacIntyre, Advisor
School of Interactive Computing
Georgia Institute of Technology

Dr. John Stasko
School of Interactive Computing
Georgia Institute of Technology

Dr. Bruce Walker
School of Psychology/
School of Interactive Computing
Georgia Institute of Technology

Dr. Melody Moore Jackson
School of Interactive Computing
Georgia Institute of Technology

Dr. Frank Biocca
Department of Telecommunication,
Information Studies & Media
Michigan State University

Date Approved: November 5, 2007

For My Children

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AR	Augmented Reality
HMD	Head-Mounted Display
AIBAS	Adaptive Intent-Based Augmentation System
OSG	Open Scene Graph
HUD	Heads-Up Display
PC	Perfect with Context
FC	Fixed with Context
RC	Random with Context
REG	Registered AR
OTS	AR – graphics off to the side
HV	HUD – graphics always visible
HS	HUD – graphics not always visible, look to side to see graphics

SUMMARY

An ongoing research focus in Augmented Reality (AR) is to improve tracking and display technology in order to minimize registration errors between the graphical display and the physical world. However, registration is not always necessary for users to understand the intent of an augmentation, especially in situations where the user and the system have shared semantic knowledge of the environment. I hypothesize that adding appropriate graphical context to an augmentation can ameliorate the effects of registration errors. I establish a theoretical basis supporting the use of context based on perceptual and cognitive psychology.

I introduce the notion of Adaptive Intent-Based Augmented Reality (i.e. augmented reality systems that adapt their augmentations to convey the correct intent in a scene based on an estimate of the registration error in the system.) I extend the idea of communicative intent, developed for desktop graphical explanation systems by Seligmann and Feiner (Seligmann & Feiner, 1991), to include graphical context cues, and use this as the basis for the design of a series of example augmentations demonstrating the concept. I show how semantic knowledge of a scene and the intent of an augmentation can be used to generate appropriate graphical context that counters the effects of registration error.

I evaluate my hypothesis in two user studies based on a Lego block-placement task. In both studies, a virtual block rendered on a head-worn display shows where to place the next physical block. In the first study, I demonstrate that a user can perform the task effectively in the presence of registration error when graphical context is included. In the second, I demonstrate that a variety of approaches to displaying graphics outside the task space are possible when sufficient graphical context is added.

CHAPTER 1

INTRODUCTION, THESIS STATEMENT AND CONTRIBUTIONS

1.1 Introduction

Augmented Reality (AR) overlays computer generated graphics on the physical world, often through the use of see-through head-worn displays. Numerous researchers have demonstrated the potential of AR as a powerful user-interface paradigm for many applications. The key advantage of these systems is that they situate the graphics *in situ* and support hands-free interaction. Tang et al. found that overlaying 3D instructions during an assembly task reduced the error rate for that task by 82%, particularly diminishing cumulative errors, as compared to printed instructions, instructions on an LCD monitor and instructions on a see-through head-mounted display (HMD) (Tang, Owen, Biocca, & Mou, 2003). They also found that mental effort decreased for the AR condition. However, one significant hurdle that must be crossed when creating AR applications is to register the graphics with objects in the world: to integrate graphics accurately with physical objects, both the user and the objects must be accurately tracked (at least with respect to each other), and the whole system (including the HMD) must be accurately calibrated. In some domains, such as medicine, accurate registration is required. However, I believe that in many situations precise registration is not as critical. For example, if a maintenance system, such as the KARMA system (Feiner, MacIntyre, & Seligmann, 1993), instructs a repair person to move a lever on a machine, and there is only one such lever in the area being augmented (such as a lever to open the top of a printer), precise registration may not be necessary.

In other words, registration requirements are not absolute; they depend on the domain, the specific context of use, and the communicative intent of the augmentation. Seligmann and Feiner described communicative intent as “the audience interpretation and consequent actions that the communicator wishes to elicit and are comprised of a set of communicative goals” (Seligmann & Feiner, 1991). Specifically, the communicative intent “provides a high-level description of what is to be communicated,” and the communicative goals “drive the process that determines what information (set of objects and properties) to use to satisfy intent.”

Seligmann and Feiner explored communicative intent deeply in the context of the automated design of graphical presentations with the IBIS system (Seligmann, 1993), and adapted IBIS to support the interactive AR system KARMA (Feiner, MacIntyre, & Seligmann, 1993). In KARMA, they took into account the basic differences between AR and static 3D images: user control of the camera and the presence of unchangeable physical objects. However, they designed their system assuming perfect tracking and registration, ignoring the inevitable uncertainty in the system created by imperfect sensors and displays. This is the case in most AR systems. Most of the research developed by the AR community has been directed towards eliminating the registration error, based on the assumption that AR applications will only be useful when the virtual-physical registration is perfect. The pursuit of perfect registration causes many researchers to develop systems assuming registration error will eventually be eliminated. Since this is not likely to happen soon, and trackers have been identified as one of the main contributors to registration error, Augmented Reality applications are sometimes fine tuned to the specifications and limitations of the tracking technology, creating a tight coupling between the trackers and the applications. The drawback of this approach is that if the tracker characteristics change, the application may fail to convey the information the application developer intended, because the developer had not planned for different tracker characteristics.

There is an (often implicit) assumption among researchers developing AR systems: close to perfect tracking and registration will be necessary to create working AR systems. In an ideal system, there should be no uncertainty in the registration of augmentations. However, I believe that in many cases, it should be possible to use knowledge of the uncertainty of the physical world to design augmentations that a user can understand, even when the registration error arising from this uncertainty is significant.

My work is based on the observation that humans are good at leveraging contextual cues to interpret ambiguous situations. Consider the simple KARMA example mentioned above. In such a maintenance system, if the augmentation of the lever is not registered with the physical lever, but there is only one lever and the augmentation is near it, a repair person should understand that the augmentation refers to the physical lever. Conversely, if there are multiple levers, but the one in question is below a unique feature (such as a large button), adding a representation of the button to the augmentation may be enough to allow the human to choose the correct lever.

The above example introduces the need for adaptive Augmented Reality applications. Adaptive Augmented Reality applications concentrate on the quality of the information presented to allow proper information to be communicated under varying circumstances. Essentially, these applications would require as an input an estimate of the uncertainty in the system, and given this estimate, they would produce an AR application that would convey the correct intent of the system in the face of the existing uncertainty. Uncertainty in the form of registration error can be estimated by observing their effects on the projection equations that are used to place the graphics overtop of the physical world. Coelho, MacIntyre and Julier (Coelho, MacIntyre, & Julier, 2004) have modified an open source scene graph (OpenSceneGraph ("Open Scene Graph")) to support the specification of uncertainty at its transformation nodes. In his dissertation, Coelho showed how to determine a registration error estimate, using the uncertainty in the transformation nodes and demonstrated how to use the estimate though a series of simple examples (Coelho, 2005). These values were then used to estimate the registration error associated with the objects in the scene graph. Using this estimate, augmentations can be designed that adapt to changing registration error.

I believe that adaptive augmentations are the intermediate solution to the uncertainty problem. I already have one of the basic building blocks needed to create an adaptive augmentation, an estimate of the uncertainty, but how can I use it to create these augmentations? How should the system react to the changing error? I believe that the key to making adaptive augmentations work is the use of context. Visual context can be added to an augmentation to help the user understand the intent of the augmentation. However, the addition of visual context raises many more questions. What is the best way to display the augmentations? Which augmentation should be used in which situation? How should transitions between different augmentations be handled? Would different ways of displaying the data be more effective than others? How much augmented information is enough? Is there a limit to how much information is helpful? Can too much information become intrusive?

These questions are the basis for the work presented in this dissertation. While I cannot answer all of them, my goal is to prove that providing context is a useful tool for battling the effects of uncertainty. After establishing a theoretic justification for the use of graphical context, based on perceptual and cognitive psychology, this dissertation has two main components. First, I describe a framework for leveraging the intent of augmentations and semantic domain knowledge embedded in an AR system that should support the creation of *adaptive intent-based augmentations* that convey their intent unambiguously in the presence of changing registration error. I demonstrate the utility of this framework by implementing a series of example adaptive intent-based augmentations. The goal of this part of the dissertation is to demonstrate that such an approach is feasible in a realistic AR application.

The second part of this dissertation focuses on evaluating the core hypothesis that users can understand the intent of an augmentation in the presence of registration error if an appropriate amount of graphical context is added to it. I begin by evaluating the impact of registration error and how users react to it in an AR system without additional graphical context. I then provide context, in the form of graphical augmentations, in the same setting and evaluate its effectiveness. This study shows that adding context to the system can alleviate most of the problems caused by the registration error.

This first study raises a number of other questions, many of which I answer in a second study. Is *in-situ*, fully registered AR really the best approach for giving task-based instruction to users? By this I mean graphics overlaid directly on top of the target object. In many scenarios, adding graphics to the user's task space raises the risk of occluding important parts of the physical world, even when registration is perfect and extra graphical context is unnecessary. What if I designed a system in which the graphics were off-screen and fixed relative to the task space or the user? For example, the graphical instructions could be situated directly to the left of the object (accurately positioned and oriented), or in front and to the left of the user, just outside of their field of view? In such a scheme, they would merely have to turn their head to the left to see the graphical instructions. These graphical augmentations would contain the same types of context that I evaluated above. Could the users perform the same tasks as used in those evaluations just as easily, given the large registration error between the augmentation and the physical world? What if I only collected orientation information between the user's body and the target object and used it to position the augmentations to their side while ensuring that the orientation of the graphics off to the side was always the same with respect to the user's body position as the orientation of the physical target object with respect to the user's body position. Would this be more helpful than presenting the augmentation in a fixed orientation? Would this type of "orientation only" AR be just as helpful as a more traditional type?

This dissertation, therefore, will focus on demonstrating and evaluating contextual visualizations in realistic settings. In order to do that, I have designed an adaptive augmentation system and experimental setup that support the specific activities that I intend to test.

1.2 Thesis Statement

In Augmented Reality, registration error between the user's view of the graphics and the user's view of the physical world can create an ambiguous scene that is confusing to the user. Providing graphical context can increase a user's ability to understand the intent of misregistered augmentations.

1.3 Contributions

1. Introduce the notion of Intent-Based Augmentations.

In order for an Augmented Reality application to be useful in a real world setting, the user must understand the intent of each augmentation. I believe that intent-based augmentations are a potential approach for dealing with registration error in AR. Different graphical techniques can convey the same intent even in the presence of registration error if registration error can be estimated. These augmentations would be able to automatically change depending on the level of error in an AR system. In order to understand how to design intent based augmentations, I revisited the concept of communicative intent, introduced by Seligmann (Seligmann, 1993). She explored communicative intent deeply in the context of automated design of graphics presentations with the IBIS system, and adapted IBIS to support the interactive AR system KARMA (Feiner, MacIntyre, & Seligmann, 1993). In order to better understand how intent can be used in Augmented Reality, I have analyzed many of the existing AR and VR systems to see how they convey intent.

2. Establish a theoretical basis that supports the use of context in adaptive AR.

In order to build the prototypes for the AIBAS system, I needed to understand how to design an AR toolkit for adaptive augmentations. I wanted to go beyond my initial understanding of context; I needed to understand how people perceive scenes and objects. Therefore I examined cognitive and perceptual psychology literature to understand how people perceive shapes and spatial relationships. This survey provides the foundation for the various types of context that may be helpful in ambiguous scenes.

3. Introduce *adaptive visual context* as a technique for ameliorating the effects of registration error.

Knowing an estimate of the registration error allows the system to convey intent to the user in a possibly confusing scene by providing various amounts and types of context. I have implemented some of Seligmann's goals and style strategies and had the style strategies adapt to registration error by providing more or less visual context. I have shown, through several examples, that adaptive context is useful.

4. Demonstrate that users can function effectively in the presence of small registration errors when appropriate graphical context is added to the augmentation.

In order to prove that context is helpful in an AR system, I designed a simple Lego block placement task that required the users to place blocks under different conditions. This study observed how users reacted to various types of registration error in AR. It also showed how the use of context can help ameliorate the effects of registration error in an AR system.

5. Demonstrate the effectiveness of context in aiding a user in a task in which the graphics are situated outside the task area.

This study analyzed the use of context in both registered AR and a non-registered graphical Heads-Up Display. In some cases the graphics were always visible in the user's field of view, while in others, the graphics were situated outside of the user's field of view. This study showed that graphics do not have to be registered to be useful; context can help a user understand a scene even if the graphics do not align with the real world.

6. Introduce an experimental methodology that can be used for creating and running user studies in Augmented Reality.

User-based experimentation in Augmented Reality is an emerging field, so there are relatively few experiments described in the AR literature. This dissertation describes the design and implementation of two user studies that can serve as models for future AR study designs.

The remainder of this dissertation will begin with a summary of the background and related work in both augmented reality and cognitive psychology. I will then discuss the AIBAS system that I built to demonstrate the potential of graphical context, and on which the user studies that are described in this dissertation are based. Then I will discuss each of the two studies in detail, including the evaluations. Finally, I will conclude with a discussion of future work.

CHAPTER 2

RELATED WORK

2.1 Introduction

In this chapter, I discuss some background and work related to augmented reality systems and how they deal with registration error, as well as some work in cognitive psychology that provides a basis on which the augmentations for this dissertation were designed.

2.2 Registration Error

There has been significant work done on reducing registration error in AR systems (e.g., (Azuma & Bishop, 1994);(Holloway, 1997);(Hoff, 1998)), far too much to summarize here. Analyzing and estimating error bounds, especially in vision-based tracking systems, is not a new idea. Holloway's work is perhaps the best-known analysis of registration error; I use his terminology and framework. Hoff used error estimates as the basis for fusing multiple sensors; like him, I represent error estimates as probability distributions. My work is complementary to research aimed at reducing registration error; as long as there is registration error, the techniques described here will be useful.

AIBAS builds on OSGAR, a previous project in our group aimed at supporting adaptation to registration errors (MacIntyre, Coelho, & Julier, 2004). In OSGAR, MacIntyre et al. used estimates of the transformation errors in an AR system (such as those introduced by tracker measurement errors, as well as errors arising from measurement and calibration error) to estimate the registration error of points in a 3D world on a 2D display. They showed how to perform simple modifications to interesting regions of the display in an AR system, such as expanding and contracting the 2D convex hull of the projection of a virtual object to find the area of the screen the object *might* and *should* occupy, respectively. In this dissertation, I expand on the idea of using registration error estimates. In AIBAS, I use these estimates to guide the creation of intent-based augmentations, rather than focusing on simple graphical transformations as was previously done by MacIntyre et al.

Other researchers are also concerned with creating AR systems that work in the presence of imperfect tracking and registration errors. A common approach is to build the AR system assuming a worst-case error, especially in mobile AR systems that use GPS for tracking. For example, the Touring Machine uses textual labels as augmentations, which do not need to be accurately registered (Feiner, MacIntyre, Höllerer, & Webster, 1997). Julier and his colleagues tried to make their AR interface more understandable by minimizing the amount of unnecessary information presented to the user using a region-based information-filtering algorithm (Julier, Lanzagorta, Baillot, & Brown, 2000). Their system dynamically responds to changes in the environment and the user’s state, but does not explicitly take registration error into account. Andre and Cutler (Andre & Cutler, 1998) used rings to represent uncertainty in the location of an object: the size of the ring was dependent upon the level of uncertainty. This approach works well for individual objects with small amounts of error, but I wish to handle varying amounts of error with multiple objects. I also wish to handle a wider range of communicative goals that show location.

AIBAS was inspired by the IBIS and KARMA systems. IBIS is a knowledge-based system that generates graphics to explain the communicative intent of a scene. KARMA, an AR system based on IBIS, generates AR illustrations for maintenance tasks on a computer printer. Neither IBIS nor KARMA takes registration error into account. AIBAS is designed to support the graphics generation component of a system like KARMA, allowing its illustrations to dynamically adapt to changing registration errors.

2.3 User-Based Experimentation in Augmented Reality

User-based experimentation in Augmented Reality is an emerging field, so there are relatively few experiments described in the AR literature and even fewer that highly relate to this research.

Tang et al. compared the effectiveness of augmented instructions in an assembly task. (Tang, Owen, Biocca, & Mou, 2003) This user study showed that the use of AR in the form of computer assisted instruction projected on a head-mounted display can improve task performance and can relieve mental workload as compared to a printed manual and computer assisted instruction using a monitor-based display.

Livingston et al. conducted a user study to determine which display attributes, including drawing style and opacity, best express occlusion relationships among far-field objects. (Livingston et al., 2003) They found that response times for a task in which the users had to determine the location of a target were slower with a "wire" drawing style than for "fill" and "wire+fill" drawing styles. These later styles produced comparable response times. However, they found that subjects made the fewest errors with the "wire+fill" task. They speculated that this style was most effective because it combines occlusion properties by using the "fill" style with wireframe outlines, which pronounce the targets' shapes. While I am not explicitly concerned with occlusion in my studies, I am concerned about the most effective drawing style for representing the augmentations. This study provided insight when designing the augmentations.

2.4 Cognitive Psychology

Perception is the process by which a person takes in sensory input and interprets this input in a meaningful way. Scientists in the field of cognitive psychology have been studying this phenomenon for many years. This research is important to the field of AR because if I know how people interpret information about their environments, I can create more meaningful AR systems.

Some motivations for my approach come from the field of Gestalt psychology, which seeks to explain how humans perceive objects in terms of perceptual outcomes, rather than focusing on cognitive mechanisms (Maren & Ali, 1988). It defines different types of perceptual relationships that play a role in how a viewer structures the elements in a scene. The principle of proximity, or nearness, explains why people group things that are close to each other in physical space. The principle of similarity explains why people group similar objects together. The principle of good continuation explains why people group together objects whose contours form a continuous straight or curved line. The principle of closure explains why humans mentally fill in gaps in an object to see a complete figure. And the principle of common fate explains why elements that move together get grouped together. To summarize, these concepts are formed by the observation that people inherently make associations and references based on the scene as a whole. Therefore, I believe that if an AR system generates a well-structured collection of perceptual cues, viewers will perceive the intent correctly.

Recognition by components is a theory of object recognition that argues that when people view objects they divide them into simple geometric components, such as cylinders, cones and blocks, called geons. (Biederman, 1987) Biederman proposed thirty six of these primitives from which humans can quickly construct mental representations of a very large set of common objects. For instance, rather than seeing a flashlight as a complicated object, a person might break that flashlight up into one short, thick cylinder for the light portion, one longer, slender cylinder for the handle portion, and a flat rectangular block for the switch. He also showed that when people view incomplete drawings, they are still capable of identifying the objects if the intact portions of the picture include object vertices. Without the vertices, the person's ability to perceive the underlying geons is compromised. These observations helped in the design of the augmentations presented in the adaptive intent-based augmentations section of this dissertation.

Piaget and Inhelder first discovered that children learn to recognize surfaces and their outlines (Piaget & Inhelder, 1956). Rock (Rock, 1975) and Zusne (Zusne, 1970) found that the silhouette of an object is the determining factor for the recognition of an object. As above, these observations guided my designs. For example, I have concluded that drawing a fully opaque, photo-realistic representation of a physical object in the virtual world is not necessary for a person to recognize that object.

Biederman, Glass and Stacy (Biederman, Glass, & Stacy, 1973) and Palmer (Palmer, 1975) found that both accuracy and the length of time needed to recognize objects vary with the context provided in a real-world scene. Woods claimed that graphical representations such as shape, symbols, size, color and position are effective in information visualization because they are mentally economical (Woods, 1995). These observations show that providing well-designed context can help a person understand a scene.

Gooch and Willemsen found that humans can perceive depth at 66% of the intended distance in an immersive environment that renders objects with only feature objects (Gooch & Willemsen, 2002). Interrante, Fuchs and Pizer found that adding sparse opaque textures to transparent surfaces can help make an object's location in space more explicit (Interrante, Fuchs, & Pizer, 1995). They also found that ridge and valley lines carry geometrical and perceptually relevant information. Although I am not explicitly concerned with depth perception, I am interested in the best way to display augmentations that present the user with the most cues for making sense of an ambiguous scene.

The McGurk effect is an auditory illusion produced by a visual experience (McGurk & MacDonald, 1976). It shows that visual information is integrated into our perception of speech automatically and unconsciously. It shows that humans are multi-sensory in nature: we do not experience a visual world, an auditory world, a tactile world, etc. We experience one world through multiple senses. The information we perceive through hearing and the information we perceive through sight are inter-related. Although in this dissertation I am not tackling any of the senses other than sight, this effect does show that humans have the ability to make sense of irregularities in their environment by using all of their senses, and points to future work.

2.5 Communicative Intent

Many researchers have had a variety of communicative intents in the graphics for their systems, both in Virtual and Augmented Reality. Chapter 3 both introduces the concept of communicative intent and provides a thorough literature search to show that these concepts cover the space of envisioned uses of AR.

CHAPTER 3

AIBAS: ADAPTIVE INTENT-BASED AUGMENTATION SYSTEM

3.1 Introduction

The goal of AIBAS (an *Adaptive Intent-Based Augmentation System*) is to understand how the semantic knowledge of a scene can be leveraged to simplify the creation of AR applications that work well in real-world situations with “good enough” tracking and registration. In this chapter, I demonstrate how such knowledge can be used to reduce the impact of registration errors by supporting the programmer in creating augmentations that contain sufficient visual context for a user to understand the intent of the augmentation. My goal is to empower programmers by providing a conceptual framework, and the associated tools, to support the creation of augmentations that function in the presence of registration error.

I assume that the underlying system provides the programmer with a continuous estimate of registration error, using the techniques described in (MacIntyre, Coelho, & Julier, 2002). I also assume the application has knowledge of the domain (such as models of the important physical objects) and the communicative intent of the augmentations; these techniques are not intended to operate on arbitrary graphics in the absence of semantic knowledge.

3.2 Communicative Intent in AR

Communicative intent is the conceptual foundation of this research; some high-level notion of the semantics of each augmentation is necessary if the system is to adjust the graphical display to account for the current viewing context. As originally defined, intent is specified as a collection of goals that an augmentation is trying to accomplish. Style strategies describe the visual effects used to achieve each of these communicative goals.

Table 3.1 lists and defines the communicative goals that I am currently studying, most of which were borrowed from (Seligmann, 1993). These goals have been demonstrated to be applicable in AR domains. I provide examples of augmentations from existing AR systems for each of the goals listed (even though most of the system authors did not explicitly use the framework of communicative intent when designing their augmentations).

Table 3.1. Communicative Goals

Communicative Goal	Description of Goal	Examples from Existing AR Systems
Show	Introduce a new object to the user or to familiarize the user with an object. Requires that the representation of the object be visible and recognizable	Transparent surfaces, selective rendering ((Darken & Cevik, 1999); (Dinsmore, Langrana, Burdea, & Ladeji, 1997)) Transparent surfaces, depth info used to determine whether virtual object is occluded by real object ((Furmanski, Azuma, & Daily, 2002); (Kanbara, Okuma, Takemura, & Yokoya, 2000)) Inset windows ((Billinghurst, Bowskill, Dyer, & Morphett, 1998); (Darken & Cevik, 1999); (Johnson, Moher, Ohlsson, & Gillingham, 1999)) User defined/ interactive viewpoints ((Darken & Cevik, 1999); (Dinsmore, Langrana, Burdea, & Ladeji, 1997); (Moezzi, Katkere, Kuramura, & Jain, 1996); (Risch, May, Thomas, & Dowson, 1996)) Cutaway view ((Bajura, Fuchs, & Ohbuchi, 1992); (Furmanski, Azuma, & Daily, 2002); (State et al., 1996)) Superimposition with anatomy (Argotti, Davis, Outters, & Rolland, 2001) Superimposed X-ray images on body parts (Navab, Bani-Hashemi, & Mitschke, 1999)
Property	Show the specific properties of an object that may be used to describe it	Displays different brain material in different colors (Grimson et al., 1996)
State	Depict features of an object that show it is in a specific state	Uses arrows to show velocity data (Ogi & Hirose, 1996) Uses streamlines, isosurfaces, and cutting planes to show velocity vectors and density scalars around an aircraft carrier (Bryson, Johan, & Schlecht, 1997) Annotations vary based on a person’s distance from the user (Newman, Ingram, & Hopper, 2001)
Location	Show where an object is. Usually implies that the object be shown in a particular context so the user may better interpret the object’s location	Inset window ((Billinghurst, Bowskill, Dyer, & Morphett, 1998); (Darken & Cevik, 1999); (Johnson, Moher, Ohlsson, & Gillingham, 1999)) Shows where certain parts of the brain are located inside the head (Grimson et al., 1996) Shows internal anatomy superimposed on body ((Argotti, Davis, Outters, & Rolland, 2001); (Navab, Bani-Hashemi, & Mitschke, 1999)) Shows internal structures of a building contained in industrial drawings
Reference	Provide additional objects in the scene in order to provide a cohesive view	Labels objects with labels that do not interfere with other objects (Bell, Feiner, & Höllerer, 2001)
Change	Show how an object changes state and the differences between these states	Uses dotted lines to show suggested shots in a pool game (Starner et al., 1998)

Table 3.1. (continued)

Communicative Goal	Description of Goal	Examples from Existing AR Systems
Relative-location	Show a group of objects in a common context, and the relationship between these objects	Displays different parts of the brain inside the head, using color to distinguish them (Grimson et al., 1996) Displays where internal structures are located inside of a body ((Argotti, Davis, Outters, & Rolland, 2001); (Bajura, Fuchs, & Ohbuchi, 1992);(Dinsmore, Langrana, Burdea, & Ladeji, 1997); (Navab, Bani-Hashemi, & Mitschke, 1999)) Displays where internal structures of a building are located inside factory (Navab, Bascle, Appel, & Cubillo, 1999) Uses transparent walls to resolve depth ambiguity (Holloway, 1997)
Identify	Help the user figure out what they are looking at by positioning identifier objects over or near object	Labels objects ((Bell, Feiner, & Höllerer, 2001); (Newman, Ingram, & Hopper, 2001); (Simon & Berger, 2002)) Lines to show linkage (Risch, May, Thomas, & Dowson, 1996)
Action	Show the user how to perform an action in the real world that enables the object in the virtual world to reach a certain state	Uses arrows to show movement ((S. Feiner, MacIntyre, & Seligmann, 1993); (Reiners, Stricker, Klinker, & Muller, 1998)) Aids navigation with virtual signposts, a 2D map, compass arrows, or turning signals (Navab, Bani-Hashemi, & Mitschke, 1999) Uses virtual cylinder to guide a needle to the correct path ((Sauer et al., 2000); (Vogt, Khamene, Sauer, & Niemann, 2002))
Move	Show how an object is to be manipulated	Uses arrows to show movement (Feiner, MacIntyre, & Seligmann, 1993) Shows the steps in placing a virtual cube on a real object (Kutulakos & Vallino, 1996)
Enhancement	Show additional objects in the scene that may not have any direct effect on the action taking place in the scene	Many systems add additional virtual objects.

Each example augmentation uses one or more style strategies to achieve these goals. Table 3.2 lists and defines a collection of possible style strategies, also borrowed from Seligmann, that are used in this research. The table also gives examples of how these strategies have been used in AR prototypes and discusses the implications of registration error for each strategy. Notice that style strategies do not define the graphical techniques to be used, but instead specify a strategy for achieving a goal. This means that a similar collection of strategies may be used for purely virtual 3D images and for AR, even though the techniques for implementing the strategies may be different. For example, to *highlight* an object in a 3D scene, I might render it in a bright, unnatural color, or cause it to flash between multiple colors. However, in an AR system, the physical object is present, so it should not be rendered, as doing so may obscure the physical world. Rather, I might render its edges or silhouette in a bold color to allow most of the physical object to be seen.

Table 3.2. Style Strategies

Style Strategy	Description of Style Strategy	Examples from Existing AR Prototypes	Strategies in the Presence of Registration Errors
Include	Used to represent objects. If the object has subparts, they are typically included.	Includes augmentations of new pipes to allow for possible collision detection between existing structures (Navab, Bascle, Appel, & Cubillo, 1999)	Highlighting physical objects near the included virtual objects will reinforce their intended relationship with the physical world.
Visible	Used to ensure the visibility of an object. Use cutaway view to show hidden objects when "camera" is under user control (e.g., in head-tracked AR).	Transparent surfaces, selective rendering ((Darken & Cevik, 1999); (Dinsmore, Langrana, Burdea, & Ladeji, 1997); (Newman, Ingram, & Hopper, 2001)) Depth info used to determine whether virtual object is occluded by real object, use transparent surfaces ((Furmanski, Azuma, & Daily, 2002);(Kanbara, Okuma, Takemura, & Yokoya, 2000)) Inset window ((Billinghurst, Bowskill, Dyer, & Morphett, 1998); (Darken & Cevik, 1999); (Johnson, Moher, Ohlsson, & Gillingham, 1999)) User defined/interactive viewpoints ((Darken & Cevik, 1999); (Dinsmore, Langrana, Burdea, & Ladeji, 1997); (Moezzi, Katkere, Kuramura, & Jain, 1996); (Risch, May, Thomas, & Dowson, 1996)) Cutaway view ((Bajura, Fuchs, & Ohbuchi, 1992); (Furmanski, Azuma, & Daily, 2002); (State et al., 1996)) Shows internal structure of leg (Argotti, Davis, Outters, & Rolland, 2001) Shows internal structure of a body via X-ray images (Navab, Bani-Hashemi, & Mitschke, 1999)	Highlighting physical objects near the cutaway will reinforce the relationship between the cutaway (and thus the exposed object) and the physical world.
Find	Used to help the user locate a certain object.	Arrow points toward off-screen landmarks (Feiner, MacIntyre, Höllerer, & Webster, 1997) Annotations to locate a person or object (Newman, Ingram, & Hopper, 2001)	Target of find may or may not be visible due to registration error. Additional context or more general directions may disambiguate.
Label	Used to help identify objects.	Labels to point out objects that do not interfere with other objects ((Bell, Feiner, & Höllerer, 2001); (Newman, Ingram, & Hopper, 2001); (Simon & Berger, 2002)) Lines to show linkage (Risch, May, Thomas, & Dowson, 1996)	Labels should avoid obscuring all possible locations of objects (Bell, Feiner, & Höllerer, 2001). Target of lines may be ambiguous, so either point to unambiguous part of object, or highlight region object might occupy.
Recognizable	Used to show certain properties of an object so it is recognizable.	Displays different brain material in different colors (Grimson et al., 1996)	Highlight sufficient physical context to make identity of recognizable objects clear
Focus	Used to draw the user's attention to the object.	Highlights and labels have been used, as in other strategies.	Highlight sufficient physical context to make identity of focal objects clear
Subdue	Used to show object is not currently significant.	No examples of use. In video-mixed AR, could desaturate or blur object	Be careful not to subdue significant objects in video due to error
Visual Property	Used to render the object such that certain property values are shown.	Size of annotations denote a person's location from a user (Newman, Ingram, & Hopper, 2001)	Analogous issues to Include and Subdue.
Ghost	Used to show an object in a scene without fully occluding other objects.	Uses ghosting to show motions of different objects ((Feiner, MacIntyre, & Seligmann, 1993); (Sung, Yang, & Wohn, 1999)) Ghosted walls resolve depth ambiguity (Holloway, 1997)	Analogous issues to Include.

My approach to dealing with registration error is to use the current error estimates to modify the selection of the style strategies used to achieve a communicative goal. When there is a small-to-moderate amount of registration error, I include style strategies designed to help the user understand the relationship between the augmentation and the physical world.

Table 3.2 (continued)

Style Strategy	Description of Style Strategy	Examples from Existing AR Prototypes	Strategies in the Presence of Registration Errors
Highlight	Used to attract the user's attention to an object using distinctive visual cues.	Highlights icons resulting from a search (Risch, May, Thomas, & Dowson, 1996) Overlaid graphics in bright, distinguishable colors ((Feiner, MacIntyre, & Seligmann, 1993); (Grimson et al., 1996);(Klinker et al., 2001))	In the face of moderate error, highlights can be expanded to encompass the possible location of an object. (MacIntyre, Coelho, & Julier, 2002)
Context	Used to include other context objects in a scene or to generate at least one illustration-object that corresponds to an ancestor of the object and all its subparts.	Inset window ((Billinghurst, Bowskill, Dyer, & Morphett, 1998); (Darken & Cevik, 1999); (Johnson, Moher, Ohlsson, & Gillingham, 1999)) Shows interior of the brain relative to the skull (Grimson et al., 1996) Overlays interior structure of a leg (Argotti, Davis, Outters, & Rolland, 2001) Overlays X-ray image of body (Navab, Bani-Hashemi, & Mitschke, 1999)	Inset window can be used to show synthetic view of scene with all relevant objects. Context objects should maintain relationship with relevant parts of augmentation, despite error.
Meta-Object	Used to generate objects that do not exist in the real-world, but help solve communicative goals.	Uses virtual arrows ((Bryson, Johan, & Schlecht, 1997); (Feiner, MacIntyre, & Seligmann, 1993); (Klinker et al., 2001); (Ogi & Hirose, 1996); (Reiners, Stricker, Klinker, & Muller, 1998)) Uses dotted lines to show suggested shots in a pool game (Starner et al., 1998) Virtual markers to show a route taken by a user (Newman, Ingram, & Hopper, 2001) Virtual pipes drawn to show possible locations (Navab, Bascle, Appel, & Cubillo, 1999) Virtual cylinder to guide a needle ((Sauer et al., 2000); (Vogt, Khamene, Sauer, & Niemann, 2002))	Analogous issues to Include, to show relationship of meta-object to physical world.

3.3 Strategies for Visual Context

Many of the graphical objects used to implement the examples in section 3.4 are similar to those used in IBIS, KARMA and other 3D graphical explanation systems (e.g., labelled arrows, wire-frame outlines of objects, 2D inset windows). In this section, I will focus on the strategies that I have used to provide the user with sufficient context to understand the relationship between the augmentations and the physical world.

As mentioned in Chapter 1, registration requirements are not absolute: they depend on the domain, the specific context, and the communicative intent of the augmentation. Even for a particular system in a fixed domain, the requirements can change from moment to moment, based on the current augmentation and the physical context in which it occurs. I have designed two visualizations aimed at providing users with sufficient visual context to allow them to understand the intent of the augmentation in the presence of registration error. Both visualizations adapt to the current registration error by showing more detail as the error increases. It is important to note that the amount of registration error that one could tolerate in a system would be application specific as well as augmentation specific.

The KARMA examples in Chapter 1 illustrate the two major classes of context I wish to convey to the user. First, my system provides *general visual context* of an augmentation in the physical world, so that a user can understand (roughly) what the intended target of an augmentation is. For example, to provide the general context for the lever on the printer, I would ensure that the printer lid (which contains the lever) is recognizable. My current approach is to highlight features of the parent object, and show more feature detail as the registration error estimate increases (refer to section 3.3.1). In Figure 3.2(b) the corners of the computer are highlighted, making the structure of the computer and the location of the power button apparent. Since there is only one button on the right side of the front of the computer, this coarse visualization is sufficient, but the precise location of the button is hard to determine. However, this visualization would be insufficient if there were multiple possible targets of an augmentation, such as the ports on the back of the computer in Figure 3.3.

The second visualization is designed to address this problem by showing the *detailed visual relationships* between an augmentation and other nearby objects in the physical world. By rendering representations of a unique collection of nearby objects, a user can differentiate between the augmentation target and other parts of the physical world that are similar. Returning to the examples in Chapter 1, if there were multiple levers on the printer, and the augmentation target is below a large button, highlighting the levers and the button would reinforce their relationship and allow the user to select the correct lever. My current approach is to highlight a unique collection of objects near the target of the augmentation in the physical world whose highlights are visible on the display, highlighting more objects as the registration error increases (refer to section 3.3.2). This visualization allows the user to easily distinguish between the various ports on the back of the computer in Figure 3.3 by displaying nearby details.

The usefulness of the additional visual context relies on the graphical objects being visible to the user. When an insufficient amount of the augmentation is visible to the user, the system uses an inset window to present the augmentation to the user. The inset window contains a complete 3D rendering of the physical objects, with the augmentation overlaid on it.

Unlike previous systems such as IBIS, the design of each augmentation (such as choosing to use an inset window or not) reacts to changing registration error estimates. Therefore, even if the augmentation is visible on the display, when the registration error is large enough, the inset window will be displayed. This is necessary because with a large registration error, there is no guarantee that the augmentation is near the corresponding physical objects, so the physical objects may not be visible even if the augmentation is.

3.3.1 The General Visual Context Visualization Strategy

This visualization draws an increasingly detailed set of edge features of the target object of the augmentation, to give the user a frame of reference to situate the augmentation relative to the physical object, without obscuring the object itself.

The implementation requires the programmer to define a collection of *feature points* for an object, and the edges that connect to each point. For example, in the examples in Figure 3.4, the eight corners of the computer are defined as feature points, with three edges connected to each corner. When the registration error is small, only a small part of each edge is drawn (e.g., Figure 3.4.b). As the registration error increases, the system draws more of each edge to make the structure of the target object clearer, until the complete edges are drawn (e.g., Figures 3.4.b and 3.4.c).

3.3.2 The Detailed Visual Relationships Visualization Strategy

This visualization highlights a progressively larger set of objects “near” the target of the augmentation, to help the user disambiguate the target of an augmentation from other similar objects.

The current implementation requires the programmer to define a collection of *feature objects* for an augmentation. Each object is given a priority level corresponding to the order in which they should be added to the scene. The priorities should be based on the uniqueness of the object and when this object should appear. For example, for small registration errors, the augmentation and feature objects will be very close to their actual physical locations, so the programmer may wish to give higher priority to objects that are farther away from the target of the augmentation to avoid obscuring it. As error increases, objects closer to the augmentation target can be used with less likelihood of them obscuring the target of the augmentation. The feature objects are stored in a priority queue, and as registration error increases, features are removed from the queue and added to the scene according to their priority.

The implementation has intentional hysteresis. In order to maintain temporal coherence, it is important that augmentations do not flicker in and out of a scene. Therefore, once a feature is drawn, it will remain in the scene until registration improves significantly.

3.3.3 Using Inset Windows to Reduce Ambiguity

As discussed above, an inset window is used to show the augmentation when the target is not visible, or when the registration error is sufficiently large that the augmentation and the target may not be visible at the same time. Inset windows are also used in other situations, as illustrated in Figure 3.4. In this example, the scene contains a virtual object, the ghosted representation of the CD tray, which is being used to show the change that occurs when the CD button is pressed. In this case, when there is more than a very small amount of registration error, the inset window is used to show this change and the virtual CD tray is removed from the augmentation. As context objects are added to the scene, I want to limit the number of objects in the augmentation to reduce the possible ambiguity if they happen to appear similar to objects in the physical world.

As with the context objects in section 3.3.2, I do not allow the inset window to flicker rapidly in and out of the scene as the augmentation moves around. Instead, it slowly fades into and out of the scene as necessary.

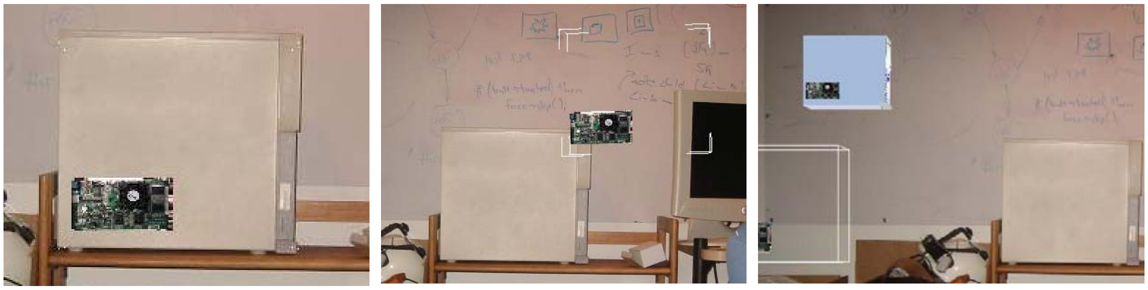
3.4 Motivating Examples

In this section, I give four examples of how context visualizations can be used. Each example implements a specific communicative goal for a hypothetical set of maintenance tasks on a computer, and represents a broad class of augmentations common in AR systems. In each example, I first show the augmentation with no registration error (part (a)), then show it with small-to-moderate error (part (b)), and finally show the augmentation with a larger error (part (c)). In each case, the transition between these augmentations is handled automatically by the system, and is based on both the amount of registration error and the visibility of the target of the augmentation. In each example, the augmentation is displayed when the error is very large (which typically appears far from the actual computer in the scene) to show the reader the degree of registration error; however, in a real system, the augmentation would be disabled when the error is this large.

3.4.1 Implementation

The version of the AIBAS system described in this chapter was implemented in Java and Java3D on a Sun Ultra 60 workstation. The core part of the system (that computes which features are visible, activates and displays the inset window, etc.) was implemented as a library that was then used to create the four example augmentations shown in Figures 3.1 to 3.4. This system has been re-implemented in C++, using the OpenSceneGraph graphics library in order to conduct the user studies.

The illustrations in this chapter were not rendered on an HMD using a live tracking system. Rather, to facilitate experimentation, I used a static image background and received position reports from a simulated tracker that lets me simulate error using a 2D graphical interface. The simulated tracker takes a single fixed location, adjusts it based on the error, and reports it to the test programs. The thresholds at which the augmentation changes are programmer defined. In Figures 3.1 to 3.4, I have zoomed in on specific areas of the scene in order to show clear views of the context strategies being applied; the user is not moving.



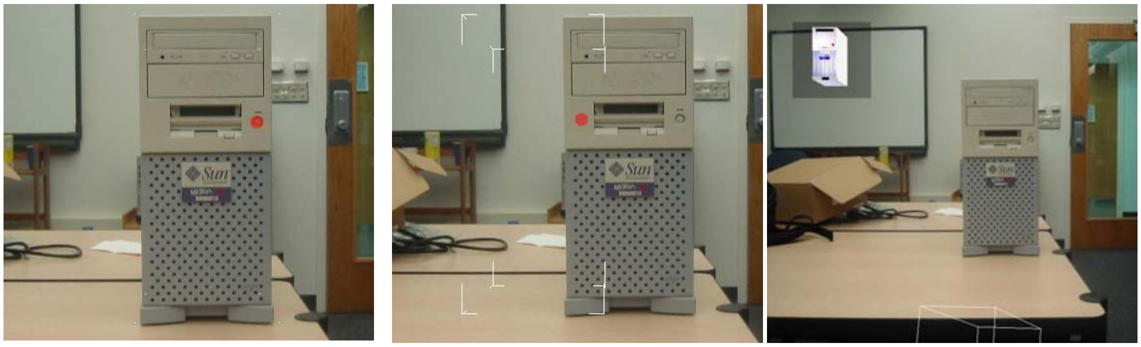
(a) (b) (c)

Figure 3.1 Augment a Hidden Object. (a) Perfect registration. Shows the computer graphics card located inside of the computer. A cutaway view is used to make the graphics card visible. (b) Moderate registration error. The edges of the computer are used to show the relative location of the graphics card within the computer. (c) Significant registration error. An inset window is drawn to show the intended location of the augmentation. (The augmentation is shown for illustrative purposes only; it would normally be removed at this point).

The cutaway view in Figure 3.1 is implemented by cutting a rectangular hole in a simple model of the computer, in real time, to create an exterior model with a cutout. By controlling the rendering order, I can render the exterior model into the z-buffer, followed by the interior model, so that the interior shows through the hole without obscuring the video image of the real computer. In the future, one could imagine creating a more stylized cutout border using a general CSG package.

3.4.2 Augment a Hidden Object

In this example, the goal is to show the graphics card located inside a workstation. The idea of using AR to give a user “X-ray” vision is one of the goals of many AR system prototypes.



(a) (b) (c)

Figure 3.2 Augment a Unique Visible Object. (a) Perfect registration. The power button on the front of the computer is highlighted. The color red is used to draw focus to the power button. (b) Moderate registration error. The edges of the computer are used to show the relative location of the power button on the front of the computer. (c) Significant registration error. An inset window is drawn to show the intended location of the augmentation. (The augmentation is shown for illustrative purposes only; it would normally be removed at this point).

(a) (b) (c)

Figure 3.3 Augment an Ambiguous Visible Object. (a) Perfect registration. Shows a particular port on the back of the computer being highlighted. The color red is used to draw focus to the port. (b) Moderate registration error. The edges of the computer and ghosting are used to show where the ports are located on the back of the computer, and nearby features (other ports) are drawn to clarify which port is of interest. (c) Significant registration error. An inset window is drawn to show the intended location of the augmentation. (The augmentation is shown for illustrative purposes only; it would normally be removed at this point).

When registration is perfect, I make the graphics card visible by using a cutaway view through the side of the case (Figure 3.1(a)). When registration error is small-to-moderate, the computer case is used as the basis for the *general visual context* visualization, causing the corners of the computer to be drawn (Figure 3.1(b)). Since the user cannot see the card, drawing additional context near the card provides no benefit. When registration error is large, the card is shown using an inset window that renders a cutaway view of the graphics card at the correct position on a 3D model of the computer (Figure 3.1(c)).

3.4.3 Augment a Unique Visible Object

In this example, the goal is to show the location of the power button on the front face of a workstation. Pointing at, highlighting and otherwise augmenting visible objects is a common goal in AR system prototypes. As is often the case, the object is unique. There are no other buttons on the computer, so there is no confusion as to which button I am trying to highlight if registration is not perfect.

When registration is perfect, the power button is highlighted by tinting it red to draw the user's focus to it (Figure 3.2(a)). When registration error is small-to-moderate, the computer case is used as the basis for the *general visual context* visualization, causing the corners of the computer to be drawn (Figure 3.2(b)). Because of the simplicity of the front of the workstation, there is no need to draw any additional features in the scene. When the error is large or the augmentation is off screen, an inset window is used to make the highlight of the button visible over a 3D model of the computer (Figure 3.2(c)).

3.4.4 Augment an Ambiguous Visible Object

In this example, the goal is to visualize the location of one of the serial ports on the back of the workstation. There are many ports and plug-ins in the back that could be confused for the intended serial port if the augmentation is misregistered. Augmenting ambiguous objects, such as parts of a machine, is also common in AR systems.

When registration is perfect, the port is highlighted by tinting it red to direct a user's focus to it (Figure 3.3(a)). When registration error is small-to-moderate, I add general context, as above, and apply the *detailed visual relationships* visualization to the visible objects around the port to show the relationship between the intended port and those other objects on the back of the computer. Each of these object features is highlighted by rendering its silhouette in black. As error gets worse, more features are added (Figures

3.3(b) and 3.3(c)). As above, when the augmentation is no longer in the field of view, or the error is large, an inset window is used to show the location of the port on a 3D model of the computer.

In this example, I also add a ghost of the computer as part of the general visual context visualization. This ghost becomes more opaque as the error increases, although it remains very transparent. (While I am not yet sure if this added information is necessary, I show it here because it was a common suggestion given to me when I demonstrated the system to visitors to our laboratory.) One possible avenue of future research is to determine experimentally if the ghost helps, hinders or does not affect a user's ability to understand the augmentation.

3.4.5 Augment a Scene with Virtual Objects

In this example, the goals are to visualize the action of pushing the CD tray button to open the tray, and the movement of the tray that results from this action. The button is beside a similar button on the CD drive. Additional objects are added to the scene to accomplish these goals: a labelled arrow, a label and leader line to the button, and a 3D model of the CD tray opening. Many AR systems include obviously synthetic objects (like labels and arrows) and models of real objects that have a specific relationship to the world.

A synthetic red arrow labelled “push” is included to show the action to take (push the button), and the button is highlighted with a red silhouette. Red is used to draw the user’s attention to the CD tray button. Another synthetic object, in this case a label with a leader line identifying the button, is included for clarity. With perfect registration, a ghosted CD tray is included in the scene to show the result of pushing the button (e.g., the tray opening and closing in Figure 3.4(a)). When registration error is small-to-moderate, I add general context as above and add object features (the neighboring button and the CD tray door) to show the detailed visual context around the button (Figures 3.4(b) and 3.4(c)), and show two different states of the visualization with slightly more error in Figure 3.4(c).

Unlike previous examples, when the error is small-to-moderate the virtual CD tray is replaced with an inset window containing a 3D model of the computer showing the tray opening and closing. The reason for this is twofold. First, since the virtual CD tray does

(a) (b) (c)

Figure 3.4 Augment a Scene with Virtual Objects. (a) Perfect registration. The CD tray button on the front of the computer is highlighted, an animated CD tray opens and closes to show what happens when the button is pushed, an arrow points to the CD tray button telling the user to “push,” and a label identifies the CD tray button. The color red is used for the outline and the arrow to draw focus to the CD tray button. (b) Small registration error. The edges of the computer are used to show the relative location of the CD tray button on the front of the computer and a feature (an outline of another button) is drawn in order to give context. The CD tray animation is moved to an inset window so it does not interfere with the other augmentations or the user’s perception of the context objects. (The CD tray in the inset is closed.) (c) Moderate registration error. A second feature (the CD tray door) is added to the context. (The CD tray in the inset is open.)

not correspond to any real object, it may be confused with the general and detailed visual context objects that have been added to the scene. Second, in this case, the CD tray model blocks one of the two feature objects being used by the context strategy, rendering it useless. Finally, when registration error is large, the synthetic objects and the highlight are moved to the inset window (not shown).

3.5 Discussion

In this chapter I have demonstrated the potential of context in AR. While the example maintenance system discussed in this chapter is not real, the rendering system is. It changes the augmentations, providing different amounts and types of visual context in real time as the registration error changes. However, the addition of this visual context raises many more questions about the proper design of an AR toolkit that can be used to battle the effects of registration error. What is the best way to display the augmentations? Which augmentation should be used in which situation? How should transitions between different augmentations be handled? Would different ways of displaying the data be more effective than others? How much augmented information is enough? Is there a limit to how much information is helpful? Can too much information become intrusive? There are many possible designs, but they are likely to be application and content dependent.

In order to begin to answer even some of these questions, I first need to understand more about the effects of registration error and visual context on people submerged in an AR environment. Thus, rather than pursue a general toolkit further, I turn to validating the basic premise on which this work is based, namely that people can understand the intent of an augmentation in the presence of registration error if context is provided.

CHAPTER 4

USER STUDY 1: EVALUATING THE EFFECTS OF GRAPHICAL CONTEXT

I believe that one of the reasons that Augmented Reality has not been widely used is because focus has been placed on perfectly registering the graphics on the physical world. However, this is impractical for many reasons, ranging from expense to a lack of precise trackers in mobile situations. I believe that AR can actually be designed to work in this situation using augmentations that adapt to the amount of registration error in the AR system. In Chapter 3, I discussed the AIBAS system, an adaptive intent-based augmentation system designed to use the communicative intent (Seligmann & Feiner, 1991) of an augmentation to simplify the creation of AR applications that work in real-world situations with "good enough" tracking (Robertson & MacIntyre, 2003). My goal was to empower programmers by providing them with a framework to create augmentations that function in the presence of registration error. Our group has also modified an open source scene graph (OpenSceneGraph) to support the specification of uncertainty at its transformation nodes (MacIntyre, Coelho, & Julier, 2004). These values can then be used to estimate the registration error associated with the objects in the scene graph. Using this estimate, augmentations can be designed that adapt to changing registration error.

As discussed in Chapter 3, I believe that the key to making adaptive augmentations work is the use of context. In particular, visual context can be added to an augmentation to help the user understand the intent of the augmentation. In this chapter, I want to focus on evaluating the effectiveness of adding graphical context to an AR environment.

The goal of the study described in this chapter is to show that providing visual context is indeed a useful tool in battling the effects of uncertainty. I will begin by evaluating two different classes of registration error and how users function when these errors are present in an AR system. I will then provide context, in the form of additional graphical augmentations, in the same setting and evaluate its effectiveness. This study will show that adding context to a system can alleviate some of the problems caused by registration error.

4.1 Theory and Hypotheses

The user study presented in this section was designed to evaluate two broad classes of registration error that could exist in an augmentation system. Adding in the case where there is no error, three different error cases are used in this experiment: no error, fixed error, and random error.

No error: When there is no visible misalignment between the graphics and the world, I can say there is no error. For my purposes, however, achieving absolutely no registration error in an AR system is impossible, so I consider *no error* to actually be equivalent to negligible error. In the case of the experimental setup, if the amount of registration error is less than half of the size of one of the Lego pegs on the base plate, there is no question as to where the block should be placed, and I consider this to represent no error. From here on I will also refer to the no error case as perfect registration.

Fixed translation error: When the error consistently manifests itself in the same direction and offset, I call this fixed error. For example, if the offset is always up and to the right 2 Lego pegs, this is considered a fixed translation error.

Random translation error: When both the direction and magnitude of the error are completely unpredictable, I consider this to be random error.

Given these three classes of error, there are six conditions: each of the three errors in a context-free environment and each in an environment where some visual context is provided. I intentionally do not include orientation errors in this study because comparing the results when there are both orientation and translation errors would be difficult. In addition, the error presented in this study is parallel to the plane of the Lego base plate because without stereo vision, other errors would be unfairly difficult.

4.1.1 Hypotheses

When exposed to different types of error in a scene in which no context is provided, there will be a different user response for each type of error. Therefore, I predict:

H1) When exposed to a fixed error, users will gradually learn how to compensate for the error; however, when exposed to random error, the task will become a guessing game as to where the block should actually be placed.

If context has the effect of providing useful clues as to the relationship between the physical and virtual worlds, placement tasks should be able to be performed with fewer errors; however, the cognitive processing of the context information might increase the trial times. Therefore, I predict:

H2) When context is added to a scene, whether fixed or random error is present, the time per trial will increase, but the total amount of errors will decrease.

When there is no error in an augmented system, the user does not need additional context to perform a placement task correctly. Therefore, I predict:

H3) When there is no registration error associated with the system, adding context neither increases nor decreases the number of errors.

4.2 Methodology

A within-subjects experiment was conducted. There were two independent variables, the type of error presented (none, fixed, random) and the amount of context presented (no context, some context.) The dependent variables include time to complete each task, the number or errors, and perceived mental workload.

4.2.1 Participants

Twenty six subjects were run in this study. Participants were solicited via email as well as student volunteers. The participant pool consisted of 26 subjects, 14 male and 12 female. The ages of the participants ranged from 19 to 56. If the subjects were not Georgia Tech employees, they were compensated with $5/half hour rounded to the nearest half hour. If they were Georgia Tech employees, they were compensated with $5/half hour rounded to the nearest half hour paid in either Target or Starbucks gift cards.

4.2.2 The Setup

Figure 4.1 shows pictures of the experiment setup used in this experiment. The subjects stood next to the desk, shown in Figure 4.1(b), on which a Lego base plate was located in a fixed position relative to fiducial markers that were hung on the wall in front of them. They wore the head-mounted display, shown in Figure 4.1(a) that contained an InterSense IS-1200 tracker, a 60 frames-per-second Point Grey Flea camera, and a Sony Glasstron video see-through optical display. The camera is mounted above a right angle prism, moving the optical center of projection of the camera closer to the subject's eyes than would otherwise be possible, with the intent of reducing the parallax offset of the video-mixed head-worn display.

(a)

(b)

Figure 4.1. The Setup

4.2.3 Session Information

Introduction to the study: When the participants arrived, they were asked to read and complete the consent form provided. They were also asked to fill out the introductory questionnaire, located in Appendix A, to provide some background information, including age, experience in AR systems, video game experience, how well they understood the concept of registration error in AR, etc. They were then asked to complete two tasks: an Edinburgh handedness test (Oldfield, 1971) and the Spatial Learning Ability Test (Embretson, 1997). The handedness test was used to ensure that they used their dominant hand to complete the experiment, as well as to see if handedness played any part in the participant's success. The spatial abilities test was given to evaluate the relationship between spatial abilities and successful task completion.

Training: They were then asked to read the registration error training document located in Appendix A. After reading the error training document, they were once again asked about how well they understood the concept of registration error in AR to see if the error training document had improved their understanding. The procedure for each block placement was then demonstrated to the participants. If they did not have any further questions, the participants were walked through a training exercise to familiarize them with wearing a HMD, how to correctly perform the block placement task, and how to ensure that they maintain proper tracking throughout their trials. They were reminded that they would be evaluated based on the amount of time that it takes them to place each block as well as the number of errors they make while placing a block; therefore, it was important for them to work as quickly and as accurately as possible.

As part of their training exercise, they were asked to locate some graphics that were drawn on their screen to ensure that the head-mounted display was properly aligned with their field of vision. They were asked to look for a greenish-black virtual circle drawn around the camera mounted directly in front of them. They were instructed that this circle would always be drawn around the camera if the tracker was working correctly. If for some reason the tracker stopped working, causing the graphics to disappear or look weird, they were instructed to look at the camera mounted on the wall directly in from of them. If the tracker was working, they would see a virtual greenish-black circle around the camera. If the circle was not there, they were instructed to wait a few seconds for the tracker to begin working again. They were also told to look at the camera on the wall in front of them between each block placement to confirm that the virtual circle was around the camera, ensuring that the tracker was working.

They were then instructed how to place three blocks using the correct procedure in the presence of the blue context blocks. After completing the three context block placements, the blue context blocks were removed and they were asked to place three blocks when no context was provided to gain experience in the no-context cases. This completed their training on block placement.

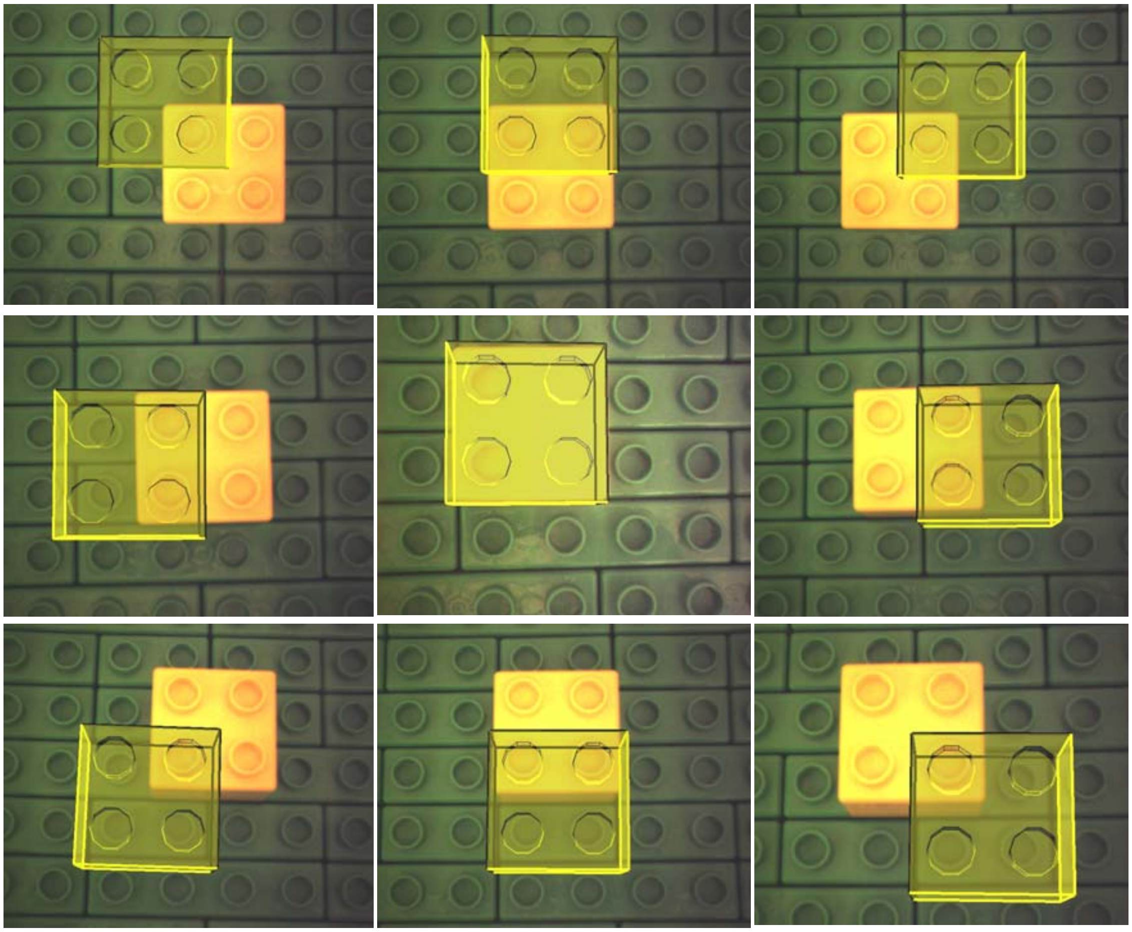


Figure 4.2. The nine possible locations for block placement. Error is on the plane of the Lego base plate

While still wearing the HMD, the participants were reminded of the possible target locations of the physical block. They were shown a yellow virtual block and were reminded that the virtual block may indicate a certain location in which to place the block, but that might not actually be the correct location to place the block because of registration error. They were then shown the nine possible target locations of that physical block given the virtual block's location on the Lego base plate (as shown in Figure 4.2).

4.2.4 The Placement Task

The task consisted of the following: picking up the yellow block, pushing a button to start the trial, placing the block, and pushing the same button to end the trial. After each trial, the subject was asked how confident they were with the block placement. The following 5-point Likert scale was used:

1 – I think the block is in the wrong place.

2 – I think the block might be in the wrong place.

3 – I do not know.

4 – I think the block might be in the correct place.

5 – I think the block is in the correct place.

If the block was indeed placed correctly, the subject was verbally informed as such, they removed the block from the base plate and advanced to placing the block in the next location. If the block was placed incorrectly, the subject was informed as such, and was instructed to attempt to place the block in the correct location again. There were no cues given as to the nature of the error. They were only informed that they had placed the block incorrectly. The steps repeated until the block was correctly placed. After all of the trials were completed, the subject answered the post block survey questionnaire, located in Appendix A, about their experience, including the NASA TLX rating (Hart & Staveland, 1988).

While this study can be considered a follow-up study to the study done by Tang et al. to compare the effectiveness of augmented instructions in an assembly task, I have chosen to have each of the tasks be individual block placements rather than one large building task. (Tang, Owen, Biocca, & Mou, 2003) I designed the experiment this way because I did not want the errors to compound as they would have if they were completing a building task. An error made in one trial does not affect the next trial as it does in Tang et al.'s experiment.

<u>Trials:</u> As mentioned above, the only variables in this task were error and context; therefore, for this task the subject was only asked to pick up a yellow 2x2 Lego block. After picking up the block, the subject was instructed to push a button to start the trial. When the button was pushed, an augmentation appeared on the subject's head-mounted display that showed the intended location of the block. The subject was instructed to place the block in the location specified on their HMD screen. After placing the block, the subject pushed the button again to end the trial. The subject was asked to keep attempting to place the block until the block was placed correctly. The subject was asked to correctly place 18 blocks per trial. If at any point in a block placement, the subject wanted to give up and move on to the next block, they were able to do so. And if they instead wanted to give up on the trial altogether, that option was provided as well.

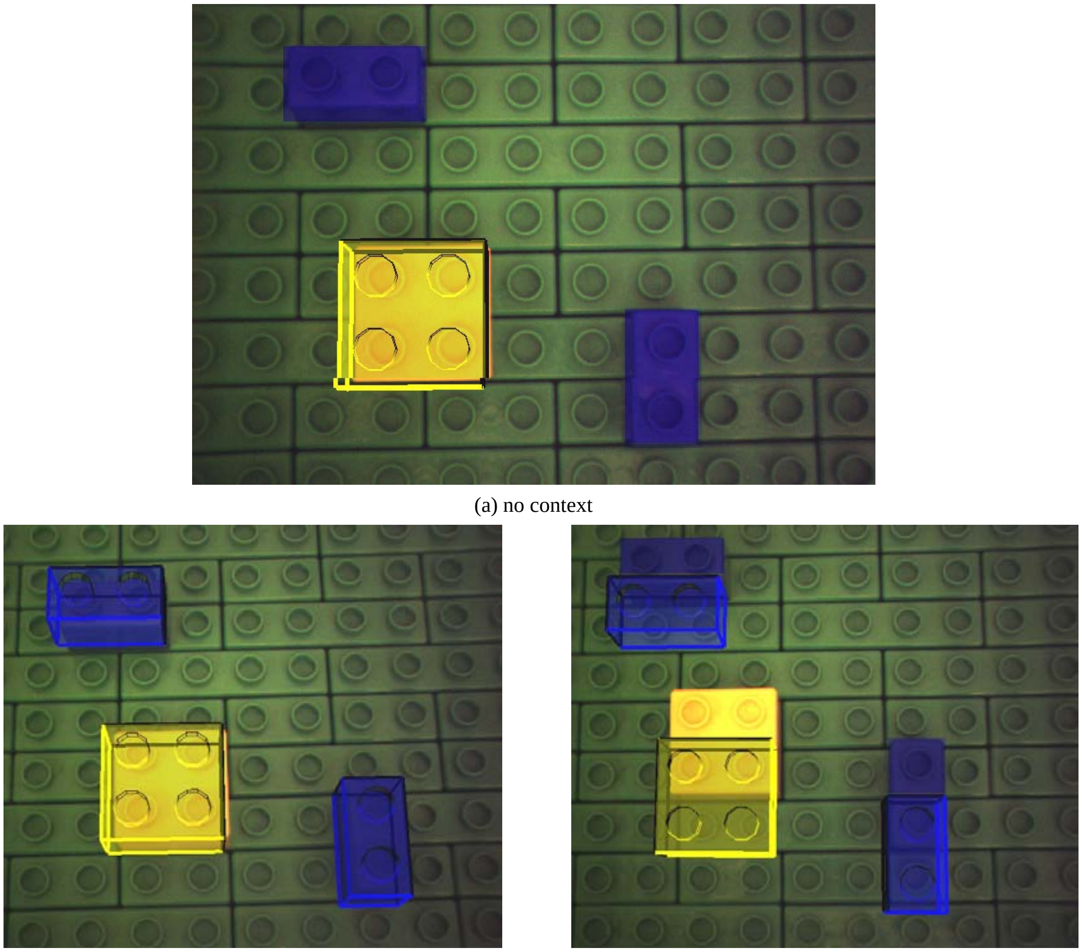
In the initial design of this study, there were a total of six blocks of trials: no error and no context, fixed error and no context, random error and no context, no error with context, fixed error with context, and random error with context. Whether there was no context or some context present in the block of trials, the following are descriptions of the types of error tested:

- No error: The subjects were presented with 18 targets.
- Fixed error: The subjects were presented with 18 targets that were offset by a fixed error. For a given amount of error, there are nine possible locations of placement for each block, as shown in Figure 4.2. Twenty-six subjects were run through this experiment and each subject was exposed to a different offset; therefore, each of the nine offsets were tested three times, with one (the perfectly aligned case shown in the middle of Figure 4.2) only tested twice. For the

purposes of this study, the magnitude of the error was set at 1 Lego peg and the error was in the plane of the Lego base plate.

- Random error: The subjects were presented with 18 targets, each of which was offset by a different random error. A blocked random design was used, so that the subjects were exposed to the 9 different offsets shown in Figure 4.2 in a random order and then again exposed to the same 9 offsets in a different random order. Each subject was presented a different random ordering of the offsets. Again, for the purposes of this study, the magnitude of the error was set at 1 Lego peg and the error was in the plane of the Lego base plate.

In half of the experimental trials the subjects participated in, some virtual context was displayed on the head mounted display. For the purposes of this study, the context took the form of two virtual blue Lego blocks that represented two physical blue Lego blocks that existed on the Lego base plate. Figure 4.3 shows the context that was provided in some trials. Figure 4.3(a) shows the physical blue context blocks. Figure 4.3(b) shows both the physical blue blocks and the virtual blue context blocks that were provided on the head-mounted display when there was no registration error in the system. Figure 4.3(c) shows both the physical blue blocks and the virtual blue context blocks that were provided on the head-mounted display; however, in this case, there is registration error in the system causing the virtual world and the physical world to be misaligned.



(a) no context

(b) context

(c) context with error

Figure 4.3. Context blocks

4.2.5 Data Recorded

Several types of data were recorded during the experiment in addition to the questionnaires. First, trial data including block data (color, size), how many times the subject attempted to place each block, the time to complete each block placement, and the tracker data for each trial was recorded. Second, video data was collected including a view of what the subject was seeing, a view of the subject from above to show where the subject's head was pointing, and a frontal and side view of the Lego base plate to see the

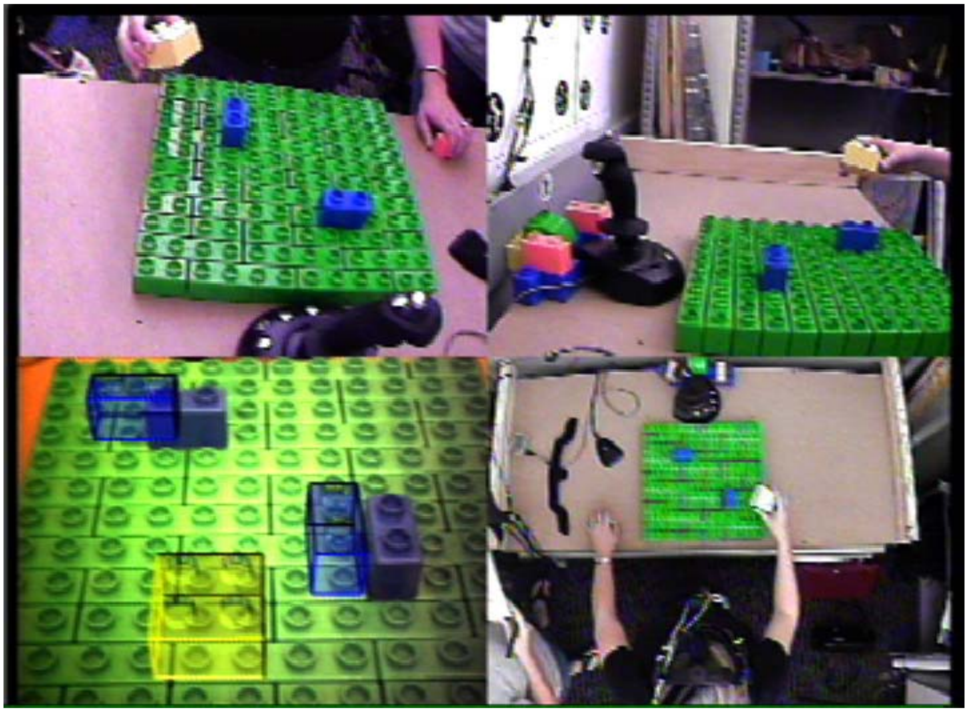


Figure 4.4. The quad view of video data collected

subject's hands and to see how and where they placed the block. Figure 4.4 shows the quad view recordings of the various video data that was collected.

4.3 The Pilot Study

There were a total of six blocks of trials for this study: no error and no context, fixed error and no context, random error and no context, no error with context, fixed error with context, and random error with context. Half of the participants were presented with the no context trials first and the other half were presented with the context included trials first. In order to eliminate any order biasing within each of the context trials, a 3x3 Latin Square was used to determine the order of presentation of the three types of error.

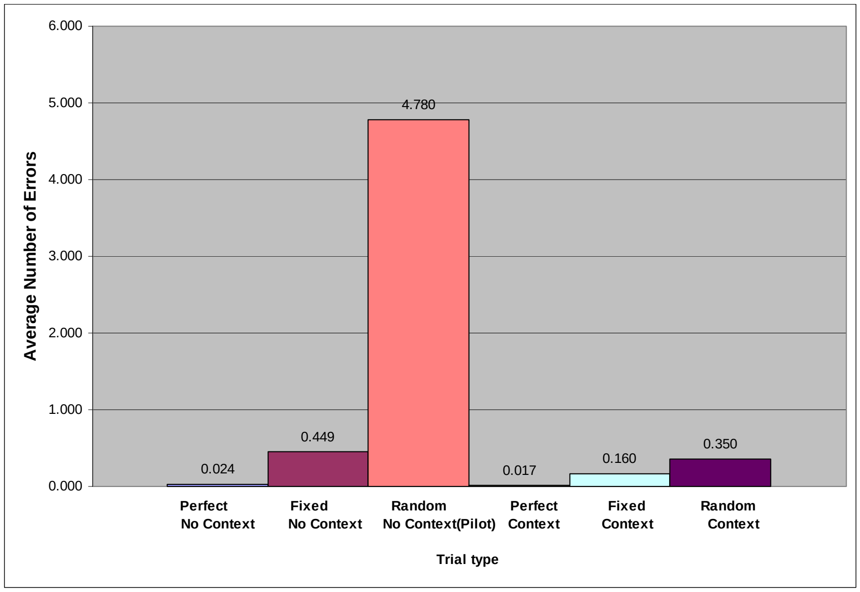
After running the pilot study, I found that, as expected, the subjects were guessing as to where to place the blocks in the random error and no context case. I found that most of the subjects adopted some sort of strategy for placing the blocks in this trial. Some tried each of the possible locations in a clockwise fashion and some in a counter-clockwise fashion. Others followed the placements using rows and columns. Regardless of their method, I found that the use of these strategic approaches produced an average of 4.780 errors for the 9 possible block placement locations, which is close to what you would expect (4.5 errors) with random placement. More seriously, these trials took some subjects a significant amount of time and were very tiring. Therefore in the full study, I elected to dismiss the random error and no context case.

4.4 The Full Study

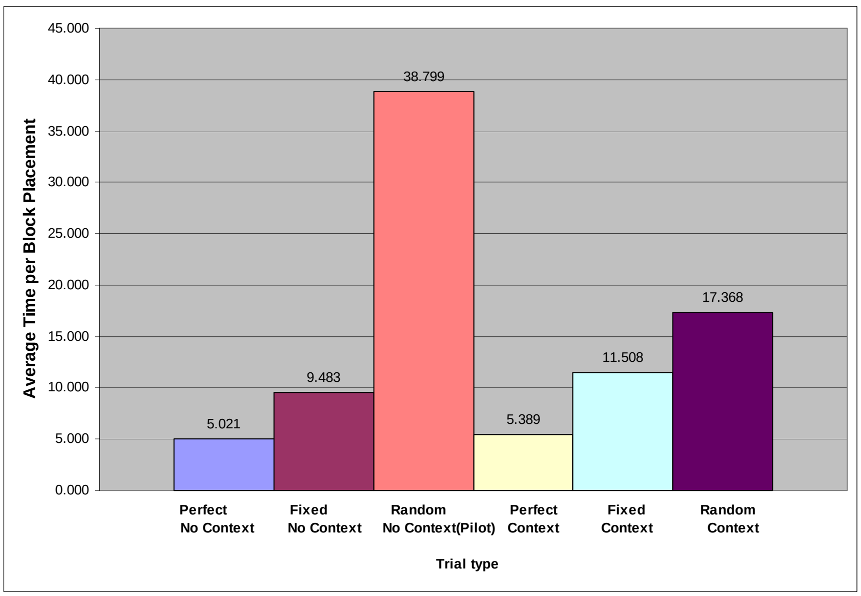
By eliminating the random error and no context case, the full study was left with 5 blocks of trials. A 5x5 Latin square design was used to determine the order of presentation of the remaining five cases.

4.5 Results

As previously stated, this was a within-subjects experiment, so each subject was asked to complete all of the blocks of trials. An alpha level of 0.05 was used for all statistical tests. In the graphs provided in this section, I have included the random no context case data that was evaluated in the pilot study, but discarded from the main study, to illustrate the vast difference between this case and the other five cases.



(a)



(b)

Figure 4.5. Average errors and time per block placement

4.5.1 Descriptive Statistics

Figure 4.5 illustrates the average number of errors per block placement and the average time per block placement in each of the six conditions in this study. Figure 4.5(a) shows that the perfect registration cases produce the least amount of error, while the random error cases produce the largest amounts of errors. It also shows that adding context to any of the three error cases reduces the amount of errors made, even in the case of no error, or negligible registration error.

Figure 4.5(b) shows that the perfect registration cases have a better performance rate in terms of time per block placement and the random cases have the longest time per block placement. Figure 4.5 also shows that while the blocks of trials with context produce a smaller amount of error as opposed to their no context counterparts, the amount of time per block placement for both perfect and static registration when context is provided actually increases. I attribute this occurrence to the fact that the subjects have to take the time to mentally process the context before they can place the block, whereas in the no context cases, this mental process does not exist.

4.5.2 Correlations

While analyzing the data I collected, I discovered several interesting relationships, some of which I expected to find and some of which I looked at only after observing the subjects complete the Lego block placement tasks.

4.5.2.1 Spatial abilities

I found some significant relationships between spatial abilities and time per block placement and number of errors made. I found significant negative correlations between block placement times for the perfect no context ($r = -0.619$, $p = 0.001$), static no context ($r = 0.-579$, $p = 0.002$), static with context ($r = -0.446$, $p = 0.22$) and random with context cases ($r = -0.650$, $p < 0.001$). These results imply that people with higher spatial abilities can complete these tasks more quickly. It also suggests that high spatial abilities were not needed in order to complete a task in which no registration error was present but context was provided anyway. This implies that people with lower spatial abilities performed as well as people with high spatial abilities in this case.

However, there is only a significant relationship between number of errors made and spatial abilities for the static no context ($r = -0.577$, $p = 0.002$) and random with context ($r = -0.657$, $p < 0.001$) cases. These results suggest that people with low spatial abilities can perform just as well as people with high spatial abilities for the perfect no context, perfect with context and fixed with context cases. I attribute the significance of the static no context and random with context cases to the observation that these cases seemed to be the most difficult cases that I studied. The static no context case required the subjects to fully understand the concept of registration error because it did not provide any contextual clues and it required them to remember which locations on the Lego base plate that they had already tried to place the block in order to keep the number of errors they made to a minimum. This proved to be difficult for some subjects, especially those that scored lower on the spatial abilities test. The random with context case was equally as difficult because it required the subjects to make a mental model of the relationship between the physical context block and the virtual context block and reverse that model to place the physical yellow block in the correct location with respect to the virtual yellow block.

I found the most frequent mistake that subjects made was not reversing the relationship between the physical and virtual worlds when trying to determine where to place the block. This reversal was very difficult and frustrating for many of the subjects in this study, and as proof of that, when I looked at the NASA TLX data that was collected, there were no significant correlations between spatial abilities and any of the NASA TLX categories except for perceived frustration in the random no context case. The lower the subject's score on the spatial abilities test, the more frustrated they were with the random with context case. (r = -0.468, p = 0.16) However a Chi Square test showed that spatial abilities do not predict frustration (Chi-Square = 2.746, p = 0.098, df=1). These results could indicate that the sample size might not be large enough to make such a prediction, that there were range restrictions in the spatial ability scores evaluated or that spatial ability really can not predict frustration levels in tasks such as the tasks in this experiment.

Another interesting observation that I made was that a subject's profession did not have any bearing on their spatial abilities. The majority of the subjects were in technology fields and scored high on the spatial abilities test. However, two subjects who had majored in business in college (and had related jobs) had two of the highest scores on the test.

4.5.2.2 Confidence

There is a negative correlation between the time per block placement and the average confidence in each of the cases. However, there is only a significant correlation in the no context cases. (Perfect no context r = -0.493, p = 0.01, Fixed no context r = -0.491, p = 0.11) I expected to see confidences levels rise as the time per block placement decreased, especially in the no context cases where the subjects just had to rely on their instincts for proper placement. I believe that there was not a significant correlation between time per block placement and the average confidence in the context cases for two possible reasons. First, block placement times tended to be longer in the context cases because the subjects had contextual clues to decipher and second, because I observed the subjects being more careful and checking and re-checking their block placements.

The only significant relationship between number of errors made and confidence was in the random error with context case. (r = -0.508, p = 0.008) In general, this was the most frustrating case, as previously discussed; the more errors people made, the less confident they were.

4.5.2.3 NASA TLX

I found many correlations when I looked at the NASA TLX data that was collected. Tables 4.1-4.3 show the correlations and significance values for each of the comparisons I made. It is important to note that in general I was looking for a significance value of 0.05 or less, which I have marked with a single asterisk, but I have also noted the cases in which significance is 0.01 or less by two asterisks.

Table 4.1 shows the correlations between total number of errors made and the perceived performance of the subjects. The significant positive correlations imply that the more errors the subjects made, the less successful they felt they were in accomplishing the goals set out for the task. The only case in which there was not a significant correlation was the perfect no context case, but people made so few errors that their perceived performance tended to always be good, with very little variation.

Table 4.1. Correlations between total number of errors made and NASA TLX perceived performance

Condition	**Pearson Correlation**	**Sig. (2-tailed)** *** significant at 0.05** **** significant at 0.01**
Perfect No Context	-0.075	0.715
Fixed No Context	0.532	0.005 **
Perfect with Context	0.624	0.001 **
Fixed with Context	0.548	0.004 **
Random with Context	0.704	0.000 **

Table 4.2 shows the correlations between perceived performance and frustration levels. Again, these significant relationships implied that the less successful people felt they

were at completing the task, the more insecure, discouraged, irritated, stressed and annoyed they became. This relationship held for all five of the conditions.

Table 4.2. Correlations between NASA TLX perceived performance and NASA TLX frustration level

Condition	Pearson Correlation	Sig. (2-tailed) * significant at 0.05 ** significant at 0.01
Perfect No Context	0.708	< 0.001 **
Fixed No Context	0.630	0.001 **
Perfect with Context	0.398	0.044 *
Fixed with Context	0.470	0.016 *
Random with Context	0.780	< 0.001 **

Table 4.3 shows the correlations between frustration levels and mental demand. They imply that the more frustrated the subjects became, the more mentally demanding the tasks became.

Table 4.3. Correlations between NASA TLX frustration level and NASA TLX mental demand

Condition	Pearson Correlation	Sig. (2-tailed) * significant at 0.05 ** significant at 0.01
Perfect No Context	0.539	0.005 **
Fixed No Context	0.449	0.022 *
Perfect with Context	0.419	0.033 *
Fixed with Context	0.634	0.001 **
Random with Context	0.610	0.001 **

The NASA TLX correlations implied that the subjects knew how they were performing in the tasks. And because they were aware of how poorly (or well) they were doing, they were able to take measures to either fix any mistakes they might have been making (if they were doing poorly) or ensure that they kept doing what they were doing (if they were doing well).

Despite the above correlations, mental demand and total number of errors made did not correlate. This makes sense because there were trials in which the subjects exerted mental effort to ensure the correctness of their block placements and did not make errors as a result.

4.5.3 Planned Contrasts

A multivariate analysis using repeated measures was used to analyze the data. The within-subjects factors were the five conditions that the subjects participated in and the two measures I was evaluating were number of errors made per block placement and time per block placement. The results of the tests of within-subjects contrasts for errors made and time per block placement can be found in Tables 4.4 and 4.5.

Table 4.4. Simple contrast matrix for number of errors made per block placement

	Perfect No Context	**Fixed No Context**	**Perfect with Context**	**Fixed with Context**	**Random with Context**
Perfect No Context	1				
Fixed No Context	F = 30.661 Sig. < 0.001	1			
Perfect with Context	F = 0.088 Sig. = 0.770	F = 26.181 Sig. < 0.001	1		
Fixed with Context	F = 19.076 Sig. < 0.001	F = 10.777 Sig. = 0.003	F = 20.327 Sig. < 0.001	1	
Random with Context	F = 24.663 Sig. < 0.001	F = 1.476 Sig. = 0.236	F = 21.157 Sig. < 0.001	F = 5.640 Sig. = 0.026	1

The simple contrasts for number of errors made showed some significant differences. In terms of errors, there was no significant difference in the perfect no context case and the perfect with context case. This implies that when there is no error in an AR system, adding context does not significantly reduce the number of errors. However, there is a significant difference in terms of errors between both of the fixed error cases. This implies that if there is registration error, adding context to an AR system significantly reduces the number of errors a person will make. The contrasts also showed no significant difference between the fixed no context case and the random with context case in terms of errors. Since these two cases were the most difficult, this result is not surprising.

The simple contrasts between the different conditions in terms of time per block placement produced different results. In terms of time per block placement, there were no significant differences between the context and no context cases for both the perfect registration and fixed error cases. This implied that adding context in each of these error conditions did not help users perform their tasks more quickly.

Table 4.5. Simple contrast matrix for time per block placement

	Perfect No Context	Fixed No Context	Perfect with Context	Fixed with Context	Random with Context
Perfect No Context	1				
Fixed No Context	F = 16.225 Sig. < 0.001	1			
Perfect with Context	F = 0.732 Sig. = 0.400	F = 11.225 Sig. = 0.003	1		
Fixed with Context	F = 24.297 Sig. < 0.001	F = 1.871 Sig. = 0.184	F = 18.724 Sig. < 0.001	1	
Random with Context	F = 24.955 Sig. < 0.001	F = 10.649 Sig. = 0.003	F = 22.140 Sig. < 0.001	F = 4.900 Sig. = 0.036	1

When looking at both of these contrasts, it is interesting to note that context does not help reduce errors or help quicken task completion when there is no error in the system. However, when there is fixed error in the system, context does help reduce the number of errors, but it takes relatively the same amount of time to perform the tasks. This phenomenon can be explained by the fact that despite the time savings in making less errors when there is context provided, there is a significant amount of time that is devoted to understanding and using the visual context blocks provided.

I did not include the results from the pilot data in the above analysis, so I am not able to address the effect of context in alleviating random registration error. However, I did a similar analysis of the pilot data and found that context significantly reduces the number of errors made ($F = 28.803$, $p = 0.003$) and the block placement time ($F = 11.061$, $p = 0.021$) when there is random error in the system. The results were obvious when watching the subjects struggle to complete the task by guessing where to place each block, but the analysis showed that the results were significant with only six people run through the pilot study.

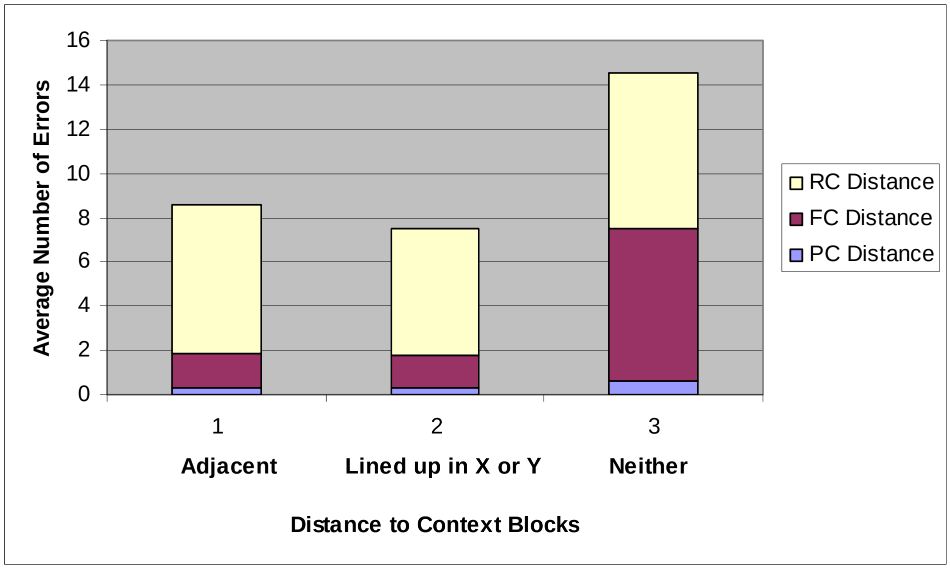
4.5.4 Distance to Context Blocks

As I was running subjects through the study, I noticed that people seemed to have an easier time placing the yellow blocks when they were located adjacent to the blue context blocks. Because of this observation, I looked to see if there was any significance to this observation.

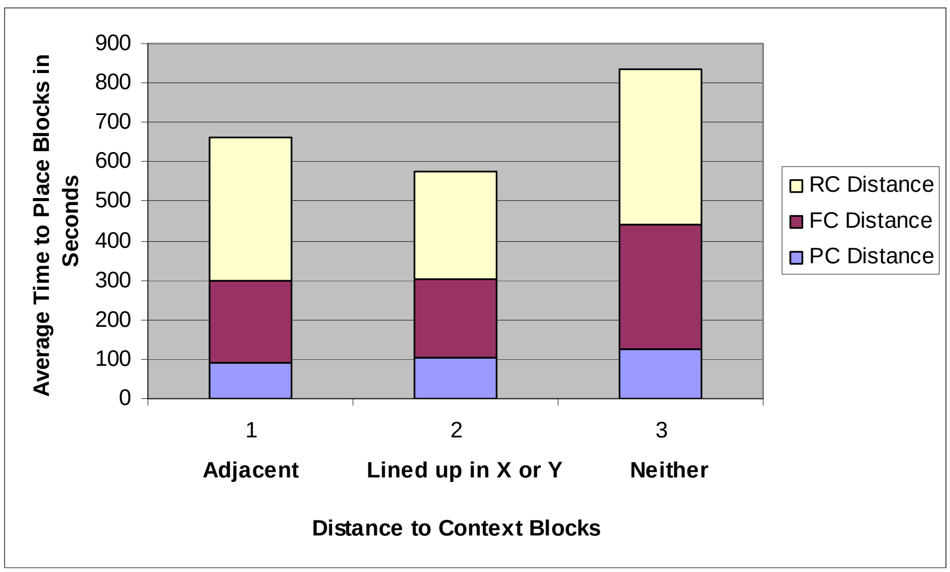
Additionally I observed that when the yellow blocks were lined up with the blue context blocks either along the X direction or the Y direction, block placement was a little easier. Therefore, I divided the block placement tasks into three types: adjacent to the context, lined up in X or Y with the context, and neither, meaning the yellow blocks were being placed somewhere else on the board, but had no adjacency or linear alignment with the context blocks. Figure 4.6 shows the number of errors and total block placement times for each of the three distances from the context blocks mentioned above. Looking at the graphs, I can see that having the yellow target block location adjacent to or linearly aligned with the blue context blocks produced the fewest number of errors and the tasks were completed in the least amount of time. However, these results are not statistically significant, likely because of the small size of the data set (there were only 13 adjacent placements, 19 linearly aligned placements and 22 non-aligned; the errors and time are the averages for that block across all subjects). Also, I had expected to see the adjacent cases produce less errors and take less time than the linearly aligned cases, but that is not what the study showed as shown in the graphs; again, this is likely due to the small data set.

I performed several univariate analyses of variance (ANOVA) to compare the total errors made and the total time taken to the distance from the context blocks. I found that in the perfect with context cases, the total number of errors made did not differ significantly between the different distance cases. However, with respect to total time taken to place the blocks, the difference between the times did significantly differ. I found that both the adjacent and linearly aligned cases differed significantly from the neither case (adjacent $F = 48.312$, $p = 0.029$; linearly aligned $F = 35.066$, $p = 0.037$), but the adjacent case and the linearly aligned case were not significantly different.

In the fixed error cases, the results varied from the perfect cases. I found that the total times did not vary significantly between the different distances, but there were some significant differences with respect to total errors. I found that there was a significant difference in number of errors made between the adjacent distance case and the neither case ($F = 5.375$, $p = 0.049$). And the difference between the linearly aligned case and the neither case was approaching significance, but was not quite significant. ($F = 5.375$, $p = 0.078$). Again there was no significant difference between the adjacent and linearly aligned cases.



(a)



(b)

Figure 4.6. Average number of errors and average time to place blocks as they relate to distance to context blocks.

In the random with context cases, I found no significant differences in the context block locations. I expected to see more significant differences between the different types of distances in the random case as well as in the perfect and fixed error cases than I actually saw. Again, I believe that the sample sizes for each of the distance types was too small to produce more significant results.

4.6 Discussion

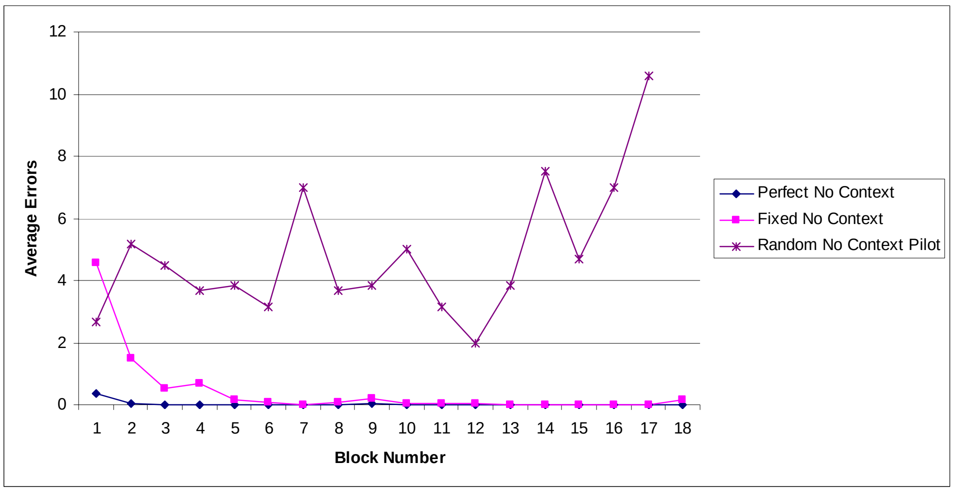
In this section I discuss the relationship between my findings and my previously stated hypotheses. Again in the graphs provided in this section, I have included the random no context case data that was evaluated in the pilot study, but discarded from the main study, to illustrate the vast difference between this case and the other five cases as well as to discuss how that case pertains to some of my hypotheses. The random data also provides the worst case base line to contrast with the perfect case baseline.

4.6.1 Effect of Type of Registration Error on Average Time and Average Number of Errors

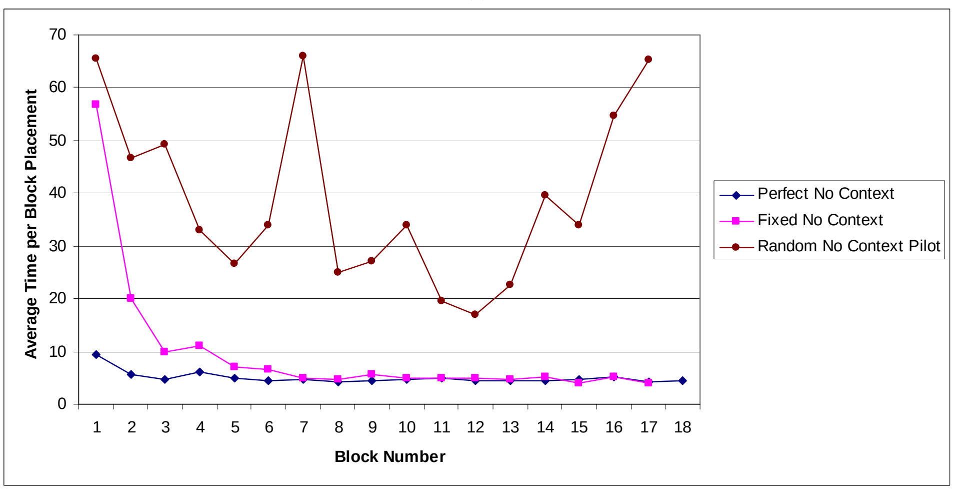
When exposed to different types of error in a scene in which no context is provided, there will be a different user response for each type of error. I predicted that when exposed to a fixed error, users will gradually learn how to compensate for the error; however, when exposed to random error, the task will become a guessing game as to where the block should actually be placed.

Figure 4.7 illustrates the number of errors made per block placement and the average time per block placement for each of the three conditions in this study when no context was provided. Figure 4.7(a) shows that when the graphics and the real world are perfectly aligned, there were almost no errors made by the participants. Two participants did make a few errors in the perfect case, but these errors can be accounted for. Subject 18 was trying to complete the perfect task very quickly and got careless throughout that block of trials. She made two errors because she did not really look around the Lego base plate to confirm the block was in the correct location. Despite being instructed during the training phase of the study to look around, this subject stood still in front of the board and did not lean over at all; she just tried to place the blocks quickly without moving. Standing back away from the board did not produce a good angle between her and the base plate for correctly placing the block. After she made those two mistakes, she slowed down and looked around more and made no additional mistakes.

In contrast, Subject 14 made nine errors on his first block placement because he had run through only error cases before being run through the perfect case, so he did not trust the graphics. He did not even try the correct location that the system was showing him until



(a)



(b)

Figure 4.7. Average number of errors and time per block placement when no context is provided

he tried all of the other eight possible locations. Once he realized that the graphics aligned perfectly, he made no further mistakes.

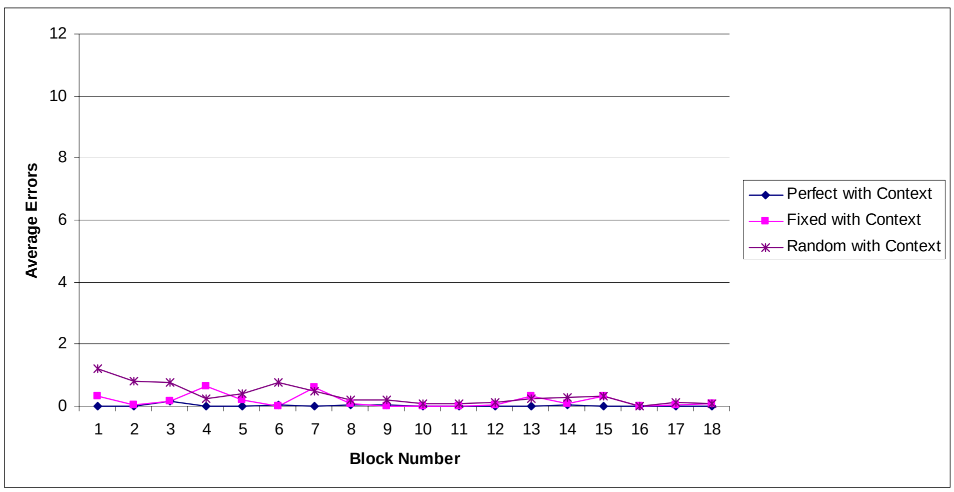
Figure 4.7(a) also illustrated some interesting results for both the fixed error and random error cases. When there was fixed error in the system, the average number of errors started off high and gradually approached zero errors as the subjects learned how to deal with this type of registration error. In the random error pilot case, users never came up with a strategy to deal with this type of error; they merely guessed until they found the correct location. This supports my first hypothesis.

Figure 4.7(b) shows similar results, but in terms of time per block placement rather than number of errors per block placement. Again, in this case, the time per block placement for the fixed error case approached the time for the perfect registration case as the task progressed and the time per block placement in the random registration error pilot case varied drastically.

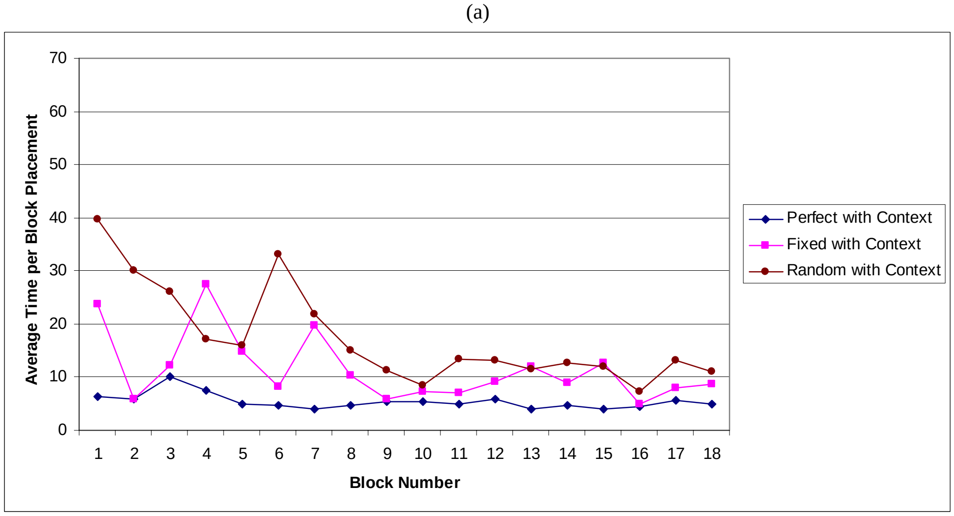
4.6.2 Effect of Context on Average Time and Average Number of Errors

If context has the effect of providing useful relationship information, placement tasks should be able to be performed with less errors; however, the cognitive processing of the context information might increase the trial times.

Therefore, I predicted that when context is added to a scene, whether fixed or random error is present, the time per trial will increase, but the total amount of errors will decrease. Figure 4.8 illustrates the number of errors made per block placement and the average time per block placement for each of the three conditions in this study when context was provided. When comparing Figure 4.7(a) and Figure 4.8(a), the difference in the number of errors in the fixed and random cases is very apparent. In the fixed error case, context seemed to quicken the learning curve involved in figuring out how to adapt



(a)



(b)

Figure 4.8. Average number of errors and time per block placement when context is provided

to the registration error, thereby reducing the number of errors made by 35.7%. However, when comparing Figure 4.7(b) and Figure 4.8(b), there is a noticeable increase in the average time taken to place the block, even though there is not such a drastic learning curve involved in figuring out where to place the block in the context case. In fact, the block placement times increased by 21.4%. I attribute this increase to the increased cognitive load required to comprehend the context provided.

In the case of random error in the pilot study, the context was so helpful in completing the task successfully, that the context improved the average number of errors per block placement by 92.6% but decreased the average time per block placement by 55.2%. In short, without the context, subjects could not successfully complete the placement task when there is random error; they merely guessed where to place the block until they guessed correctly. I did not expect to see such a drastic improvement in time per block placement for the random case, but quickly realized that portion of my hypothesis was incorrect.

Therefore, I found that my hypothesis with regards to number of errors made and block placement times holds true for fixed error, but not for random error. Only my hypothesis that the number of errors made would reduce holds true for the random case; the hypothesis concerning time per block placement does not.

4.6.3 Effect of Context on Perfect Registration

When there is no error in an augmented system, the user does not need additional context to perform a placement task correctly. Therefore, I predicted that when there is no registration error associated with the system, adding context neither increases nor decreases the number of errors. I did not anticipate any errors being made in the perfect cases, but I neglected to factor in subjects rushing through the tasks and being careless. I also did not anticipate anyone not trying the target location shown because they had only been exposed to error cases up until that point. Figure 5(a) shows that there were a few errors made in both of the perfect error cases and there was a slight difference in the number of errors made between the no context and context cases. In fact, there were fewer errors made in the perfect with context case.

However, despite the slight, yet visible differences between the context and no context cases when registration was perfect, there was no significant difference between the number of errors made ($F = 0.088$, p =. = 0.770) and there was no significant difference between the time per block placement ($F = 0.732$, $p = 0.400$). Therefore, this implies that when there is perfect registration, a small amount of context does not provide any added benefit, nor does it hinder performance.

4.6.4 Effect of Context on Confidence

Although I did not have any hypotheses related to confidence, I did make a few observations with regard to confidence that are interesting. Figure 4.9(a) shows the average confidence per block for the no context cases. It shows that the subjects gradually became more confident as the placement task progressed for both the perfect and fixed error cases. This shows that when there is no context present, subjects can eventually figure out how to complete the task successfully, thus boosting their confidence. This figure also shows that in the pilot study, confidence levels decreased as the task progressed for the random case. The decrease implies that as people began to realize that they just had to guess to try to find the correct location for the block, they became less confident.

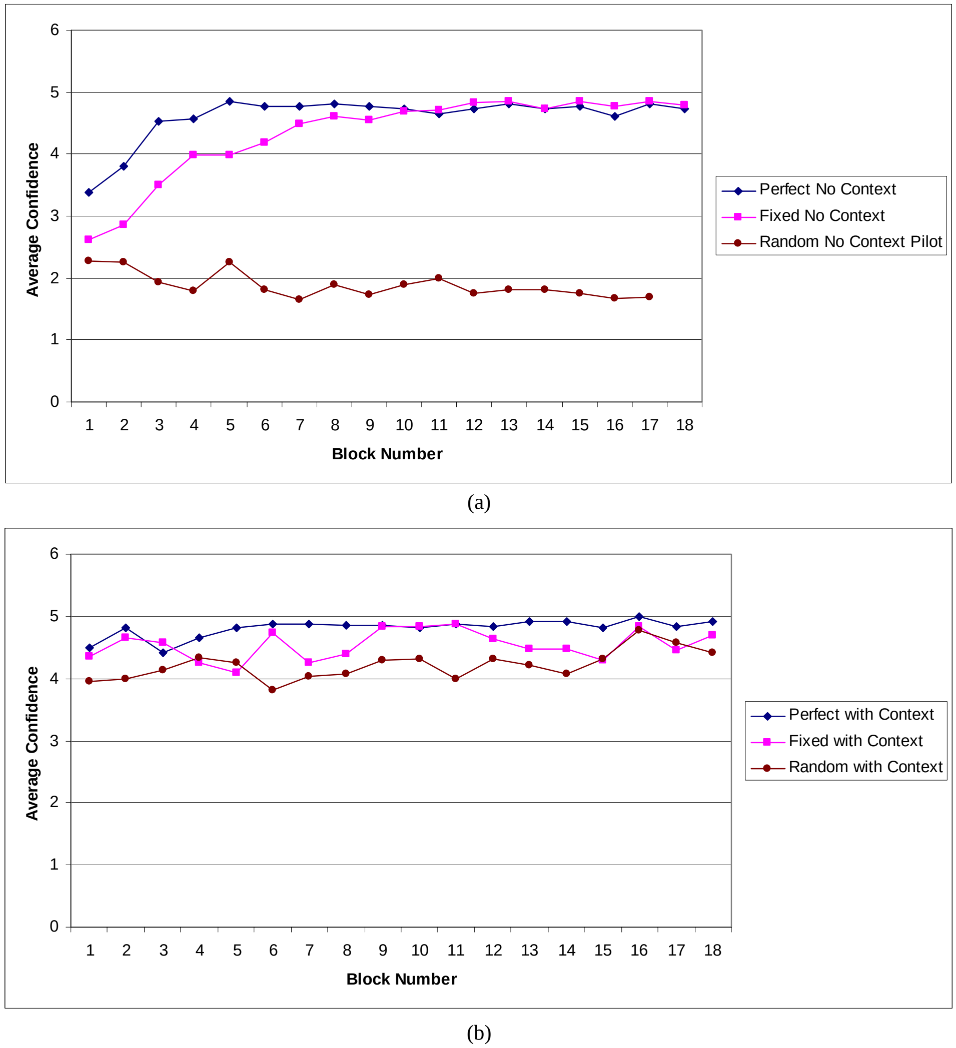


Figure 4.9. Average confidence per block

Figure 4.9(b) shows the average confidence per block for the context cases. In general, the average confidence for all three cases started higher than the no context cases. In the case of perfect registration, the confidence levels were higher on average for the context case (average confidence = 4.814) than in the no context case (average confidence = 4.603), thus showing that even though context does not significantly help reduce errors or block placement time, it does help people feel more confident about their performance. In the fixed error no context case, there was a bit more fluctuation in the confidence, although the average confidence in the context case (average confidence = 4.542) was still higher than in the no context case (average confidence = 4.324). I attribute this fluctuation to an observation that I made while conducting this study. I noticed that in many cases, despite the fact that the error was in the same direction and magnitude for each of the block placements, a large number of the subjects did not notice that occurrence and continued to try to figure out the relationship between the real world and the virtual world each time there was a new block. This caused their confidence to fluctuate as much as it did in the random error with context case.

While it is important to note that the confidence levels did fluctuate in the random error with context case, the confidence levels on average for the context case (average confidence = 4.212) were a great deal higher than in the no context cases conducted during the pilot study (average confidence = 1.880). Basically this implies that adding context turned a task that people felt they were constantly failing at into a task that they felt they were quite successful in completing.

Therefore, on average, I found that context helped people feel more confident when completing these tasks.

4.6.5 Observations

While running subjects through this study, I noticed some very interesting behavior. On a bit of a funny note, it was amusing to listen to the comments that people were making to themselves out loud while completing the tasks. I heard many comments, such as "Why are they moving?" in the random error case when people had not quite figured out which case they were in. I also heard comments like, "Oh, I get it now" or "I see" or "I've got the pattern now" when the particular trial finally made sense to them. I even heard comments like "I don't trust you" when they were in the error cases. On a more serious note, I noticed many differences in the strategies the subjects used for placing the blocks as well as other higher level observations.

4.6.5.1 Block Placement Strategies

As I previously mentioned, subjects used many different strategies for placing the physical blocks. In general, some subjects were extremely confident in the placements and immediately placed the physical block in the correct location, but usually they developed their own strategy to use.

When no context was present, the strategies were more like guessing games. Some subjects immediately tried the shown target location no matter what, while others who had been through some error trials before did not trust where the system was telling them to place the block and would try all of the other eight locations before trying the shown target location. As previously mentioned, I noticed that people tended to search for the correct location around the virtual target by either going through the 9 possible locations in a clockwise or counter-clockwise fashion, while a few others tried their placements using rows or columns. A few less successful subjects randomly tried the possible locations, but quickly forgot where they had previously tried and ended up repeatedly trying the same locations.

The placement strategies also differed if there was context present. When the virtual blue context blocks were present, some subjects used the information they provided for every single block placement no matter what type of error was present in the system, usually costing the subjects more time. However, others quickly learned the correct offset (if there was an offset) for the no error and static error cases and completely ignored the context blocks after they learned the offset. This learned behavior actually saved those subjects time in placing their blocks. In the random error case, the subjects were forced to use the context for every block placement. In addition, when there was context present and it was located next to or just a peg or two away from the target location, subjects tended to more quickly place the blocks without having to think too much about the correct displacement. They could just see where they needed to place it. However, the larger the distance between the context blocks and the target location, the more the above strategies were used.

The subjects differed on how they used the context information. Some would mentally do the mapping between the virtual world and the physical world. Others used some sort of hands-on strategy. Some subjects would place the physical block in the location that the virtual block was shown and then move the block once they figured out the proper translation. Some would count the pegs in both directions from the virtual context blocks to the physical context blocks and count that same number of pegs from the virtual target location to decide where to place the physical target block.

4.6.5.2 Common Mistakes

The most common mistakes people made were not related to the system at all, but were related to inexperience with an AR system in general. It sometimes took quite a while for people to feel comfortable enough with the system to move around and look at the Lego base plate from different perspectives. Without these different perspectives, it was sometimes hard to see the proper location for the block, especially for people who were not as tall as others. It was very easy for them to mistake one row for the next.

Another common mistake the subjects made was not trusting the system. Due to the Latin Squares design, some people received all of the error cases first before any of the no error cases. Once they got to the no error cases, many of these subjects did not even try the location that the virtual block was showing them because they did not trust the information they were being given. These types of human error mistakes accounted for quite a few of the errors that were recorded.

The biggest conceptual mistake that I noticed people making was reverse mapping the relationship between the virtual context and the real world. If the scene showed that the blue virtual context block was up and to the right of the physical blue context block, numerous subjects would attempt to place their physical yellow block down and to the left of where the yellow virtual target was pointing them to place the block. It sometimes took several trials before the subjects realized their mistakes, but once they did make the correct association, they very rarely made that same mistake again.

4.6.5.3 General Opinions

The subjects varied in their opinions about the study. Some of the subjects loved having the context blocks present, no matter which type of error was present, because the context gave them more confidence in their block placements. Other subjects only found the context blocks necessary in the random error case because they felt like they could complete the tasks quicker without feeling the need to interpret any context that was present.

I received several comments about the shape of the context blocks that I had not anticipated. Some subjects thought that they could have mapped the difference between the virtual blue context blocks and the virtual yellow target block better if they had been the same shape, while other subjects liked the fact that they were a different shape than the physical block they were trying to place. In fact a couple of subjects commented on how helpful the orientation of the 1x2 peg Lego blocks were for context because I aligned one of the context blocks to have its longer side on the vertical plane and one on the horizontal plane, as shown in Figure 4.3. They felt that this planar information gave them an additional type of context to use.

A few subjects mentioned that they found it harder to place the blocks when their target locations were at the back of the Lego base plate, furthest away from them. This is probably due to the fact that the subjects had to bend over more to get a good overhead view of the target location. One subject suggested tilting the board on an angle to eliminate this difference between the front and back of the base plate.

I asked the subjects if they had any ideas about different types of context to add to this system and I received a variety of responses. As mentioned above, some wanted the context blocks to be the same size and shape as the physical target block. Others wanted the entire base plate to be drawn. Some wanted a graphical indication of where they had already tried to place the block previously, for instance a grayed out virtual representation of the block in all of the locations that had been tried. Some suggested different colors of context for the different directions of error. Some suggested that I draw arrows to show the directions in which there was error, while others wanted both arrows and a number to indicate how many pegs in that direction that the block was off. Some wanted audio feedback, like a beep when you got close and a distinct bell when you were over the correct location. While some of these ideas are interesting and could be implemented in the future, most are not feasible in a real-life AR system because they rely on knowing exactly what the error is: if a system knew the error, it could just be corrected for.

4.7 Conclusions

This study has shown that adding context to a scene that is ambiguous because of registration error can help a user make sense of the ambiguity. I have shown that context is not really needed when there is perfect registration in an augmented environment, but it does help people feel more confident. I have also shown that context can not only help reduce the number of errors that people make in a Lego block placement task when registration error is present, but it can also help to reduce the time it takes a user to complete the task when random registration error is present. In addition, in the case of random registration error, context can actually make a completely impossible task doable by almost anyone.

CHAPTER 5

USER STUDY 2: EVALUATING CONTEXT WHEN GRAPHICS ARE OUTSIDE OF THE TASK AREA

As I previously mentioned, Augmented Reality has not been widely used for a variety of reasons. The first reason, which I discussed in Chapter 4, is that too much focus has been placed on perfectly registering the graphics on the physical world. I have shown that perfectly registered graphics are not always necessary. A second reason is that there is a concern, voiced occasionally, about the inappropriateness of having computer graphics block a worker's view of the task space, thus interfering with their primary task. Such graphics could not only be annoying, but in certain tasks, it could also be very dangerous. A desire to limit the amount of graphics in the task space guided my designs in AIBAS and the first experiment. However, when error, augmentations and context are present, the user's view of the task space may be unacceptably obscured.

I believe that AR can still be useful in this situation and this chapter discusses a user study designed to validate this intuition. In this study, I evaluated the impact of situating graphics outside of the task area, including the situation when only orientation tracking is available. This study shows that graphical augmentations do not need to be located in the task area to be useful, thus eliminating concerns about using AR in real world situations when the task space must be clear. Also, this study shows that low-level orientation-only tracking can be used to provide enough information to create useful augmentations if a more sophisticated tracking system is not available.

5.1 Theory and Hypotheses

The user study presented in this chapter is designed to evaluate context in less traditional forms of AR. Many researchers have proposed the use of Augmented Reality for repair tasks. For example, Honda deployed a Nomad Expert Technician System, a hands-free wearable display that provided access to vehicle history and repair information. But one of the biggest concerns with non-AR heads-up displays is blocking the real world with the graphics. I have shown in the previous study that context is useful in registered AR, but I also want to prove the benefit of context in non-registered AR, as well as on a heads-up display (HUD). The question I am asking could be phrased: When provided enough context, is registration really important? I have chosen to evaluate four cases.

Fully registered AR: When there is no visible misalignment between the graphics and the world, I can say there is no error. For my purposes, however, achieving absolutely no registration error in an AR system is impossible, so, as with the previous study, I consider *no error* to actually be negligible error. In the case of the experimental setup, if the amount of registration error is less than half of the size of one of the Lego pegs on the base plate, there is no question as to where the block should be placed, and I consider this to represent no error. From here on, I will also refer to this case as the AR-registered case or REG.

Non-registered AR: If I know there is even a small amount of registration error in an AR system and the context is such that the graphics and context would obscure too much of the task space, I can purposely locate the graphics far enough away from the actual intended location at a fixed position and orientation with respect to the Lego base plate. By doing this, I still have useful orientation information while being able to avoid the frustration of the misalignment between the real world and the graphical world. From here on, I will also refer to this case as the AR-off-to-side case or OTS.

Heads-up display with the graphics always visible in the field of view: With orientation only sensing, it is possible to display the graphics in a fixed position on the head-mounted display. The orientation information can be used to ensure the graphics are oriented in roughly the same orientation as the user's view of the physical base plate. (I discuss how this can be implemented below.) These graphics are always visible in the user's field of view (FOV) in order to have constant reference to the graphical display. From here on, I will refer to this case as the HUD-visible case or HV.

Heads-up display with the graphics not always visible in the field of view: With orientation only sensing, as in the previous case, I can also try to only display the graphics when the user is looking away from the base plate. Thus, the graphics are not always visible in the user's field of view. To see the graphical instructions, the user must turn their head to the side to see the graphics. In this experiment, the angle between the user's head and the user's body must be 30 degrees or more in either direction in order for the graphics to appear on the head- mounted display. From here on, I will refer to this case as the HUD-side case or HS.

These cases are not only designed to evaluate the usefulness of registered verses non-registered graphics, but I also want to see if orientation information can be used to generate something better than a simple HUD display when spatial registration is not possible. By this I mean that if an augmentation is not superimposed directly over the physical world, is displaying the graphics relative to the user's viewpoint on a HUD still useful?

5.1.1 Orientation-only Tracking

One of goals of this study is to evaluate the use of orientation-only tracking in AR. There are several benefits to this type of tracking, including cost and ease of design. Tracking systems, such as the InterSense tracker used in both of my experiments, are extremely expensive compared to orientation-only sensors (such as InterSense's InertiaCube3). If I could design an AR system using orientation-only tracking that is close to the same effectiveness as one using full position and orientation tracking, the cost difference would make such a system worth considering. In addition, calibrating and fine tuning a position tracker is a very complicated and time consuming procedure, and current systems only cover a small area. Even when properly set up, current systems are far from providing perfect tracking.

The initial design for the orientation-only tracking was to use three orientation sensors: one on the subject's body, one on their head and one on the Lego base plate. If we assume the subject is facing the base plate, the angle between the sensor on the subject's body and the sensor on the base plate would show which side of the base plate the subject was located. The angle between the sensor on the head and the sensor on the body would allow me to implement the "turn your head to the side to see the graphics" feature I discussed above.

When I implemented the orientation-only tracking, I realized that the tracker I was using, the InterSense 1200, already provided me with the alignment between the user's head and the world, and I already knew where the base plate was located in the world. I added one additional sensor, an InterSense InertiaCube2, and calibrated it with respect to the coordinates of the InterSense 1200, providing me with the orientation between the user and the base plate. Together, these two sensors give all of the necessary orientation information to create the HUD cases.

In these two HUD cases, I wanted to see if performance in terms of error and time per block placement as well as cognitive load are comparable enough to the AR cases to validate the usefulness of orientation-only tracking. If they are, the results could have a significant effect on application design. .

5.1.2 Hypotheses

When exposed to registered AR and non-registered graphics, a user can perform placement tasks very easily with few errors, but the time it takes to complete the tasks may differ because of the nature of each task. Therefore, I predict:

H1) When exposed to registered AR and non-registered graphics, users will perform placement tasks with little to no errors in each of the four cases; however, the time it takes to complete each task will differ.

When comparing fully registered AR to the three other types of non-registered graphics, subjects will perform better in the fully registered AR case and will find that case easier to complete than the other three cases. Therefore, I predict:

H2) When comparing the fully registered AR case to the three non-registered graphics cases, the subjects will have lower trial times and errors as well as cognitive load in the fully registered AR case.

When exposed to both AR and a HUD, the AR conditions will seem more natural to a user because the graphics remain in the same position, much like a user manual placed next to the user on a desk. Therefore, I predict:

H3) The AR conditions will have lower trial times and errors as well as cognitive load as compared to the Heads-Up Display conditions.

The time taken to complete the placement tasks will differ between the cases for several reasons. Placement time will be affected by the head movement required for each of the cases. Some of the cases require no head movement, while others require looking to the side to see the graphics. In addition, the amount of clutter on the screen will affect the placement time for the given tasks. Tasks in which the graphics interfere with the user's view of the real world will be slower than tasks that have less clutter in the field of view. Therefore, I predict:

H4) The block placement times will be slower for the two cases in which the users have to turn their heads to the side to see the graphics: the AR-off-to-side case and the HUD-side case.

H5) The block placement times will be slower for the case in which the graphics are always located in the field of view: the HUD-visible case.

The perceived mental workload and frustration of a subject will be affected by several factors including location of the graphical instructions and clutter. In the cases where the graphics are located outside of the subjects' field of view, the subjects will have to develop strategies for remembering where to place the block when they look back at the task space. Conversely, when the graphics are in the field of view, but blocking their view of the real world, the subjects will have to develop a strategy for changing their focus between the real world and the graphical world. Therefore, I predict:

H6) The perceived mental workload and frustration of a subject will increase when the graphics are not located in their field of view.

H7) The perceived mental workload and frustration of a subject will increase when the graphics are cluttering their view of the task space.

The perceived physical demand of a subject will be affected by the location of the graphics. When the graphics are located in the subject's field of view, the task will be less physically demanding to complete than when the graphics are outside of the user's field of view because there is no additional head movement required. Therefore, I predict:

H8) The perceived physical demand of a subject will increase when the graphics are not located in their field of view.

As in the first experiment, the distance between the context blocks and the target location of the virtual block will affect a subject's ability to place a block. Therefore, I predict:

H9) When the context block is adjacent to the target location of the block, the subjects will perform better in terms of placement time and errors than if the target location of the block is lined up horizontally or vertically with a context block or if the target location has no relation to the context block.

H10) When the context block is lined up horizontally or vertically with a context block, the subject will perform better in terms of placement time and errors than if the target location has no relation to the context block.

5.2 Methodology

A within-subjects experiment was conducted. The independent variable in this study is the four possible methods for displaying the graphics on the head-mounted display. The dependent variables include time to complete each task, the number of errors, and perceived mental workload.

5.2.1 Participants

Twenty-eight subjects were run in this study. Participants were solicited via email and some were student volunteers. The participant pool consisted of 28 subjects, 12 male and 16 female. The ages of the participants ranged from 18 to 29. The subjects were compensated with $5/half hour rounded to the nearest half hour paid in either Target or Starbucks gift cards.

5.2.2 The Setup

I used the same setup for this study as I did in the first study. Figure 4.1 shows pictures of the experiment setup I used in this experiment. The subjects stood next to the desk, shown in Figure 4.1(b), on which a Lego base plate was located in a fixed position relative to fiducial markers that were hung on the wall in front of them. They wore the head-mounted display, shown in Figure 4.1(a) that contained an InterSense IS-1200 tracker, a 60 frames-per-second Point Grey Flea camera, and a Sony Glasstron video see-through optical display. The camera is mounted above a right angle prism, moving the optical center of projection of the camera closer to the subject's eyes than would otherwise be possible, with the intent of reducing the parallax offset of the video-mixed head-worn display. They also had an InterSense InertiaCube2 orientation-only sensor attached to their waist. This was used in two of the four blocks of trials.

5.2.3 Session Information

Introduction to the study: When the participants arrived, they were asked to read and complete the consent form provided. They were also asked to fill out the introductory questionnaire, located in Appendix A, to provide some background information, including age, experience in AR systems, video game experience, how well they understood the concept of registration error in AR, etc. They were then asked to complete two tasks: an Edinburgh handedness test (Oldfield, 1971) and the Spatial Learning Ability Test (Embretson, 1997). The handedness test was used to ensure that they used their dominant hand to complete the experiment, as well as to see if handedness played any part in the participant's success. The spatial abilities test was given to evaluate the relationship between spatial abilities and successful task completion.

Training: They were then asked to read the training document located in Appendix A. It gave a brief introduction about what they would be doing in the study and briefly described each of the four cases of the study. After reading the training document, they were asked to predict which cases they thought were going to be easiest and which they thought were going to be the hardest. In order to evaluate this, they were asked to rank the four cases from expected easiest to the hardest. The procedure for each block placement was then demonstrated to the participants. If they did not have any further questions, the participants were walked through a training exercise to familiarize them with wearing a HMD, how to correctly perform the block placement task, how to ensure that they maintain proper tracking throughout their tracked trials, and how the calibration procedure would be performed in the orientation only trials. They were reminded that they would be evaluated based on the amount of time that it takes them to place each block as well as the number of errors they make while placing a block; therefore, it was important for them to work as quickly and as accurately as possible.

As part of their training exercise, they were asked to locate some graphics that were drawn on their screen to ensure that the head-mounted display was properly aligned with their field of vision. They were asked to look for a greenish-black virtual circle drawn around the camera mounted directly in front of them. They were instructed that this circle would always be drawn around the camera if the tracker was working correctly. If for some reason the tracker stopped working, causing the graphics to disappear or look weird, they were instructed to look at the camera mounted on the wall directly in from of them. If the tracker was working, they would see a virtual greenish-black circle around the camera. If the circle was not there, they were instructed to wait a few seconds for the tracker to begin working again. They were also told to look at the camera on the wall in front of them between each block placement to confirm that the virtual circle was around the camera, ensuring that the tracker was working.

They were then instructed how to place six blocks using the correct procedure. During the training exercise, there were no context blocks on the board and the graphics were perfectly registered. The purpose of this training exercise was to allow the subjects to get used to wearing the HMD, to get accustomed to looking through the HMD, and to familiarize them with placing the blocks on the board while using the correct procedure. This completed their training on block placement.

5.2.4 The Placement Task

The task consisted of the following: picking up the yellow block, pushing a button to start the trial, placing the block, and pushing the same button to end the trial. After each trial, the subject was asked how confident they were with the block placement. The following 5-point Likert scale was used:

1 – I think the block is in the wrong place.

2 – I think the block might be in the wrong place.

3 – I do not know.

4 – I think the block might be in the correct place.

5 – I think the block is in the correct place.

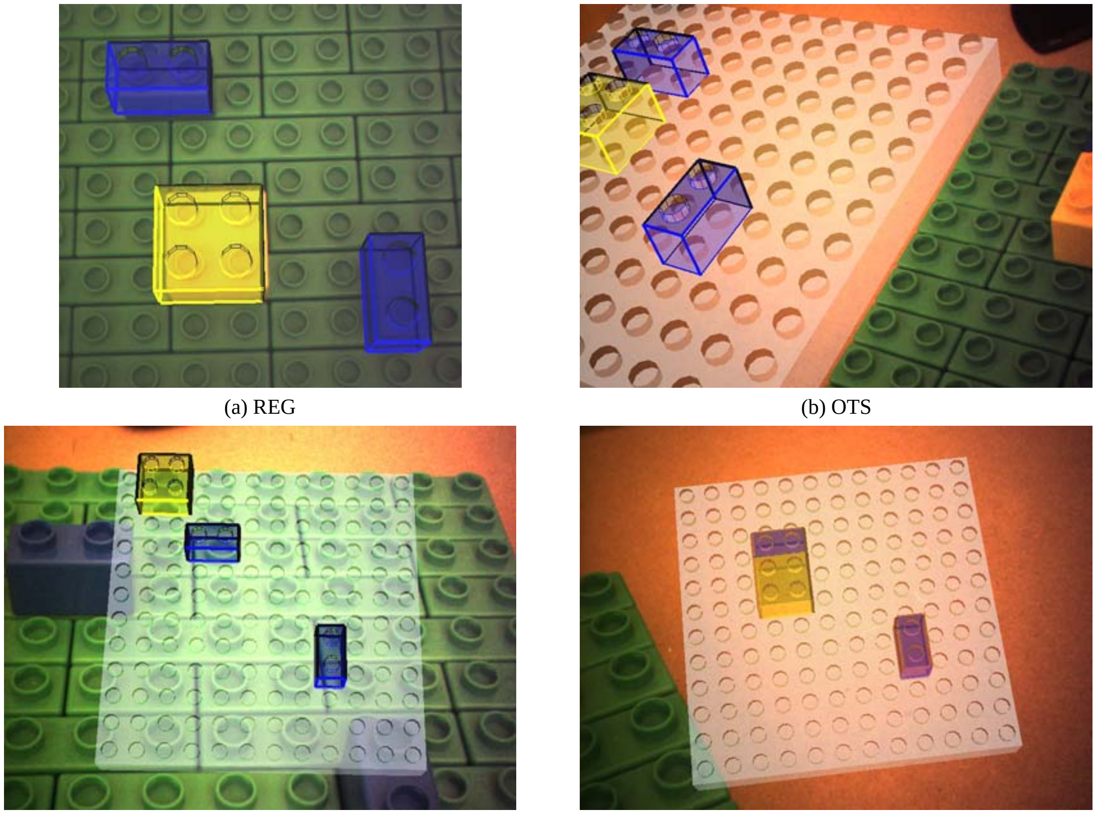
If the block was indeed placed correctly, the subject was verbally informed as such, they removed the block from the base plate and advanced to placing the block in the next location. If the block was placed incorrectly, the subject was informed as such and was instructed to attempt to place the block in the correct location again. The subjects were given no clues as to why their placement was incorrect. The steps repeated until the block was correctly placed. After all of the trials were completed, the subject answered the post block survey questionnaire, located in Appendix A, about their experience, including the NASA TLX rating (Hart & Staveland, 1988).

<u>Trials:</u> As mentioned above, the variable in this task was the location of the on-screen instructions. After picking up the block, the subject was instructed to push a button to start the trial. When the button was pushed, an augmentation appeared on the subject's head-mounted display that showed the intended location of the block. The subject was instructed to place the block in the location specified on their HMD screen. After placing the block, the subject pushed the button again to end the trial. The subject was asked to keep attempting to place the block until the block was placed correctly. The subject was

asked to correctly place 18 blocks per trial. If at any point in a block placement, the subject wanted to give up and move on to the next block, they were able to do so. And if they instead wanted to give up on the trial altogether, that option was provided as well.

In the design of this study, there were a total of four blocks of trials: perfectly registered graphical instructions (AR-registered, shown in Figure 5.1(a)), graphics located to the left of the physical board (AR-off-to-side, shown in Figure 5.1(b)), heads-up display with the graphics always visible (HUD-visible, shown in Figure 5.1(c)), and heads-up display where you have to turn your head to the right or left for the graphics to become visible (HUD-side, shown in Figure 5.1(d)). There were context blocks shown in the graphics for all four blocks of trials. For the purposes of this study, the context took the form of two virtual blue Lego blocks that represented two physical blue Lego blocks that existed on the Lego base plate. In the three non-registered cases, the base plate was also drawn. For each of the blocks of trials, the subjects were presented with 18 targets.

In two of the experimental trials, the AR-registered case and the AR-off-to-side case, the subjects were tracked using position and orientation information. In these trials the graphics are positioned relative to the world. In the other two trials, the subjects were tracked using only orientation sensors. In these trials the graphics were displayed like a heads-up display: attached to the users head and not drawn with respect to the world.



(a) REG (b) OTS

(c) HV (d) HS

Figure 5.1. The four blocks of trials. (a) Registered AR. (b) Graphics located off to the side – AR-off-to-side (c) Heads-up display with the graphics always visible – HUD-visible. (d) Heads-up display where you have to turn your head to the left or right for the graphics to become visible – HUD-side.

Blocks of trials: There were a total of four blocks of trials in this study: one for fully registered graphics (AR-registered), one non-registered AR with fixed position and orientation with respect to the Lego base plate (AR-off-to-side), one for a heads-up display with the graphics always visible (HUD-visible), and one for a heads-up display with the graphics not always visible (HUD-side). In order to eliminate any order biasing, a 4x4 Latin Square was used to determine the order of presentation of the blocks of trials.

5.2.5 Data Recorded

Several types of data were recorded during the experiment. First, trial data including block data (color, size), confidence levels, how many times the subject attempted to place each block and the time to complete the trial was recorded. Second, video data was collected including a view of what the subject is seeing, a view of the subject from above to show where the subject's head is pointing, and a frontal and side view of the Lego base plate to see the subject's hands and to see how and where they placed the block. Figure 4.4 shows the quad view recordings of the various video data that was collected.

5.3 The Study

The four blocks of trials described above were evaluated in the pilot study. Six subjects were run to ensure that I was getting viable data. The subjects I ran were all members of my research group. All of the data I collected looked reasonable and had sufficient variability, despite the fact that I ran somewhat "expert" users in the pilot. Therefore, each of the four cases seemed appropriate to run in the full study, so nothing was changed before running the full study.

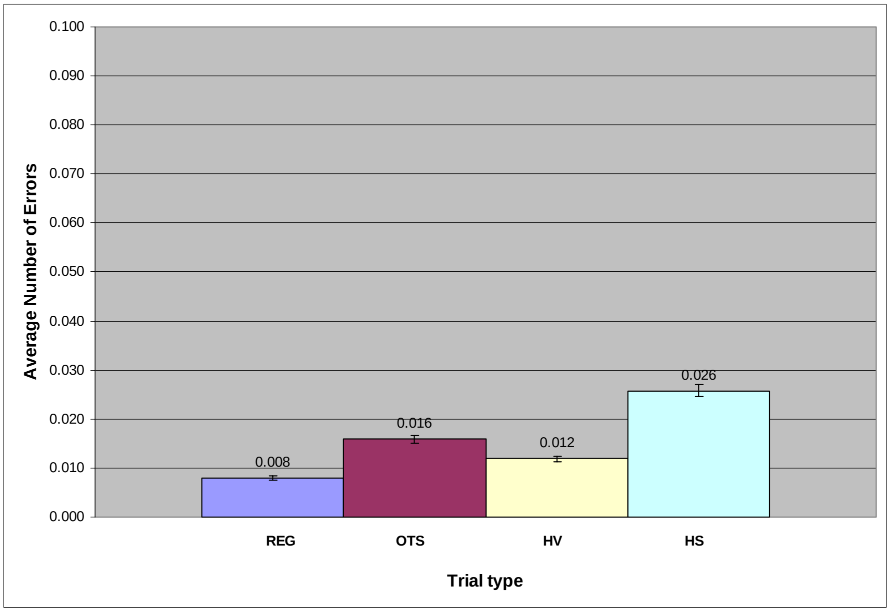
5.4 Results

As previously stated, this was a within-subjects experiment, so each subject was asked to complete all of the blocks of trials. An alpha level of 0.05 was used for all statistical tests.

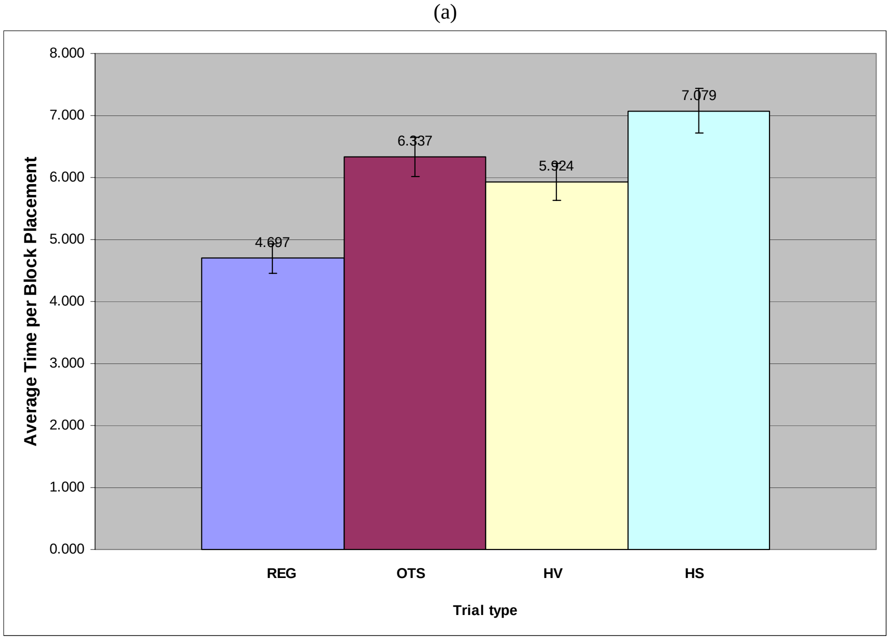
5.4.1 Descriptive Statistics

Figure 5.2 illustrates the average number of errors per block placement and the average time per block placement in each of the six conditions in this study. Figure 5.2(a) shows that the AR-registered case produces the least amount of errors, while the HUD-side case produces the largest amount of errors. It also shows that the two cases in which the graphics are always located on the screen (AR-registered and HUD-visible) had fewer block placement errors than the cases which involved more head movement, probably because the graphics were not visible while looking at the Lego base plate. However, it should be mentioned that the actual number of errors for each of the cases is quite small.

Figure 5.2(b) shows that the AR-registered case has the best performance rate in terms of time per block placement and the HUD-side case has the longest time per block placement. Figure 5.2(b) also shows that the two cases in which the subjects have to



(a)



(b)

Figure 5.2. Average errors and time per block placement

turn their heads to the side (AR-off-to-side and HUD-side) have longer block placement times than the two cases in which the graphics are always displayed on the screen (AR-registered and HUD-visible).

5.4.2 Correlations

While analyzing the data collected, I discovered several interesting relationships, some of which I expected to find and some of which I looked at only after observing the subjects complete the Lego block placement tasks.

5.4.2.1 Spatial abilities

I found some significant relationships between spatial abilities and time per block placement. I found significant negative correlations between block placement times for all four of the cases: AR-registered case ($r = -0.431$, $p = 0.022$), AR-off-to-side case ($r = 0.-522$, $p = 0.004$), HUD-visible ($r = -0.393$, $p = 0.038$) and HUD-side ($r = -0.491$, $p = 0.008$). These results imply that people with higher spatial abilities can complete these tasks more quickly. For the AR-registered and HUD-visible cases, I believe that the people with higher spatial abilities completed the tasks quicker by placing the block and quickly pushing the button, already confident of their placement. In contrast, the subjects with lower spatial abilities tended to spend more time looking around and confirming their placements. In the AR-off-to-side and HUD-side cases, I believe the significant correlation between time and spatial abilities can again be attributed to less double checking. The people with higher spatial abilities developed their strategies for placing the blocks quickly and did not feel the need to look to the side more than once to confirm their placements.

5.4.2.2 Block Placement Time and Confidence

There is a significant positive correlation between all of the cases for time per block placement and average confidence. These results are not very surprising. I anticipated that if a subject quickly completed any one of the tasks that they would be able to quickly complete all of the tasks. Similarly, I also anticipated the same results with respect to confidence levels. If a subject was confident in any one of the tasks, I predicted that they would be confident in all of them. It is important to note that in general I was looking for a significance value of 0.05 or less, which I have marked with a single asterisk, but I have also noted the cases in which significance is 0.01 or less by two asterisks.

Table 5.1. Pearson Correlation between placement times and confidence and the four cases
Sig. (2-tailed), * significant at 0.05, ** significant at 0.01

	REG	OTS	HV	HS
REG	1			
OTS	**Time** r = 0.527** p = 0.004 **Confidence** r = 0.678** p < 0.001	1		
HV	**Time** r = 0.718** p < 0.001 **Confidence** r = 0.597** p = 0.001	**Time** r = 0.703** p < 0.001 **Confidence** r = 0.840** p < 0.001	1	
HS	**Time** r = 0.527** p = 0.004 **Confidence** r = 0.705** p < 0.001	**Time** r = 0.668** p < 0.001 **Confidence** r = 0.893** p < 0.001	**Time** r = 0.548** p = 0.003 **Confidence** r = 0.930** p < 0.001	1

4.5.2.3 NASA TLX

I found many correlations when I looked at the NASA TLX data collected. Tables 5.2-5.5 show the correlations and significance values for each of the comparisons made. It is important to note that in general I was looking for a significance value of 0.05 or less, which I have marked with a single asterisk, but I have also noted the cases in which significance is 0.01 or less by two asterisks.

There were no significant correlations between total number of errors or time per block placement and any of the NASA TLX indicators. I believe this lack of correlation is due to the fact that the subjects performed very well in all four of the conditions. Therefore, they all felt successful and rated the NASA TLX indicators as such. However, there were some correlations among the NASA TLX indicators. Perceived mental demand was correlated with several other NASA TLX indicators including frustration level, perceived performance, and physical demand.

Table 5.2. Correlations between NASA TLX mental demand and NASA TLX perceived performance

Condition	**Pearson Correlation**	**Sig. (2-tailed)** *** significant at 0.05** **** significant at 0.01**
REG	0.444	0.018 *
OTS	0.408	0.031 *
HV	0.298	0.124
HS	0.464	0.013 *

Table 5.2 shows the correlation between perceived mental demand and perceived performance. The significant positive correlations imply that the less mentally demanding the task, the more successful they felt they were in accomplishing the goals set out for the task. The only case in which there was not a significant correlation was

the HUD-visible case. I believe this case is not significant because, in general, it is one of the more mentally demanding cases (second worst to the HUD-side case), but people still did quite well on it. Therefore it was rated higher than the other cases in mental demand, but people still felt like they performed well.

Table 5.3 shows the correlation between perceived mental demand and perceived frustration level. These significant relationships implied that the more mentally demanding the tasks were to complete, the more insecure, discouraged, irritated, stressed and annoyed they became. This relationship held for all four of the conditions.

Table 5.3. Correlations between NASA TLX mental demand and NASA TLX frustration level

Condition	**Pearson Correlation**	**Sig. (2-tailed) * significant at 0.05 ** significant at 0.01**
REG	0.628	< 0.001**
OTS	0.560	0.002**
HV	0.457	0.014*
HS	0.706	< 0.001**

Table 5.4 shows the correlation between perceived mental demand and perceived physical demand. There was not a significant correlation between mental demand and physical demand for the AR-registered case. I believe this is due to the fact that the subjects merely had to look at the graphical target locations already shown on the physical Lego base plate and simply place the blocks. In the other three cases, there is more physical effort required and more thought processes that have to occur because of the physical motion. In both the AR-off-to-side case and the HUD-side case, the subjects had to turn their heads to the side to see the graphical augmentations. This head movement and the location of the graphics outside of the field of view while looking at the physical Lego board caused the subjects to have to develop some sort of strategy for remembering where to place the block. Therefore these extra mental efforts combined

with the extra head movements explain the positive correlation between these two indictors.

Table 5.4. Correlations between NASA TLX mental demand and NASA TLX physical demand

Condition	Pearson Correlation	Sig. (2-tailed) * significant at 0.05 ** significant at 0.01
REG	0.290	0.134
OTS	0.376	0.048*
HV	0.546	0.003**
HS	0.545	0.003**

While the AR-off-to-side case is not quite as significant as the HUD-side case, it is still significant. I believe this is because the similarity of the size and location of the graphical board with respect to the physical board is more relatable than the size difference and board placement in the HUD-side case. There was more mental effort required in the second case, thus causing the correlation between mental demand and physical demand to be more significant. In the HUD-visible case, again the change in size of the board resulted in more mental modeling and so did the constant switching of focus between the physical board and the graphical board cluttering the subject's field of view. However, there was no actual physical demand in this case due to head movement like the AR-off-to-side case and the HUD-side case. I believe that there is a significant correlation between mental demand and physical demand for the HUD-visible case because people were definitely under more mental demand in this case and they perceived this additional mental demand as physically demanding as well.

Table 5.5 shows the correlations between perceived performance and frustration levels. These significant relationships implied that the more insecure, discouraged, irritated, stressed and annoyed they became, the less successful people felt they were at completing the task. Only the HUD-visible case was not significant, although it was very closely approaching significance. I believe that this case was only approaching significance because it is the most frustrating of the cases, but people still felt they did really well at it. Having the graphics always visible in their field of view was really frustrating, but it did not interfere with their ability to successfully complete the task.

Table 5.5. Correlations between NASA TLX perceived performance and NASA TLX frustration level

Condition	Pearson Correlation	Sig. (2-tailed) * significant at 0.05 ** significant at 0.01
REG	0.524	0.004**
OTS	0.532	0.004**
HV	0.369	0.053
HS	0.467	0.012*

The NASA TLX correlations implied that the more mentally and physically demanding the tasks were, the more frustrated the subjects got. And in turn, the more frustrated the subjects got, the more their perceived successfulness in completing the tasks decreased.

5.4.3 Planned Comparisons

In this section, I describe several multivariate analyses using repeated measures that I used to evaluate the data.

5.4.3.1 Average Error and Average Block Placement Time between the Cases

The within-subjects factor was the display condition, and the two measures I was evaluating were average number of errors made per block placement and time per block placement. The results of the pair wise comparisons for the estimated marginal means for number of errors made and time per block placement can be found in Tables 5.6 and 5.7.

The pair wise comparisons between the different conditions for average number of errors made, shown in Table 5.6, showed no significant differences between the cases. These results are due to the fact that only a small amount of errors were made in general. In terms of number of errors made, there was only an almost significant difference between the AR-registered case and the HUD-side case. I believe this difference lies within the physical and mental demands of the individual tasks. The AR-registered case shows the graphical target right on the Lego base plate and in the same size as an actual block, while the HUD-side case requires the subject to turn their head to the side to see the graphical display of the Lego board and memorize where to place the block when they look back at the physical board. In addition, the HUD-side case displays a graphical Lego base plate that is actually smaller than the physical Lego board and the subject must deal with the additional mental demands due to the size difference. It should be noted that in general the subjects mostly made mistakes when they were trying to rush through the tasks and were not being careful enough when placing the blocks. The subjects that took their time and/or double checked their placements almost never made a mistake.

Table 5.6. Pairwise comparisons for average number of errors made per block placement

	REG	**OTS**	**HV**	**HS**
REG	1			
OTS	F = -0.010 Sig. = 0.170	1		
HV	F = -0.004 Sig. = 0.602	F = 0.006 Sig. = 0.477	1	
HS	F = -0.016 Sig. = 0.073	F = -0.006 Sig. = 0.523	F = -0.012 Sig. = 0.161	1

The pair wise comparisons between the different conditions in terms of average time per block placement, shown in Table 5.7, produced different results. In terms of time per block placement, almost all of the cases were significantly different from each other except for one. This implied that the AR-registered case was significantly quicker than all of the other cases, the AR-off-to-side case was significantly quicker than the HUD-side case, and the HUD-visible case was significantly quicker than the HUD-side case.

As already stated, there were two cases that were not significantly different in terms of time per block placement: the AR-off-to-side case and the HUD-visible case. The results showed that the AR-off-to-side case was slower than the HUD-visible case, but the difference was only approaching significance. I believe that the difficulties associated with these cases (turning your head in the AR-off-to-side case and switching focus between the graphics and the real world in the AR-visible case) while being totally different in terms of actions required, had similar effects on the time to place the blocks.

Table 5.7. Pairwise comparisons for average time per block placement

	REG	OTS	HV	HS
REG	1			
OTS	F = -1.640** Sig. < 0.001	1		
HV	F = -1.227** Sig. < 0.001	F = 0.413 Sig. = 0.064	1	
HS	F = -2.382** Sig. < 0.001	F = -0.742** Sig. = 0.004	F = -1.155** Sig. < 0.001	1

When looking at both of these comparisons, it is interesting to note that location of the graphical instructions plays a part in successful task completion both in terms of time per block placement and number of errors made. Factors such as head movement and clutter on the screen greatly affect success rates.

5.4.3.2 NASA TLX Results between the Cases

The within-subjects factor was the condition and the measures I was evaluating were the NASA TLX results including perceived mental demand, physical demand, temporal demand, performance, effort, and frustration level. The results of the pair wise comparisons for the estimated marginal means for the NASA TLX results can be found in Tables 5.8 through 5.13.

The pair wise comparisons for NASA TLX mental demand, shown in Table 5.8, showed significant differences in the mental demand between the AR-registered case and all of the other cases. This implies that factors such as head movement and screen clutter require higher mental demand.

Table 5.8. Pairwise comparison for NASA TLX mental demand

	REG	OTS	HV	HS
REG	1			
OTS	F = -4.607** Sig. < 0.001	1		
HV	F = -4.929** Sig. < 0.001	F = -0.321 Sig. = 0.646	1	
HS	F = -5.107** Sig. < 0.001	F = -0.500 Sig. = 0.539	F = -0.179 Sig. = 0.825	1

The pair wise comparisons for NASA TLX physical demand, shown in Table 5.9, showed significant differences in the physical demand between the AR-registered case and the HUD-side case as well as the HUD-visible case and the HUD-side case. It also showed differences between the AR-registered and the AR-off-to-side cases as well as between the AR-off-to-side and the HUD-visible cases that were approaching significance. This implies that the act of having to turn your head to the side increases the physical demand on a subject.

Table 5.9. Pairwise comparison for NASA TLX physical demand

	REG	OTS	HV	HS
REG	1			
OTS	F = -2.143 Sig. = 0.066	1		
HV	F = -0.429 Sig. = 0.603	F = 1.714 Sig. = 0.079	1	
HS	F = -2.714* Sig. = 0.017	F = -0.571 Sig. = 0.549	F = -2.286** Sig. = 0.008	1

The pair wise comparisons for NASA TLX temporal demand, shown in Table 5.10, showed no significant differences among the cases except for between the AR-registered case and the HUD-side case. This implies that, for the most part, the subjects felt like they were under the same amount of time pressure for all of the cases. The significant difference between the AR-registered case and the HUD-side case is probably due to the fact that these cases have the greatest difference in the amount of time it takes to complete these tasks (4.697 seconds per block placement for the AR-registered case and 7.079 seconds per block placement for the HUD-side case), thus causing people to feel like they are under more time pressure in the HUD-side case.

Table 5.10. Pairwise comparison for NASA TLX temporal demand

	REG	**OTS**	**HV**	**HS**
REG	1			
OTS	F = -1.000 Sig. = 0.213	1		
HV	F = -0.429 Sig. = 0.648	F = 0.571 Sig. = 0.423	1	
HS	F = -1.643* Sig. = 0.041	F = -0.643 Sig. = 0.605	F = -1.214 Sig. = 0.148	1

The pair wise comparisons for NASA TLX perceived performance, shown in Table 5.11, showed significant differences in the perceived performance between the AR-registered case and all of the other cases. This implies that the fully registered case is much easier than the other cases, probably due to less head movement and memorization required as well as less screen clutter.

Table 5.11. Pairwise comparison for NASA TLX perceived performance

	REG	OTS	HV	HS
REG	1			
OTS	F = -1.607* Sig. = 0.035	1		
HV	F = -2.214** Sig. = 0.001	F = -0.607 Sig. = 0.381	1	
HS	F = -1.786** Sig. = 0.007	F = -0.179 Sig. = 0.790	F = 0.429 Sig. = 0.620	1

The pair wise comparisons for NASA TLX effort, shown in Table 5.12, showed significant differences in the effort required between the AR-registered case and all of the other cases. This again implies that the fully registered case is much easier than the other cases, probably due to less head movement and memorization required as well as less screen clutter to decipher.

Table 5.12. Pairwise comparison for NASA TLX effort

	REG	OTS	HV	HS
REG	1			
OTS	F = -2.607** Sig. = 0.005	1		
HV	F = -3.143** Sig. = 0.002	F = -0.536 Sig. = 0.496	1	
HS	F = -3.214** Sig. < 0.001	F = -0.607 Sig. = 0.355	F = -0.071 Sig. = 0.906	1

The pair wise comparisons for NASA TLX frustration level, shown in Table 5.13, showed significant differences in the effort required between the AR-registered case and all of the other cases. This again implies that the AR-registered case is much easier than the other cases and thus less frustrating, again probably due to less head movement and memorization required as well as less screen clutter to decipher.

Table 5.13. Pairwise comparison for NASA TLX frustration level

	REG	OTS	HV	HS
REG	1			
OTS	F = -1.893* Sig. = 0.033	1		
HV	F = -3.036** Sig. = 0.003	F = -1.143 Sig. = 0.333	1	
HS	F = -1.929* Sig. = 0.011	F = -0.036 Sig. = 0.968	F = 1.107 Sig. = 0.237	1

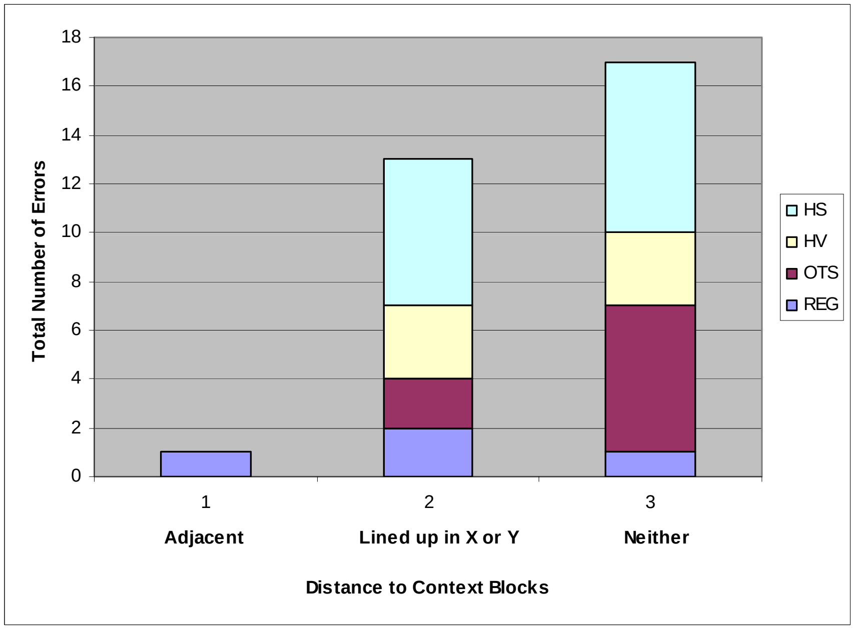
When looking at all of these comparisons, it is interesting to note that the AR-registered case is significantly different from the rest of the cases and the other three cases are not significantly different from each other. In terms of the NASA TLX indicators, the AR-registered case is significantly less demanding than the other three cases. The results of this analysis have some implications on future application development. They imply that if you can not fully register the graphics in an AR system, than it will be difficult to create something significantly better than a HUD. Orientation-only tracking is much less expensive and easier to implement, so if perfect registration if not possible or not required, there is no need to use an expensive tracking system. However, it is important to note that even though the results of this study imply that orientation-only tracking is an ideal option, especially the HUD-visible case because it scored so well in terms of number of errors made and block placement times, it is not always a good solution. Other factors need to be considered such as the task being performed, the possible effects of clutter on the screen, the frustration levels associated with the HUD cases, etc.

5.4.3.3 Distance to Context Blocks

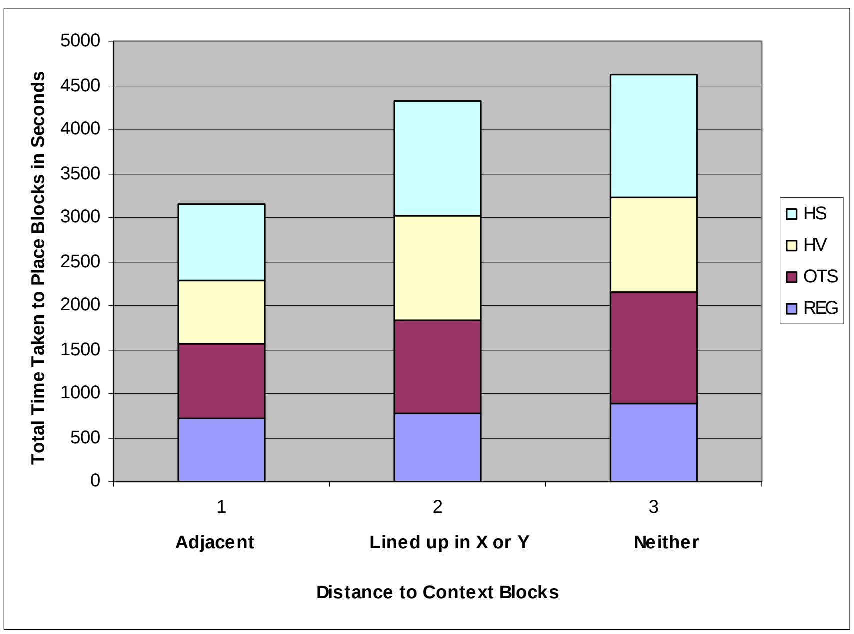
As I was running subjects through my previous study discussed in Chapter 4, I noticed some interesting behavior regarding distance between the blue context blocks and the target locations. People seemed to have an easier time placing the yellow blocks when they were located adjacent to the blue context blocks or when the yellow blocks were lined up with the blue context blocks either along the X direction or the Y direction. Therefore, I divided the block placement tasks into three types: adjacent to the context, lined up in X or Y with the context, and neither, meaning the yellow blocks were being placed somewhere else on the board, but had no adjacency or linear alignment with the context blocks.

Because of this observation, I took a closer look at this phenomenon while running this study. I designed the target locations so that for each of the 18 blocks placed per block of trials, six would be adjacent to the context blocks, six would lined up in X or Y with the context, and six would not have either of the above relations to the context blocks. A 3x3 Latin squares design was used within each of the blocks of trials to determine the ordering of each of the distance possibilities. And each of the four conditions of the trials had a different starting distance and ordering of the blocks to avoid learning effects.

Figure 5.3 shows the number of errors and total block placement times for each of the three distances from the context blocks mentioned above. The graphs show that having the yellow target block location adjacent to or linearly aligned with the blue context blocks produced the fewest number of errors and the tasks were completed in the least amount of time. I ran a univariate analysis of variance (ANOVA) on the data and looked at the pair wise comparisons of the estimated marginal means. I discovered that there is a significant difference in error between the adjacent case and the neither case ($F = -0.667$, Sig. = 0.014) and the difference between the adjacent case and the lined up in X or Y case is approaching significance ($F = -0.500$, Sig. = 0.063). However, there was no significant difference in error between the lined up in X or Y or neither cases.



(a)



(b)

Figure 5.3. Average number of errors and average time to place blocks as they relate to distance to context blocks.

I also discovered that there is a significant difference in time per block placement. Again there is a significant difference between the adjacent case and the neither case (F = -61.298, Sig. < 0.001) and between the adjacent case and the lined up in X or Y case (F = -48.411, Sig. < 0.001). Again there was no significant difference between the lined up in

X or Y case and the neither case. I can attribute these differences in time and error in the adjacent case to the ease of being able to simply place a block right next to a context block without even having to think about it. And in terms of the lined up in X or Y case, while it was a time savings and fewer errors were made, as compared to the neither case, for the subjects to put the yellow block next to one of the context blocks and run it up or down the axis to the correct location with only having to count pegs along one axis instead of two, the differences were not significant.

I performed several other univariate analyses of variance (ANOVA) to compare the total errors made and the total time taken to the distance from the context blocks. I found that in the AR-registered case, the total number of errors made did not differ significantly between the different distance cases. However, with respect to total time taken to place the blocks, the difference between the times did significantly differ. I found that the adjacent and neither cases differed significantly ($F = -28.149$, $p = 0.033$), but the adjacent case and the linearly aligned cases and the linearly aligned and neither cases were not significantly different.

In the AR-off-to-side case, the results varied from the perfect cases. I found that there was a significant difference in number of errors made between the adjacent case and the neither case ($F = -1.000$, $p = 0.044$). I found that the total times varied significantly between the adjacent case and the neither case ($F = -69.402$, $p < 0.001$) and between the linearly aligned case and the neither case ($F =-39.212$, $p = 0.022$). Again there was no significant difference between the adjacent and linearly aligned cases.

In the HUD-visible case, I found no significant differences in error between the different distances to the context block locations. In terms of time, there were significant differences between the adjacent case and the linearly aligned case (F = -79.096, p =

0.001) and between the adjacent case and the neither case (F = -60.013, p = 0.005). Again there was no significant difference between the linearly aligned and the neither cases.

In the HUD-side case, I again found no significant differences in error between the different distances to the context block locations. In terms of time, there were significant differences between the adjacent case and the linearly aligned case (F = -72.363, p = 0.017) and between the adjacent case and the neither case (F = -87.628, p = 0.005). Again there was no significant difference between the linearly aligned and the neither cases.

In summary, although the levels of significance (or approaching significance) did vary a bit, the overall observation is that the target blocks that are located adjacent to the context blocks are easier to place in terms of errors and times than both of the other location possibilities.

5.4.4 Confidence

One of the big differences I saw in this study as compared to the previous study was in subject confidence levels of block placements. Since the confidence levels were all so high, I looked at the median confidence levels per condition for each of the subjects and found a median confidence level of 5 (out of 5) for each of the cases. Therefore I looked at the frequencies of each of the confidence levels. In 3 out of the 4 conditions, everyone reported a median confidence of either 4 or 5. And in one condition, the HUD-visible case, there was one confidence value of 3 reported (3.6%). In both the AR-registered and AR-off-to-side cases, 89.3% of the time a confidence level of 5 was reported and in the HUD-visible and HUD-side cases, 85.7% of the time a confidence level of 5 was reported. I believe that this difference in confidence levels between the studies is due to the fact that the first study imposed several types of error into the system that required the subjects to develop many mental models to deal with the error causing many mistakes to be made, influencing confidence levels. In this study, a full rendering of the task, including the base plate, provided much greater context at the expense of screen clutter. So, as long as the subject took their time, there was little chance of making an error.

5.5 Discussion

In this section I discuss the relationship between my findings and my previously stated hypotheses.

5.5.1 Effects of Registered AR and Non-Registered Graphics on Average Number of Errors and Average Placement Time

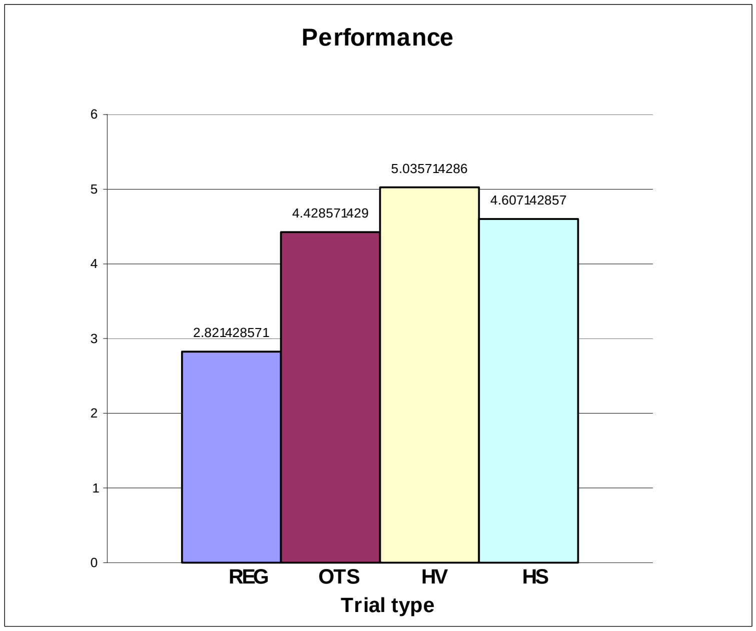
When exposed to registered AR and non-registered graphics, I predicted that a user can perform placement tasks very easily with few errors, but the time it takes to complete the tasks may differ because of the nature of each task. As discussed in the Descriptive Statistics section, Section 5.4.1, the subjects completed the four Lego block placement tasks with few errors, but the times did vary among the conditions due to several factors such as head movement, need for memorization and screen clutter.

5.5.2 Comparing Fully Registered AR to Non-Registered Graphics

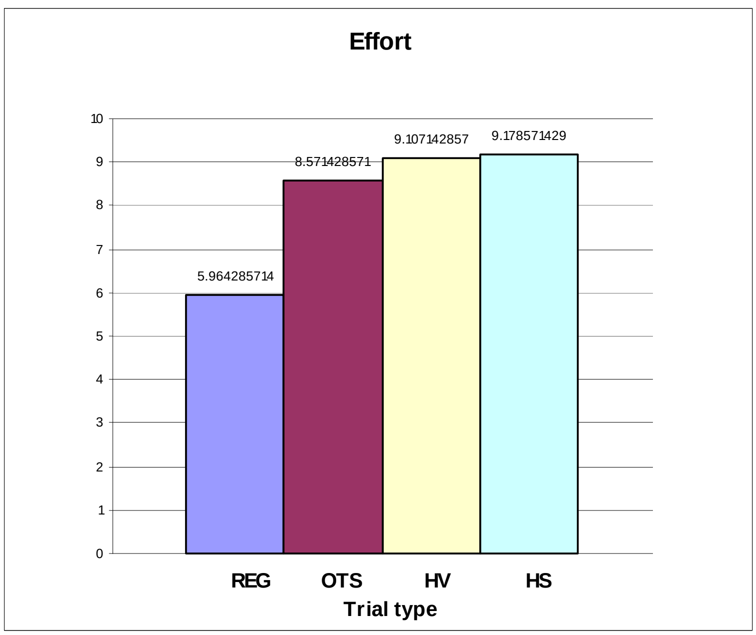
When comparing fully registered AR to the three other types of non-registered graphics, I predicted that subjects will perform better in the fully registered AR case and will find that case easier to complete than the other three cases. I also predicted that the subjects will have lower trial times and errors as well as cognitive load in the AR-registered case. As previously mentioned in the results section, and seen in Figure 5.2, the AR-registered case was significantly faster than all of the other conditions in terms of time per block and was easier in terms of number of errors made as compared to the other cases, but there was not a significant difference. In terms of cognitive load, the AR-registered case performed better in all six measures of the NASA TLX: mental demand, physical demand, temporal demand, performance, effort, and frustration level. The results of the multivariate analyses using repeated measures can be seen in Tables 5.8-5.13. While the differences between the AR-registered case and the other cases were not always significant, the AR-registered case always outperformed the other cases.

5.5.3 Comparing Augmented Reality and a Heads-Up Display

When exposed to both AR and a HUD, the AR conditions will seem more natural to a user because the graphics remain in the same position, much like a user manual placed next to the user on a desk. Therefore, I predicted that the AR conditions will have lower trial times and errors as well as cognitive load as compared to the Heads-Up Display conditions. In terms of trial times and errors, the AR-registered case upheld this hypothesis, but in the AR-off-to-side case, this hypothesis did not hold. I actually found that the HUD-visible case outperformed the AR-off-to-side case both in terms of errors made and block placement times. I failed to anticipate the effects that head movement would have on placement times and the effects that memorization requirements would have on number of errors made and block placement times. These factors played a large role in shaping task performance in terms of error and time, as well as perceived performance, as shown in Figure 5.4(a). However, it did seem like the AR conditions were more natural to the users than the HUD conditions as evidenced by their NASA TLX ratings for effort, shown in Figure 5.4(b).



(a)



(b)

Figure 5.4. NASA TLX perceived performance and effort between the conditions

5.5.4 Effects of Head Movement on Block Placement Time

I expected that placement time will be affected by the head movement required for each of the cases. Some of the cases require no head movement, while others require looking to the side to see the graphics. Therefore, I predicted that the block placement times will be slower for the two cases in which the users have to turn their heads to the side to see the graphics: AR-off-to-side case and the HUD-side case. My hypothesis regarding head movement held. Subjects clearly took less time to complete the tasks in which the graphics were always located on the screen, shown in Figure 5.2(b). There was a significant difference between the AR-registered and the AR-off-to-side cases as well as between the AR-registered and the HUD-sides cases, shown in Table 5.7. The AR-registered case was significantly faster than the other two cases because of less head movement required. In addition, Table 5.7 shows that the HUD-visible case took less time then both the AR-off-to-side case and the HUD-side case; however, only the difference between the HUD-visible case and the HUD-side case was significant. The HUD-visible case was approaching significantly less time than the AR-off-to-side case, but it was not actually significant. This implies that while the HUD-visible case was faster than the AR-off-to-side case, the fact that the users had to deal with the graphics cluttering up the view screen caused the difference in speed to be insignificant.

5.5.5 Effects of Screen Clutter on Block Placement Time

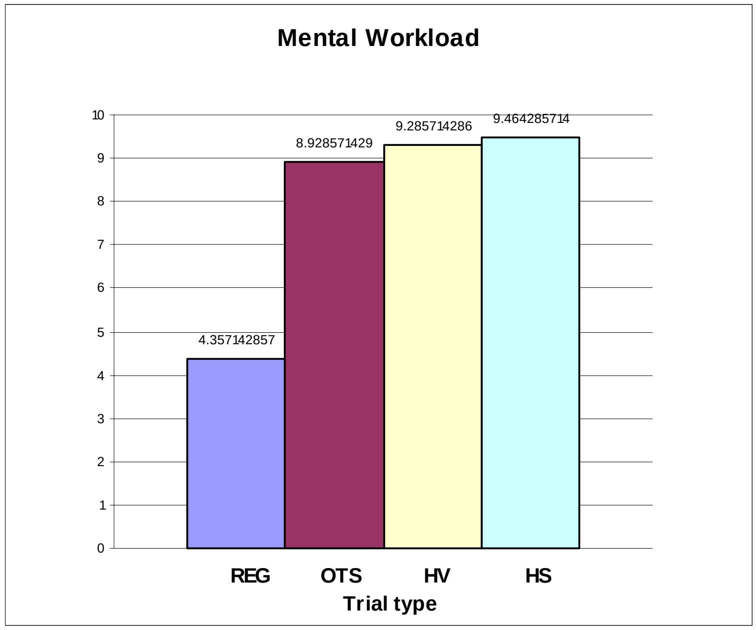
I expected that the amount of clutter on the screen will affect the placement time for the given tasks. Also, tasks in which the graphics interfere with the user's view of the real world will be slower than tasks that have less clutter in the field of view. Therefore, I predicted that the block placement times will be slower for the case in which the graphics are always located in the field of view: the HUD-visible case. Surprisingly, despite the fact that the HUD-visible case was extremely annoying and frustrating to the users, they still were able to complete the tasks quickly. These results actually show that technically graphics always visible via a HUD is a good option performance wise, if registered AR is not possible. Although for user friendliness, as evidenced by the NASA TLX indicators mental workload, effort, perceived performance and frustration, this method is either the worst or very close to the worst.

5.5.6 Effects of Head Movement on Perceived Mental Workload and Frustration

The perceived mental workload and frustration of a subject will be affected by the location of the graphical instructions. In the cases where the graphics are located outside of the subject's field of view, the subjects will have to develop strategies for remembering where to place the block when they look back at the task space. Therefore, I predicted that the perceived mental workload and frustration of a subject will increase when the graphics are not located in their field of view. This hypothesis holds true for a fully registered AR system, but not for a HUD where the graphics constantly block the task space, as seen in Figure 5.5. The extra annoyance of having to switch focus between the physical Lego board and the graphics blocking the screen space greatly affect mental workload as well as frustration and cause the differences to be insignificant.

5.5.7 Effects of Screen Clutter on Perceived Mental Workload and Frustration

The perceived mental workload and frustration of a subject will be affected by the amount of clutter on the screen. When the graphics are in the field of view, but blocking their view of the real world, the subjects will have to develop a strategy for changing their focus between the real world and the graphical world. Therefore, I predicted that the perceived mental workload and frustration of a subject will increase when the graphics are cluttering their view of the task space. This hypothesis holds true, as seen in Figure 5.5. While the increase in mental demand and frustration for this case is significantly more than the AR-registered case, it is still higher than the AR-off-to-side case in both mental workload and frustration and almost equally as mentally demanding as the HUD-side case, but much more frustrating.



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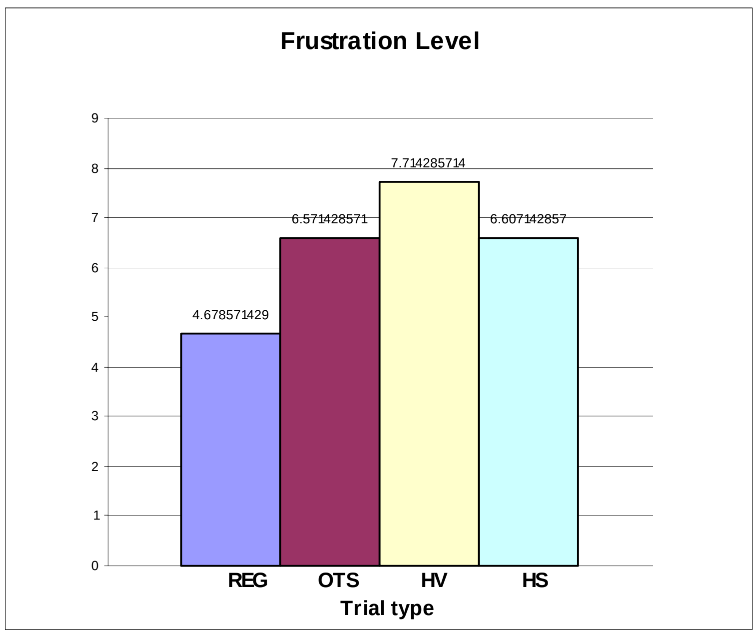
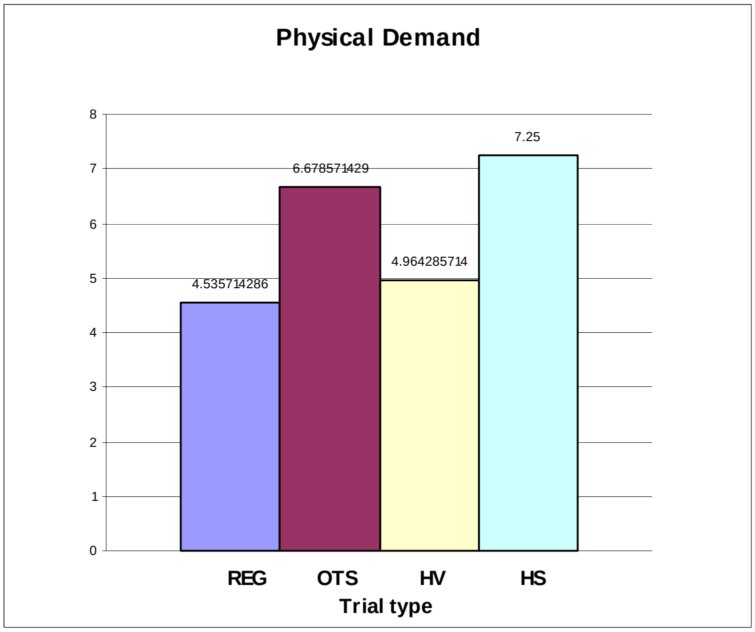


(b)

Figure 5.5. NASA TLX mental demand and frustration level between the conditions

5.5.8 Effects of Head Movement on Perceived Physical Demand

The perceived physical demand of a subject will be affected by the location of the graphics. When the graphics are located in the subject's field of view, the task will be less physically demanding to complete than when the graphics are outside of the user's



(a)

Figure 5.6. NASA TLX physical demand between the conditions

field of view because there is no additional head movement required. Therefore, I predicted that the perceived physical demand of a subject will increase when the graphics are not located in their field of view. As seen in Figure 5.6, this hypothesis holds true, but the values are not significantly different between all of the cases, as shown in Table 5.9.

5.5.9 Effects of Block Location on Errors and Placement Time

The distance between the context blocks and the target location of the virtual block will affect a subject's ability to place a block. Therefore, I predicted that when the context block is adjacent to the target location of the block, the subjects will perform better in terms of errors and placement time than if the target location of the block is lined up horizontally or vertically with a context block or if the target location has no relation to the context block. I also predicted that when the context block is lined up horizontally or vertically with a context block, the subject will perform better in terms of errors and placement time than if the target location has no relation to the context block. As seen in

Figure 5.3 and discussed in Section 5.4.3.3, having the target location adjacent to the context blocks outperformed both of the other distance cases both in error and time. And the linearly aligned case outperformed the neither case in both error and time. These results have implications for designing AR systems. When designing an AR system that uses context, it is important to take in as many contextual cues as possible. It would behoove a designer to put thought into the relationship between the context and the task because well-placed context definitely improves task performance.

5.5.10 Observations

While running subjects through this study, I noticed some very interesting behavior.

5.5.10.1 Block Placement Strategies

The subjects in this study used many different strategies for placing the physical blocks. In general, some subjects were extremely confident in their placements and immediately placed the physical block in the correct location, but usually they developed additional strategies.

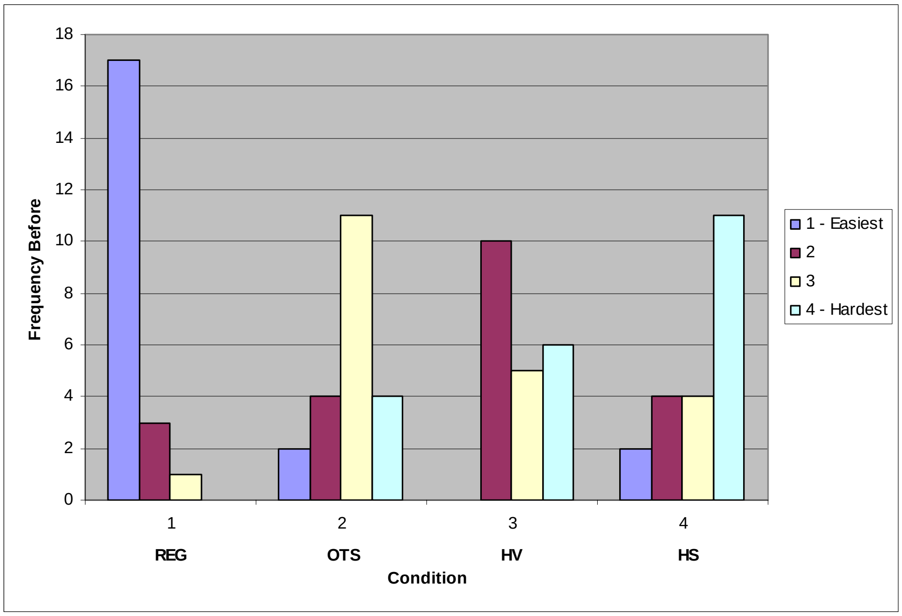
Many of the strategies I noticed concerned speeding up block placement times. In the AR-off-to-side and HUD-side cases, some subjects would turn their heads to the side before they pushed the start button in order to speed up their placement times. Since the HMD screen did not completely block the subject's field of view to the outside world, I noticed several people looking outside of the HMD screen to place the blocks. In the HUD-visible case a few subjects did this to avoid the on screen clutter and in the HUD-side case one subject positioned her body so that the graphical instructions were displayed on the HMD screen at all times and then looked out the side of the HMD to actually place the block, avoiding extra head movements.

In terms of general block placement, several subjects used their fingers to count the pegs between the context blocks and/or the edges of the base plate in order to place their block. Several subjects would line up the yellow block with the context block and then move it up the row or column until the correct position was reached. In the AR-off-to-side case I noticed one subject drawing a line with their finger from the graphical row to the physical row since they were perfectly aligned.

5.5.10.2 Subject Predicted Results of the Various Conditions

I asked the subjects to rate each of the cases in order of easiness to complete both before they completed the tasks and after. I wondered if they had any preconceived notions about how they might like data to be displayed on an HMD screen and whether those notions held true after they actually performed the tasks.

As seen in Figure 5.7, in general the majority of the subjects thought that the AR-registered case would be the easiest case to perform. Before completing the tasks, the majority of the subjects thought that the HUD-visible case would be the second easiest task, but by the time they completed the tasks they quickly realized how frustrating it was and rated it as the hardest case. There were many comments made such as "I don't like looking through the virtual board" and "that was really annoying." This is interesting because even though they liked the HUD-visible case the least, they performed better in that case than they did in the AR-off-to-side case and the HUD-side case. In both before and after completing the tasks, the subjects thought that the AR-off-to-side case would be easier than the HUD-side case. While these results do not have any statistical value, it was interesting how people thought they would like certain conditions and how after they experienced them they changed their mind.



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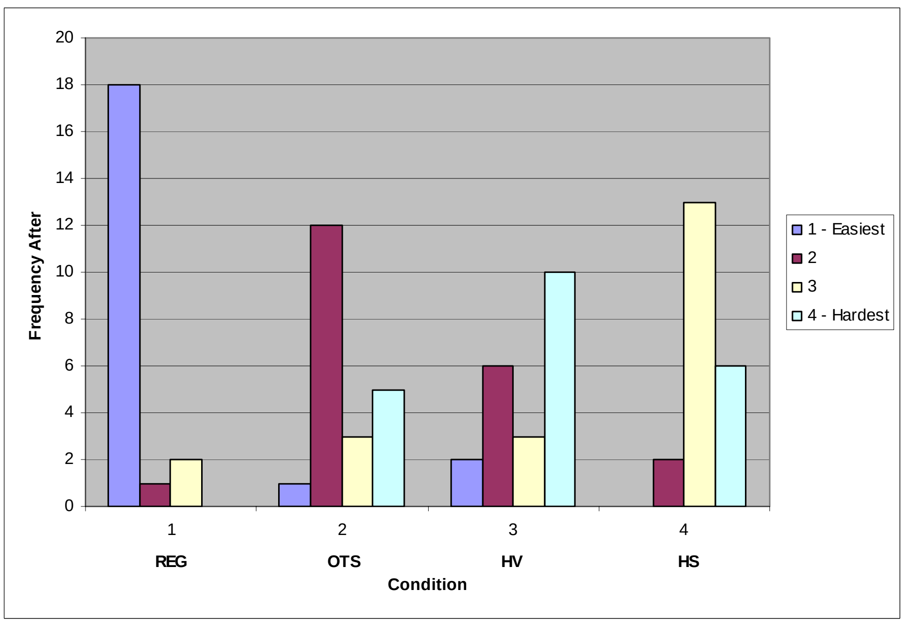


(b)

Figure 5.7. The four conditions rated easiest to hardest before (a) and after (b) the subjects completed the tasks

5.5.11 Implications for AR Design

One of the goals of this study was to gain some insight into how to better design AR systems. I learned several things in this study that have significant implications for future AR designs.

First, the use of appropriate context does improve task performance and therefore, some careful thought should be exercised when designing an AR system in which registration error cannot be totally eliminated. Carefully placed context is a very useful contextual cue. However, I do realize that the use and choice of context is extremely task specific. I am aware of the fact that I cannot make any speculations as to what kind of context is most useful in general. I can perhaps suggest some guides regarding alignment of context. But in general, I can suggest that the use of context is helpful and should be considered.

Second, as mentioned in the introduction to this chapter, I was motivated by the inappropriateness of having computer graphics block a worker's view of the task space for some tasks. I learned that displaying the graphics in a user's field of view, thus blocking the real world, can be useful in terms of success rates, but extremely frustrating in practice if it is not registered. Therefore, while this is a viable option, care must be taken when looking at the requirements of an AR or wearable system. Adding any non-trivial amount of frustration or confusion by blocking a worker's field of view could be detrimental to the task. At one extreme, if a surgeon was using an AR system to aide in surgery, blocking the field of view would probably not be wise. However, even though there might not be as much obvious cause for concern in a non-safety critical task, such as an AR system being designed to walk a repair person through a repair task, blocking the workers view might create safety concerns for the worker. The chief technology officer for John Deere[1], for example, expressed extreme hesitance to add any technology

[1] Personal communication.

to an assembly line that could reduce a worker's view of the task space, citing worker safety and associated legal liability issues for the company.

Third, I wanted to evaluate the usefulness of orientation-only tracking. I found that low-level orientation-only tracking can be used to provide enough information to create useful augmentations. While the AR-registered case and the AR-off-to-side case had some benefits over the heads-up display cases, only the AR-registered case was significantly better than the heads-up display cases for all of the metrics analyzed. The fact that the AR-off-to-side case was not significantly different than either of the heads-up display cases is an important discovery because the heads-up display cases are easier and cheaper to implement. There appears to be no need to waste time and money designing an AR system that utilizes an expensive tracker if you cannot get perfect registration, since a heads-up display accomplishes the required goals of the system design. This discovery has significant implications on the designs of future AR systems for many reasons. More sophisticated tracking systems are not always available and are most definitely not as easy to implement. If precisely registered graphics are not a requirement of the system, the use of orientation-only tracking is an easy and inexpensive way to implement an AR system that keeps graphics from cluttering the task space.

5.6 Conclusions

This study has shown that registered AR outperforms both non-registered AR and graphics displayed on a heads-up display. I have also shown that non-registered AR does not offer any significant performance advantages over a heads-up display, but is rated as less intrusive and can keep non-registered graphics from cluttering the task space.

CHAPTER 6

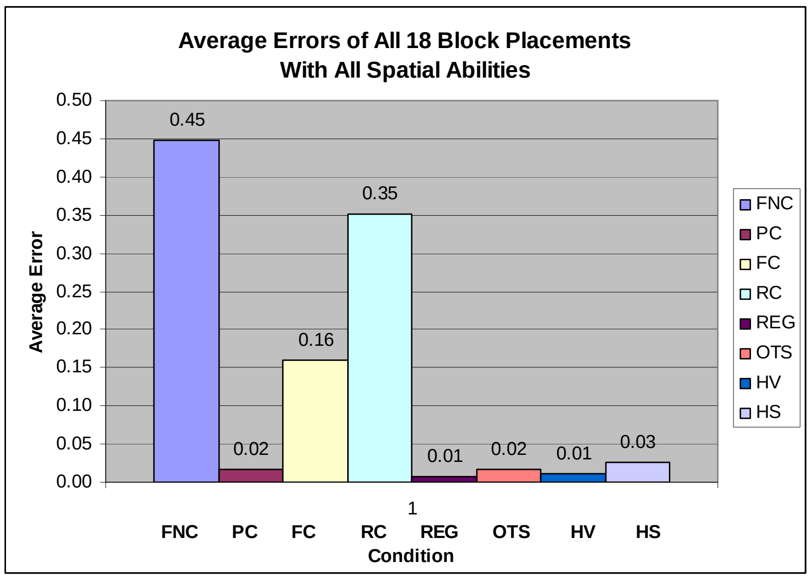
DISCUSSION OF STUDY 1 AND STUDY 2 RESULTS

The intent of this dissertation was to show that AR systems can function even when registration error between the user's view of the graphics and the user's view of the physical world creates an ambiguous scene that is confusing to the user. My thesis is that providing graphical context can increase a user's ability to understand the intent of misregistered augmentations. I attempted to prove this statement by running two user studies: one study that evaluates the use of graphical context in fighting the effects of several different types of registration error and another study that shows that graphical augmentations and context do not need to be located in the task area to be useful.

In Chapter 5 I noted that if precisely registered graphics are not a requirement of the system, situating graphics outside of the task area, including using orientation-only tracking, is an easy and inexpensive way to implement an AR system that keeps graphics from cluttering the task space. Even though doing a separate study to directly compare the two approaches is beyond the scope of this dissertation, in this chapter I will compare the results of both studies and discuss the relative merits of both approaches: adding graphical context to compensate for registration error and situating the graphics outside of the task area.

6.1 Comparison of Errors and Block Placement Times

Figure 6.1 shows the average number of errors and average time per block placement for the context cases in the first study as well as all of the cases in the second study. In addition, I have included the fixed error no context case from the first study because after the subjects learned how to cope with the registration error in the system, their performance tended toward the perfect case. I did not include the perfect no context case in this analysis because I found no statistical significance between the perfect no context case and the perfect with context case. Also, it is important to note that in all of these analyses the perfect with context case in the first study and the AR-registered case in the second study represent the exact same experimental conditions, even though the values differ slightly. Because these two conditions are identical, the data within the two studies can be compared.



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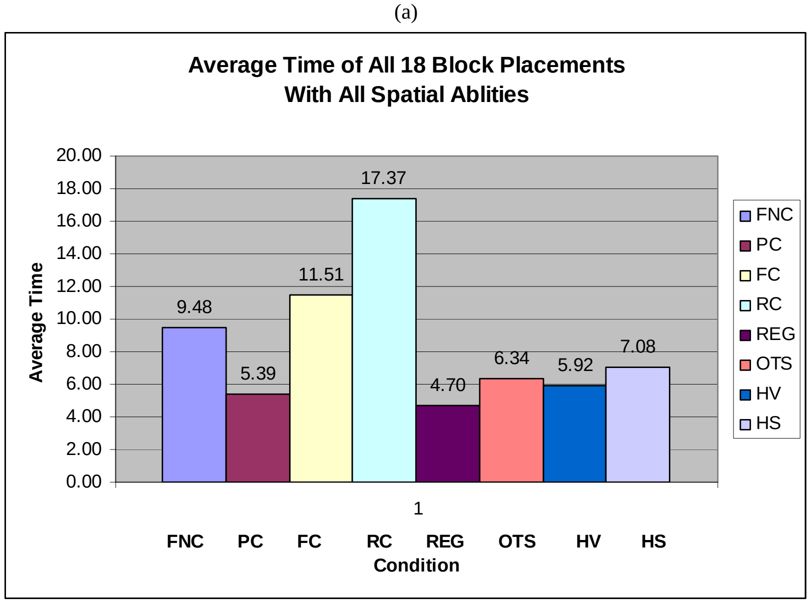


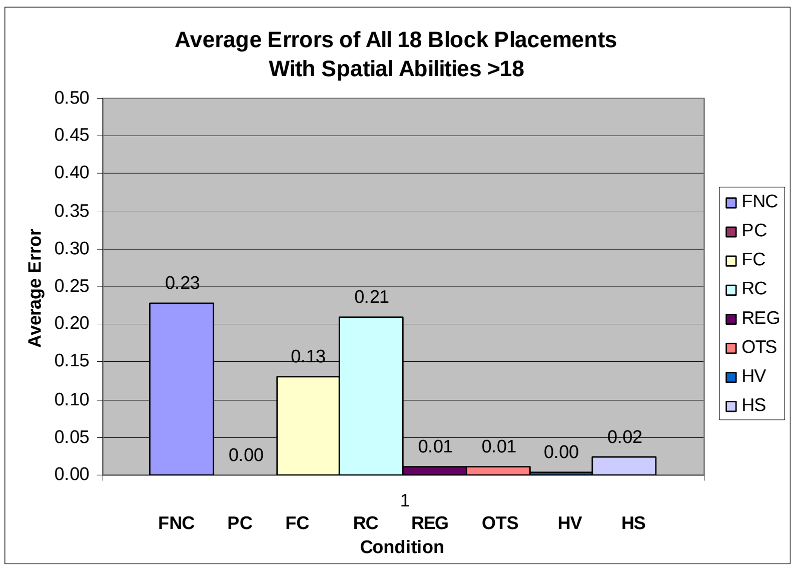
(b)

Figure 6.1. Comparing error and time data from study 1 and study 2

Figure 6.1(a) shows that the average number of errors were larger in the first study than in the second study. Figure 6.1(b) shows that the average time per block placement was higher in the first study than in the second study. I believe that there are several reasons that the error and time results are worse for the first study than they are for the second study.

I believe one of the reasons there is such a difference between the two studies is that on average, the spatial abilities of the subjects in the first study were lower that the spatial abilities of the subjects in the second study. The average spatial abilities score in the first study was 15.65/21 and the average score in the second study was 17.65/21. Because of this difference in spatial abilities scores, I broke down the data and analyzed the error and time scores for people with high spatial abilities. The results of this analysis are shown in Figure 6.2. Figure 6.2 shows that both the time and error results for the first study are still worse than for the second study, but the differences between the values have greatly decreased and are much more comparable.

Another factor that I believe may be responsible for the differences between the studies related to the conditions subjects were exposed to in the two studies. In the first study, the subjects were trained on how to place blocks when no registration error was present, and they were not informed what type of error they were being exposed to in the different trials. It was their responsibility to figure out what type of error they were dealing with on their own. The unknown error condition in each trial caused the subjects not to trust what the system was showing them. Therefore, they were prone to making more errors, spending more time per block placement. In addition, time per block placement was greatly affected by the context that was provided. The subjects took a lot of time interpreting the graphical context provided, and in many cases the context appeared to be a crutch that the subjects leaned on. In the perfect with context and fixed with context cases, the subjects should not have needed the context after they figured out the correct displacement of the target block, but in a lot of cases, the subjects would continue to use the context for every block placement in the trial. The context, in these cases, seemed to dissuade the subjects from learning. Perhaps in a "real" situation, where people were using this day in and day out, they would eventually learn, but in the context of this experiment, they did not try to learn.



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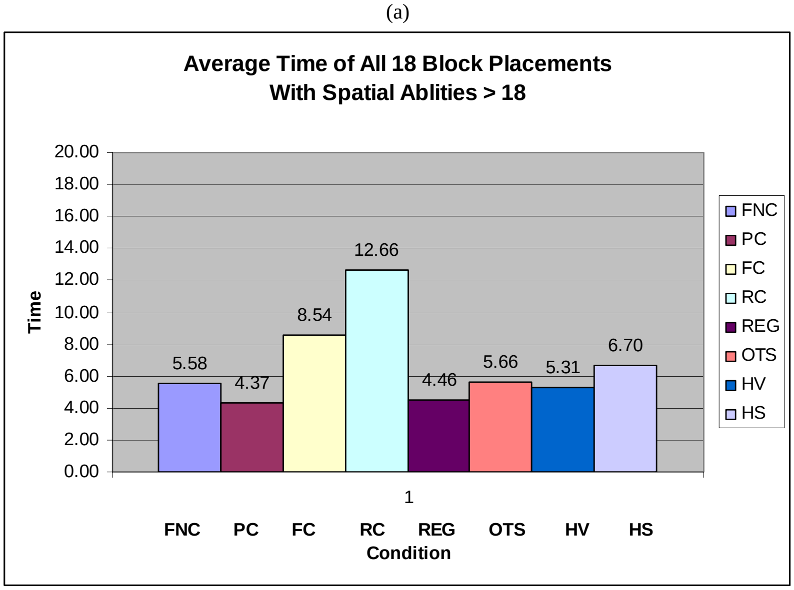

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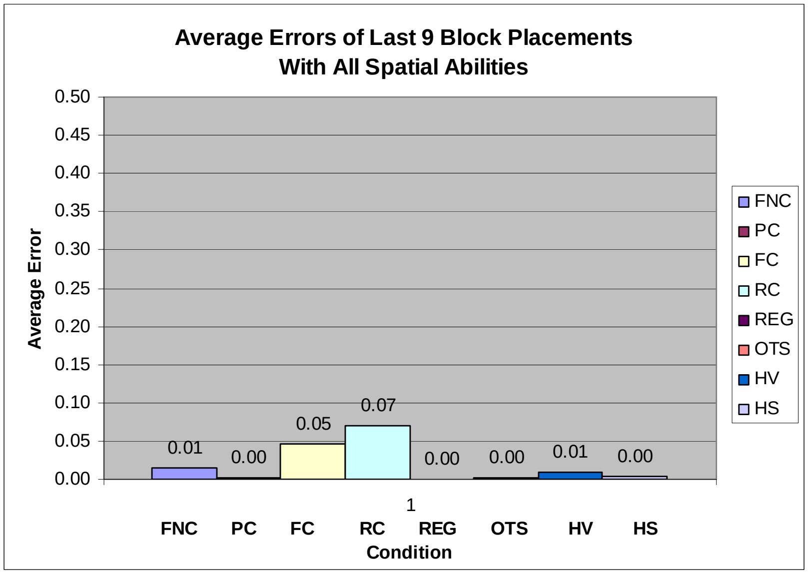
Figure 6.2. Comparing error and time data from study 1 and study 2 for spatial abilities over 18



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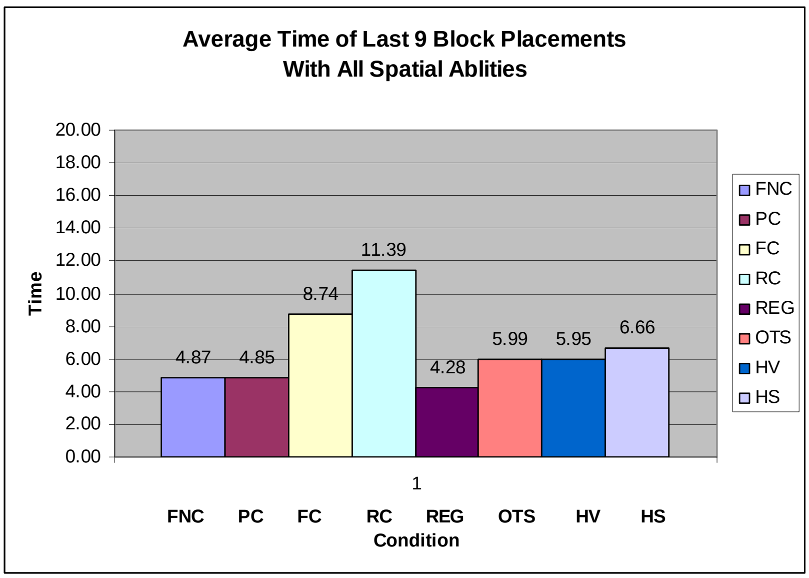

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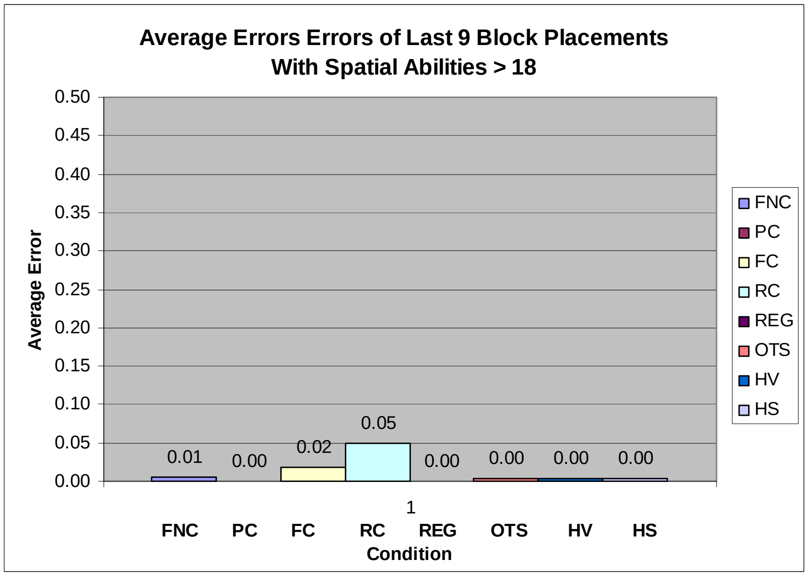
Figure 6.3. Comparing error and time data from study 1 and study 2 for only the last nine block placements

In the second study, there were no significant errors in the system to deal with, only differences in how and where the information was displayed on the screen. Also, the subjects were told which condition they were in before they started each trial. Therefore, the learning curve was much lower in the second study. Figure 6.3 shows the error and time per block placement results for only the last half of the block placements. I removed the data from the first nine block placements per condition to attempt to reduce the learning effects. Figure 6.3 shows that the fixed no context case is similar to the conditions in the second study for both time and error, but the fixed and random context cases are still not performing as well. This is interesting because the fixed with context case should actually be as good as the fixed no context case after the initial learning stages of both conditions. But, as can be seen in Figure 6.3, this is not the case. As mentioned before, people appeared to be using the context as a crutch and relying too heavily on it. This caused both their errors and times to be greater than necessary. It is also important to note here that the average number of errors per block placement is less than 0.1 for all of the cases, which is a very small number of errors.

After looking at these two possible reasons for the differences between the two studies, I also examined the last nine block placements for subjects with high spatial abilities. While this drastically cuts down on the amount of data and thus the significance of the data, the results are interesting. Figure 6.4 shows the graphs of average error and time per block placement. It shows that after the learning phase is complete, people with high spatial abilities can complete both the context cases as well as the non-registered graphics cases with about the same number of errors made and in the same amount of time. While the random with context case is still worse in terms of performance as compared to the rest of the cases, it is still comparable. In addition, the data shows that the fixed no context and fixed with context cases actually perform better than the non-registered graphics cases.



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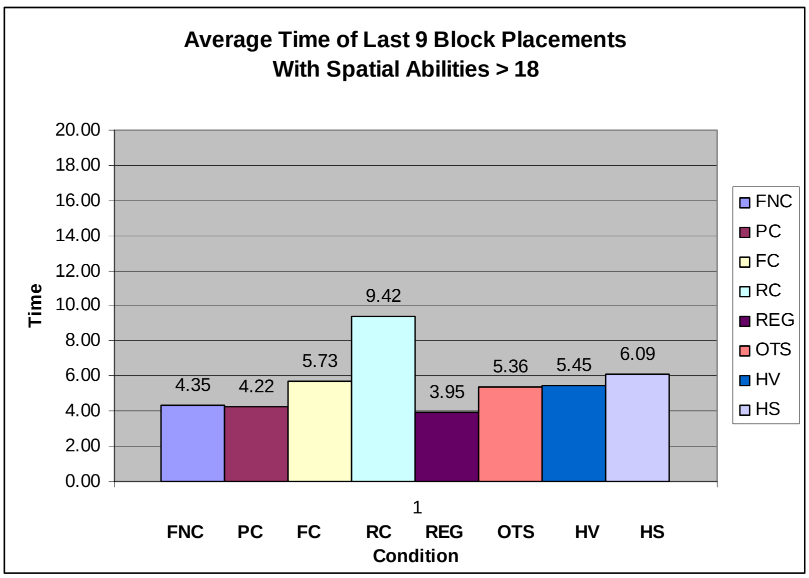

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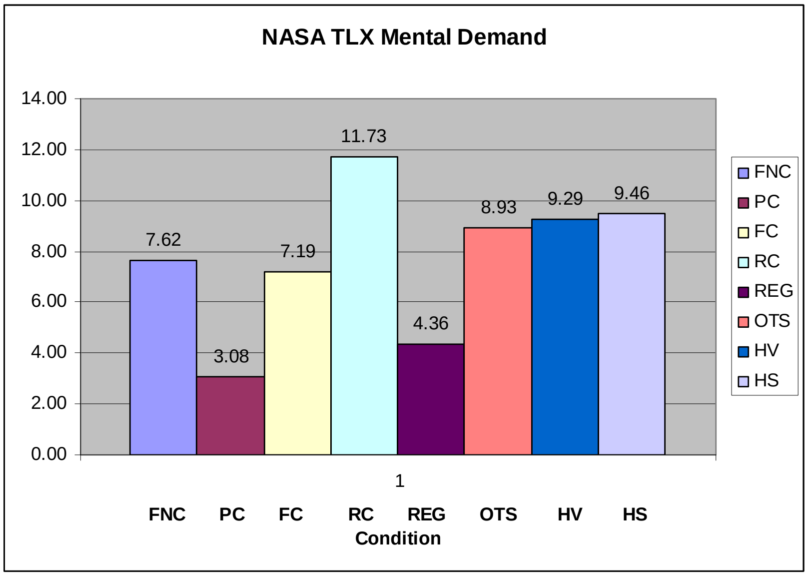
Figure 6.4. Comparing error and time data from study 1 and study 2 for only the last nine block placements and for spatial abilities over 18

6.2 Comparison of NASA TLX Data

I also analyzed the NASA TLX data between the cases and I found some interesting results. In particular, for the most part, the subjects like the context cases better than the non-registered graphics cases.



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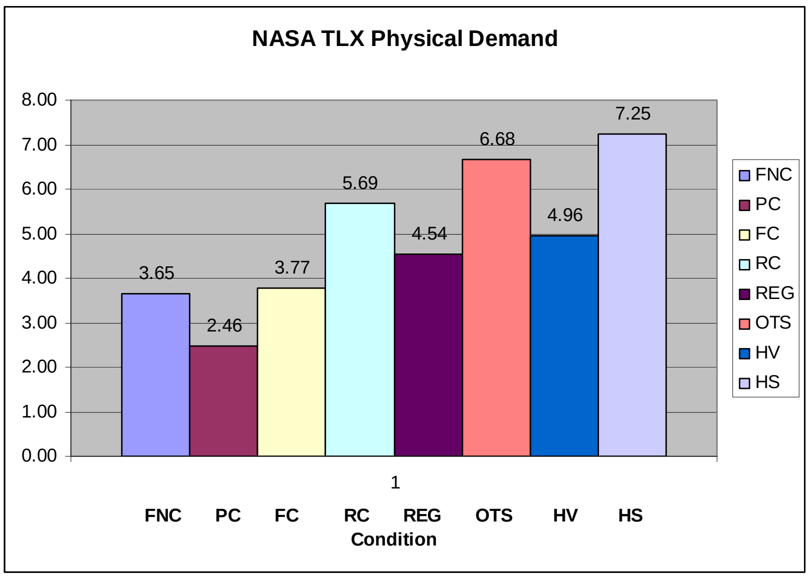

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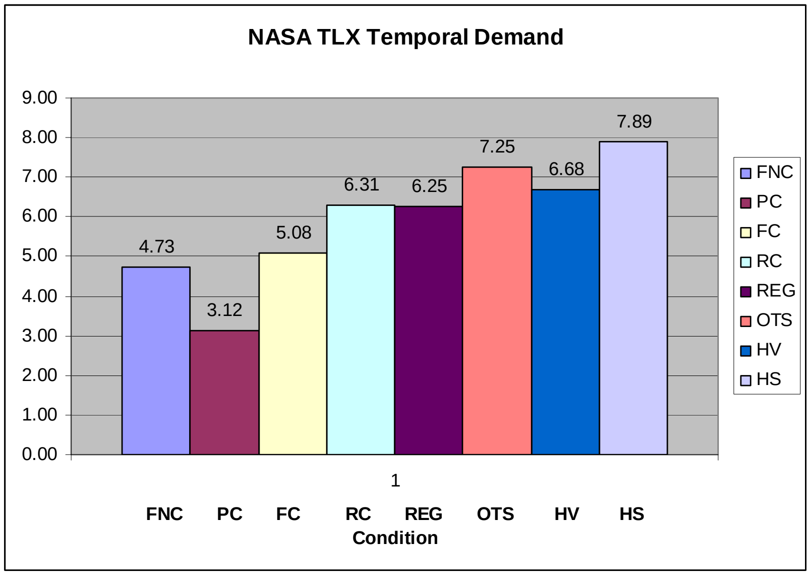
Figure 6.5. Comparing NASA TLX data from study 1 and study 2 for mental and physical demand

Figure 6.5 shows the results of mental and physical demand, Figure 6.6 shows the results of temporal demand and perceived performance, and Figure 6.7 shows the results of effort and frustration. All of the NASA TLX data shows that the context cases require less cognitive load, except for the random with context case. This case is higher than all of the non-registered graphics cases in terms of mental demand, performance and effort.



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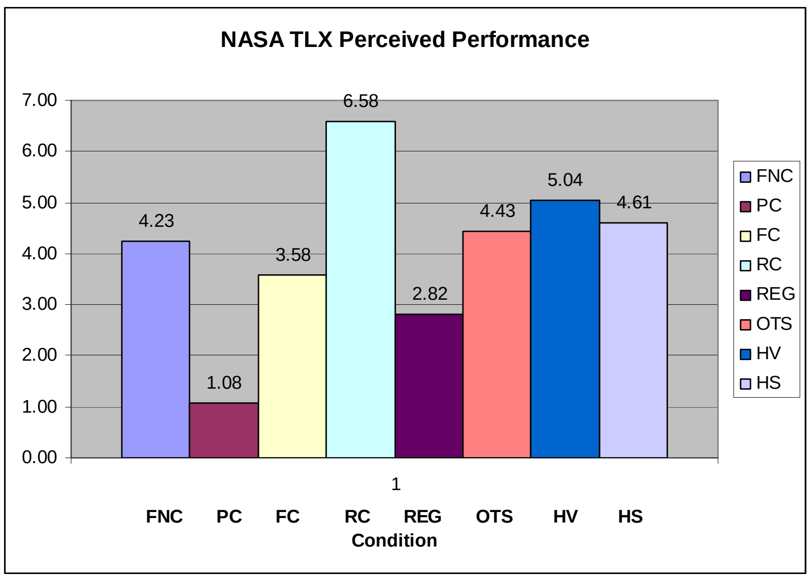

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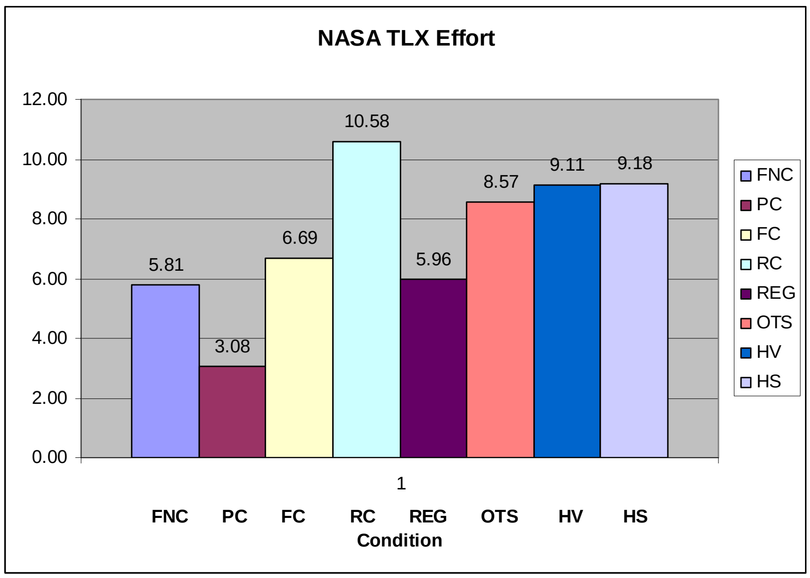
Figure 6.6. Comparing NASA TLX data from study 1 and study 2 for temporal demand and perceived performance

This is not a surprising result because the random with context case was by far the most difficult case I tested in the two studies. It required more mental demand than all of the other cases because the subjects were required to map a new relationship between the virtual world and the physical world during every trial. And the common error of not properly reverse mapping this relationship caused most of the errors that were made, and thus the perceived performance ratings to drop. In addition, they spent more time in the head-mounted display in this case because they made more errors and had to think more during each block placement, which probably led to the higher effort scores.

In the other TLX indicators—frustration, physical demand and temporal demand—the results of the random with context case varied with respect to the non-registered graphics cases. The random with context case was not as frustrating as the HUD-visible case,



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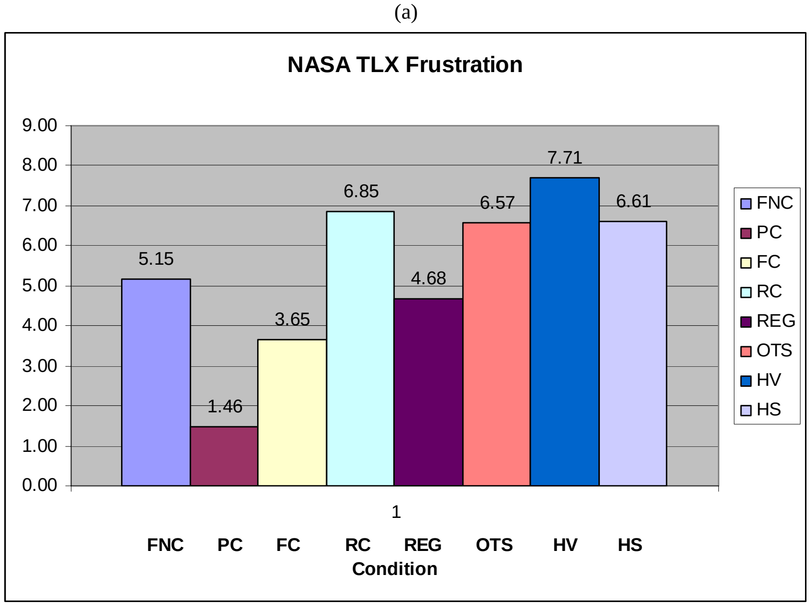

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Figure 6.7. Comparing NASA TLX data from study 1 and study 2 for effort and frustration

which implied that adding context when the graphics are not perfectly registered is more acceptable than screen clutter and occlusion. The random with context case was not as physically demanding as the AR-off-to-side case and HUD-side case which implies that head movement is more tiring. And temporally, the subjects in the first study felt that they were not under as much time pressure as the subjects in the second study.

In general, the perfect with context case (PC) and the AR-registered case (REG) are the same exact cases, but as shown in Figure 6.7, with respect to effort, for example, the PC case required half the amount of effort than the REG case and with respect to frustration, the PC case was one-third less frustrating. This seems to imply that people in general liked the context cases more than the graphics off to the side cases, but the observation that there were such drastic differences between the PC and REG results for the same exact condition raises the question of whether these results are actually comparable.

I believe that the differences between the results of the perfect with context case and the AR-registered case could partially be attributed to the fact that in the second study, the subjects did not have to think about error at all, whereas in the first case they did. Because error was much more difficult to deal with than having the graphics located outside of the task error, the perfect with context case was deemed to be so much easier than the other context cases. In comparison, the ease of the AR-registered case as compared to the non-registered graphics cases did not have the same drastic difference.

6.3 Conclusions

Because of the observations made in this chapter, I do not believe I can say that context is better than non-registered graphics, but I can also not say that it is worse. The results of this analysis warrant a future study to compare context cases directly with HUD and graphics off to the side cases. In addition to comparing the cases I currently have, it might be more interesting to compare a HUD where the graphics are small and off to the side. I discuss this condition in more detail in Section 7.1.

CHAPTER 7

FUTURE WORK

The work presented in this dissertation opens up many possible avenues for future work, including some possible additions to my studies to broaden the results as well as some additional studies to evaluate other types of context.

7.1 Broadening the Results of the Current Studies

While both of the studies discussed in this dissertation produced some very interesting and significant results, there were many things about these studies that could be improved upon. In this study, I recruited most of the participants from the undergraduate and graduate population at Georgia Tech. This meant that the majority of the participants were in technology related fields and tended to be similar in age, spatial abilities, etc. I also had a huge majority of the subjects that were right-handed (20 out of 26 in the first study and 26 out of 28 in the second study.) It would be interesting to carry on with these studies and try to recruit a larger variety of participants. I would like to get a better range for spatial abilities, age, and handedness to see if any of these traits significantly affect a subject's ability to successfully complete these tasks. I was able to see some correlations in successful task completion in relation to spatial ability, but I could not see any causation. I believe that part of this is due to the skewed nature of the spatial ability data. This holds true as well for the handedness and age data. (Also, what other factors play into successful performance in these tasks?)

In addition, it might be interesting to compare some different display methods to the methods I chose for my previous studies. For example, in the second study I chose to compare two AR conditions to two HUD conditions. The HUD conditions were designed so that the graphics was centered on the screen and either always visible or the subject had to look to the side to see the graphics. It would be interesting to compare the current choices to a HUD display where the graphics are always on the screen, but they are placed off to the side. However, an interesting question in regards to these displays is that they tend to be very small and will people like the size difference in the graphics? I purposely did not want to study this particular case in this experiment in order to reduce the number of variables between the cases; however, it would be interesting to study this case in the future.

Also, as discussed in Chapter 6, it might be interesting to run a study comparing the context cases run in study 1 to the AR and HUD cases run in study 2. By directly comparing these cases, I should be able to draw some better conclusions about which is better, context or non-registered graphics.

7.2 Understanding the Effects of Orientation Information

In the second study, I looked at the differences between registered AR, non-registered AR and a heads-up display. Since the AR conditions were using position and orientation tracking, the graphics displayed on the HMD was oriented with respect to the real world, i.e. the graphical representations of the Lego base plate and pieces were drawn in the same orientation with respect to the user as the physical Lego base plate and pieces. This gave the users a significant amount of useful contextual cues. When I designed the heads-up display cases, I also displayed the graphical base plate and pieces in the same orientation with respect to the user as the physical base plate and pieces using the orientation data from both of the tracking systems. I thought that this orientation information would enable the subjects to understand the scene more easily because the similarity between the graphical world and the real world would be more natural. I also did this to maintain orientation consistency among the trials. However, in these two cases, the orientation data was only in one of the three planes. The board only rotated about the X-axis. While some people found this contextual cue to be useful, the majority of the subjects either did not notice the rotation data or found it extremely distracting.

One of the reasons that I believe this data was not as useful as I had hoped was because of the task itself. Because the subjects were standing directly in front of the Lego base plate and merely asked to place blocks, the orientation between the subject's body and the setup rarely moved and when it did it was just small enough to be annoying. When designing this system, I failed to notice that as people reached over to push the button, their bodies rotated and as they removed their hand from the button, their bodies rotated back to their original position or somewhat close to it. The majority of subjects did not like viewing this rotation, especially in the HUD-visible case. The subjects could see every small move that they made and it was distracting. Also, in the HUD-side case, when the subjects turned their heads to the side to look at the graphics, they almost always rotated their body a little bit along with their heads, causing the orientation of the graphics to be off-center. I noticed this during the pilot study, but decided at the time not to make any changes to this study. I believed that closely studying the effects of orientation information would be more suitable for a follow-up study.

There are a number of questions a follow-up study could answer. When subjects are not required to move around much while completing a task, is orientation information all that useful? Could the subjects have performed the tasks quicker and with more accuracy if the graphics had a static orientation? What if the task was designed so that the subjects had to place blocks while walking around a Lego base plate that was sitting in a fixed position on a pedestal? This setup would be analogous to trying to fix a large piece of equipment, such as a car or photocopier. If a worker was only given a frontal view of the equipment and asked to fix something on the back, would they have enough information in that frontal view to get the task done? Even if a "most appropriate view" was chosen for each graphical instruction, as is done in traditional manuals and in systems such as IBIS, would it be more useful if the view of the equipment changed as they walked around it? Would the orientation information play a more significant role in this situation? Would it be more useful if the graphics only rotated in big steps, for instance only one orientation per side of the equipment, to avoid annoying jitter?

7.3 Evaluating Types and Amounts of Context

It would also be interesting to evaluate different amounts and types of graphical context to see what the best combination of context is for successful task completion. I could study the use of color and size of blocks to see if they play a part in success. It would be interesting to look at varied ways of displaying peg information on the base plate. For instance I could draw only the pegs between the nearest virtual context block and the virtual target block to see if that extra information is helpful or just intrusive in the viewing plane. I could compare a fully rendered virtual representation of the base plate and blocks to just wire frame representations, etc. I noticed in the two studies that the relationship between the context block and the target augmentation was an important contextual cue. What if I could draw lines between the context and the augmentation to gain the advantage of being "lined-up" with the context? I have noticed that the more I study context, the more questions that emerge and the more possibilities for future studies arise. The drawback to studies like these is that there is a limit to the generality of the information gathered. Are the findings general, or would they be specific to the particular application the study was designed for? I believe to some degree the data evaluated would be application specific, but I also believe the data would be helpful in guiding the design of augmented environments.

7.4 Exploring Other Types of Error

In these studies I only looked at translation error in the plane of the base plate so that I could study several specific cases and draw meaningful conclusions. It would be useful to evaluate more realistic forms of error such as translation error off the plane of the base plate, rotational error, three-dimensional error and various kinds of jitter. These errors are more indicative of real world errors and would be interesting to study. However, since these errors will likely move the augmentation away from the surface of the base plate, I may need use a stereo display rather than a biocular display to avoid confounds arising due to the visual anomalies when the graphics are not aligned with physical objects in the world.

7.5 Comparing Stereo and Biocular Displays

As mentioned in the previous section, it may be necessary to implement a stereo display in order to study other types of error that could exist in an AR system. This brings up the question of whether a stereo display would change the results of the current studies. Can people understand and adapt to registration error, even in the simple situations of these studies, better when using a stereo display?

7.6 Using Multiple Modalities

In the related work section of this dissertation, I discussed the McGurk effect. It showed that humans are multi-sensory in nature: we do not experience a visual world, an auditory world, a tactile world, etc. We experience one world through multiple senses. In the studies described in this dissertation, I only used visual context to help the subjects deal with the effects of registration error. But what if I added audio context? Would this extra information allow people to disambiguate the situation even better than when only visual context is provided? Would adding the ability to use more than one of our senses help us to more quickly and easily make sense of ambiguous situations?

7.7 Designing a Visualization Toolkit

As I mentioned in the introduction, the original direction of this dissertation was to design a visualization toolkit that would enable AR designers to quickly and easily design applications that adapt to registration error. I believe the key to designing such a toolkit lies in the results of AR user studies such as those described in this dissertation. However, I have only touched the surface of potential studies needed to inform the design of such a visualization toolkit. There are many more questions to be answered and many more studies that could be done to better inform and refine the design of a toolkit. What is the best way to display the augmentations? Which augmentation should be used in which situation? How should transitions between different augmentations be handled? Would different ways of displaying the data be more effective than others? How much augmented information is enough? Is there a limit to how much information is helpful? Can too much information become intrusive? These questions, posed in the introduction, are just a few of the questions that need to be answered to design an adaptive AR toolkit.

Also, I discovered in my studies that adjacent context is the best context in regards to performance. However, in my original design of the visualization toolkit, I proposed to only draw context that was further away from the target than the error estimate so that the context would not block the user's view of the target of the augmentation, due to the registration error. Therefore, should I choose lined-up context over near-but-not-adjacent context? Or is it better to choose adjacent context that might block the user's view? Some additional studies concerning context position could be run.

In addition, there are application specific studies that could be done. As I have mentioned before, the results of these studies are application specific, so some attention should be given to studying the effects of context in different applications. And then, there is the toolkit itself. What is the best way to design a visualization toolkit? What should be included in it? How should it be implemented?

7.8 Conclusions

In this dissertation, I have found that context can alleviate the problems associated with registration error in an Augmented Reality system. I have found that context can help in both registered AR as well as non-registered graphical Heads-up Displays. Additional work in this line of study could include refining my knowledge of context by designing more studies to evaluate different types of context or the effects of orientation information. Another option would be to take the information I have learned and build some real applications or tools. This might be a more interesting way to use what I have learned and have a greater impact on the AR community.

APPENDIX A

USER STUDY 1 DOCUMENTS AND QUESTIONNAIRES

Research Consent Form for Adaptive Intent-Based Augmentation System Study

Project Title: Adaptive Intent-Based Augmentation System Study
Investigators: *Blair MacIntyre, Cindy Robertson,*
Georgia Institute of Technology

You are being asked to be a volunteer in a research study.

Purpose:

"Augmented Reality" is a variation of Virtual Reality that uses see-through displays (usually see-through goggles worn on the head) to draw graphics on top of the wearer's view of the world around them. For example, the "1st and 10" system used during football games on TV is an augmented reality system that draws the 1st down line on the field for the TV audience. Another example would be a car repair system that draws maintenance instructions directly on a repairperson's view of the engine when they look at it. A major problem with creating augmented reality systems is that it is hard to make the graphics line up ("register") with the user's view of the world, primarily because it is hard for the computer to know exactly where the user and the objects in the world are.

However, we believe that it is not always necessary that the graphics precisely line up with the real world for users to understand what the computer is telling them. We have designed a set of AR graphical displays that we think should be understandable by people even when they do not line up with the physical world.

The purpose of this study is to test one of these graphical drawing techniques, virtual context, in an augmented reality system. This experiment will help us understand how well context helps to reduce the effects of graphical misalignments in Augmented Reality. This is the first step in creating a general-purpose graphics toolkit of AR drawing techniques that help programmers to create AR systems that function in the presence of registration error.

Procedures:

If you decide to be in this study, you will be asked to complete a series of tasks while immersed in an Augmented Reality Environment. You will be asked to wear a head-mounted display that is being tracked by the computer, and follow a set of instructions in order to complete a set of building tasks using Lego building blocks. You will be instructed to pick up a particular block and place it on a building platform. If the block is not placed correctly, you will be asked to try again. The series of tasks will test how different kinds of graphical instructions help you to complete the task when there are different types of misalignment between the graphics and the real world. .

Your time commitment will be approximately 90 minutes. During that time, the researcher will give you instructions on how to complete the experiment you are about to participate in. You will be asked to fill out an introductory questionnaire. You will then be asked to perform a series of block placement tasks. After each task, you will be asked to fill out a trial survey and after completing all of the tasks, you will be asked to fill out a survey about your entire experience.

Three types of data will be recorded during this study. First, data will be recorded while you are going through the experiment. This type of data will include, for example, how long you take to complete each block placement, how many incorrect blocks you placed, etc. The second type of data is your survey responses. The third type of data will be a video-taped record of your session. All of these types of data will be stored for analysis which may extend over several years of research. We will use this data to assess the types of visualizations that may be useful for inclusion in our toolkits. We will keep the video locked in our lab in TSRB and will destroy it after our research has been completed. You consent to the capture of data and the use of it for these research purposes.

Risks/Discomforts

You may face some risks or discomforts due to being part of this study. Some people may experience dizziness and/or headaches while wearing a head-mounted display.

Benefits

You will be compensated $10 per hour for participating in this study. Also, results from the study will help to design better graphics for augmented reality environments.

Compensation to You

We will compensate you $10 per hour rounded to the nearest half hour. (For example, if your study lasts for 1 hour and 35 minutes, you will be paid $15, but if your study lasts for 1 hour and 45 minutes, you will be paid $20.)

Confidentiality

The following procedures will be followed to keep your personal information confidential in this study: Your identity will be coded, and all data will be kept in a secured, limited access location. Your identity will not be revealed in any publication or presentation of the results of this research. However, confidentiality cannot be guaranteed; your personal information may be disclosed if required by law. To ensure that this research activity is being conducted properly, Georgia Institute of Technology and Governmental agencies (I.e. Office of Human Research Protections), have the right to review study records, but confidentiality will be maintained to the extent allowed by law.

Costs to You

You shall incur no costs by participating in this study.

In Case of Injury/Harm

If you are injured as a result of being in this study, please contact Blair MacIntyre at (404) 894-5224. Neither the Principal Investigator nor the Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting form participation in this study.

Subject Rights

Your participation in this study is voluntary. You do not have to be in this study if you do not want to be. You have the right to change your mind and leave the study at any time without giving any reason, and without penalty. Any new information that may make you change your mind about being in this study will be given to you. You will be given a copy of this consent form to keep. You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject

If you have any questions about the study, you may contact Cindy Robertson at telephone (404) 385-1104 or Blair MacIntyre at telephone (4040) 894-5224. If you have any questions about your rights as a research subject, you may contact Ms. Alice Basler, Georgia Institute of Technology at (404) 894-6942.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

Subject's Name: ____

Subject's Signature: ______________________________ Date:____________

Person Obtaining Consent Signature: ____________________ Date:____________

We would like to be able to contact you if we have any follow-up questions. If you consent to us contacting you in the future, please provide your email address.

Email address: ____

Registration Error

This study is designed to test your ability to complete a Lego placement task where you will be shown a yellow virtual block on the Head Mounted Display (HMD) telling you where to place a yellow Lego piece on the green Lego base plate. One of the main problems in Augmented Reality is the existence of registration error in the system. Registration error is the misalignment between the graphical world that will be displayed on the HMD you will be wearing and the physical world. In Figure 1, a physical Lego block is shown in the correct location. The virtual block may seem to indicate a different location because of the registration error between the physical world and the graphical world. This is an example of the misalignment that you will be dealing with in this study.

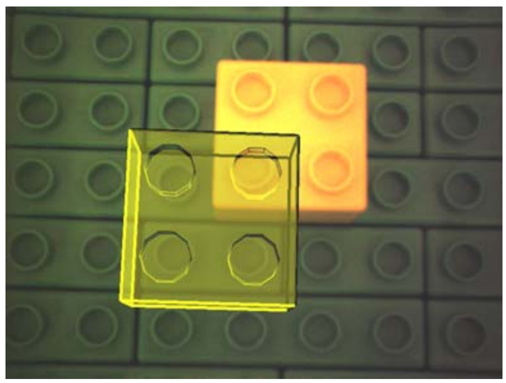


Figure 1: Registration Error

For each set of 18 Lego blocks you place, the virtual block shown on the Head Mounted Display will be affected by the same type of registration error. There are 3 possible types of registration error between the virtual block and the target location of the physical block: no error, static error, and random error.

No Registration Error: When the graphical world and the physical world align properly, there is little to no registration error present in the system. Figure 2 is an example of the graphical world and the physical world aligning almost perfectly; thus there is an insignificant amount of registration error in the system.

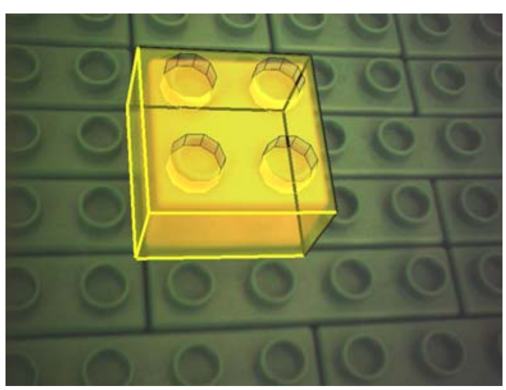


Figure 2: No error

In the next two cases, there are nine possible directions for the registration error. Relating these directions to a compass, the possible directions for the registration error include north, south, east, west, north-east, north-west, south-east, south-west, and dead center (there is a possibility that the registration error could be 0 in both direction and magnitude, therefore simulating the no error case.)   Figure 3 shows an illustration of the possible directions that the registration error can take.

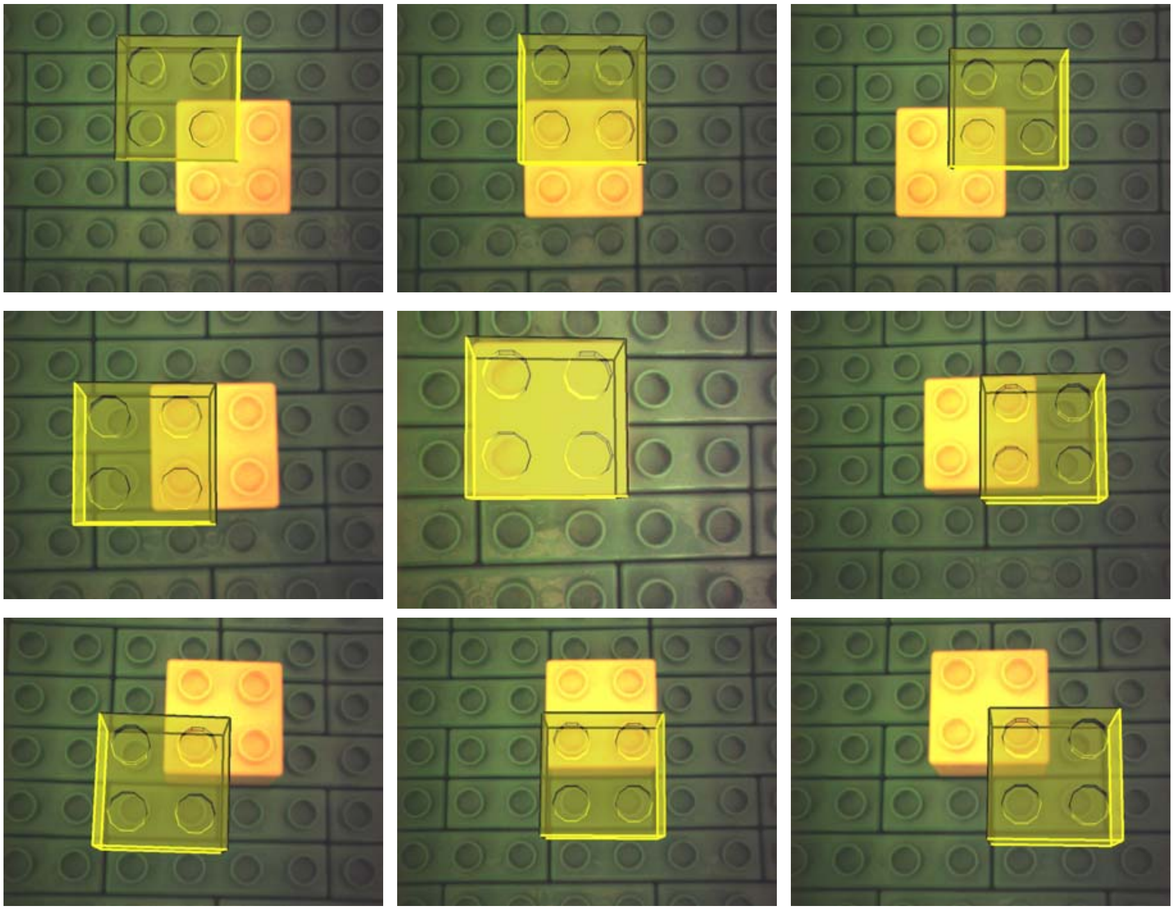
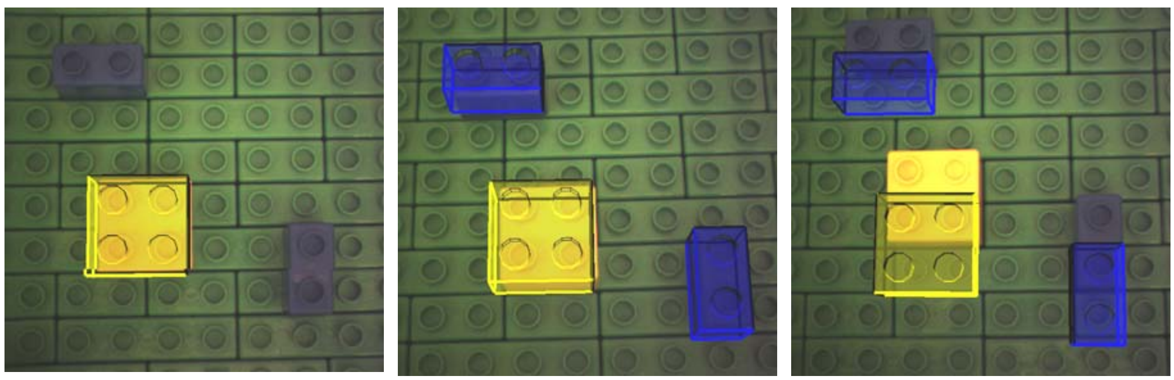


Figure 3: Possible directions for the registration error.

Static Registration Error: When the error between the graphical world and the physical world is constant in magnitude and direction, there is static registration error present in the system. Therefore when static registration error is present, the magnitude of the registration error is 1 peg on the Lego base plate for all block placements in that trial and the direction of the error can be any of the nine possible directions in Figure 3, but that direction will remain the same for every block placement in that trial.

Random Registration Error: When the error between the graphical world and the physical world is constant in magnitude but not in direction, there is random registration error present in the system. Therefore when random registration error is present, the magnitude of the registration error is 1 peg on the Lego base plate for all block placements in that trial, but the direction of the error can be any of the nine possible directions in Figure 3 and the direction will change for every block placement in that trial.

Blue context Lego blocks: In half of the experimental trials you participate in, some virtual context will be displayed on your head mounted display. For the purposes of this study, the context will take the form of two virtual blue Lego blocks that represent two physical blue Lego blocks that exists on the Lego base plate. Figure 4 shows the context that you will be provided in some trials. Figure 4(a) shows the physical blue context blocks. Figure 4(b) shows both the physical blue blocks and the virtual blue context blocks that will be provided on the head-mounted display when there is no registration error in the system. Figure 4(c) shows both the physical blue blocks and the virtual blue context blocks that will be provided on the head-mounted display; however, in this case, there is registration error in the system causing the virtual world and the physical world to be misaligned.



(a) **(b)** **(c)**

Figure 4: Context blocks

This study: In this study, you will be asked to complete 5 sets of tasks. You will be asked to complete these tasks in the face of the three errors described above when only the yellow virtual block representing the target is shown on the display (no context cases), as well as when blue virtual blocks representing some existing blue context Lego blocks are also shown (context cases). The 5 tasks are as follows:

1. place 18 blocks with no error and with no context
2. place 18 blocks with static error and with no context
3. place 18 blocks with no error and with blue context blocks present
4. place 18 blocks with static error and with blue context blocks present
5. place 18 blocks with random error and with blue context blocks present

For each set of 18 blocks, the magnitude of the registration error will be **1 Lego peg** and it will **remain constant** even if the direction changes.

While completing this study, we will evaluate you based on two different metrics: the amount of time that it takes you to place each block and the number of errors you make in placing each block. Therefore, it is important to perform this task as **quickly** and as **accurately** as possible!

Intro Questionnaire

Thank you for your participation in this experiment.

1. Age: ______

2. Gender: M / F

3. Are your right-handed or left-handed? ___ right-handed ___ left-handed

4. Education level: ___ High school
   ___ Undergraduate degree
   ___ Graduate degree
   Other: _____________________

   If you are still in college, how many semesters have you been at your university? ____

   What is/was your major? ____________________________________

5. Occupation: _______________________________

6. Hobbies: ___ Jigsaw Puzzles
   ___ Lego blocks
   ___ Building toys
   Other similar hobbies: _________________

7. Experience using computers:

Never use	Occasional	Everyday	Expert User

1 -----------2 -----------3 -----------4 -----------5 -----------6 ------------7

8. Do you have any experience with video games? (check all that apply)

   ___ I do not own a video game machine
   ___ I own a video game machine

   ___ I have never played video games
   ___ I have played video games a few times
   ___ I play video games occasionally
   ___ I play video games weekly
   ___ I play video games daily

   Estimated hours playing video games per week: ___

9. What are your favorite kinds of games? (check all that apply)

   ___ Action Adventure
   ___ Role-Playing
   ___ First Person Shooters
   ___ Strategy Games Including Real-Time Strategy
   ___ Adventure
   ___ Sports
   ___ Puzzle
   ___ Sim series games (e.g. Simcity, Sims roller-coaster)
   ___ Massively Multiplayer
   ___ Casual games (web based)
   ___ Other _________________________

10. Do you have any experience in Augmented or Virtual Environments?

   ___ yes ___ no

Please explain:

11. Do you have any experience using a Head Mounted Display? (check all that apply)

   ___ None
   ___ One time
   ___ Two times
   ___ More than two times
   ___ Some in courses
   ___ Some in research
   ___ Some commercial
   ___Other (Please explain)

12. On a scale from 1 to 5, how well do you understand the concept of registration error in Augmented Reality?

1 ------------------ 2 ------------------- 3 ------------------- 4 ------------------- 5
Not at all Very well

13. Do you wear glasses or contact lenses? ___ yes ___ no

14. Is your vision corrected right now?

   ___ no ___ yes, glasses ___ yes, contact lenses

15. Are you aware of any other vision problems you might have? ___yes ___ no

   If yes, what? ____________________

16. (Complete after reading the error training document.) On a scale from 1 to 5, how well do you understand the concept of registration error in Augmented Reality?

1 ------------------ 2 ------------------- 3 ------------------- 4 ------------------- 5
Not at all Very well

Post Block Questionnaire

1. On a scale from 1 to 5, how successful do you think you were at completing the task?

   1 --------------------- 2 ---------------------- 3 ---------------------- 4 ---------------------- 5
   Not successful   Successful

   Please explain:

2. On a scale from 1 to 5, rate the difficulty level of the task with the information provided on the Head Mounted Display?

   1 --------------------- 2 ---------------------- 3 ---------------------- 4 ---------------------- 5
   Easy   Hard

   Please explain:

3. On a scale from 1 to 5, did you feel that there was enough information displayed on the Head Mounted Display, too much information, or not enough information?

   1 --------------------- 2 ---------------------- 3 ---------------------- 4 ---------------------- 5
   Not enough   Just right   Too much

   Please explain:

4. (Answer only if context was shown.) On a scale from 1 to 5, do you feel that the blue context provided to you on the Head Mounted Display helped you to perform your task faster or slower than if no blue context information had been provided?

   1 --------------------- 2 ---------------------- 3 ---------------------- 4 ---------------------- 5
   Slower   No difference   Faster

   Please explain:

5. What particular strategy or strategies did you have for completing the task in this set?

6. How did the amount and/or type of information provided play a role in formulating your strategies? Please explain.

Please consider only the block that you have just completed while answering these questions.

MENTAL DEMAND

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Low **High**

PHYSICAL DEMAND

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low **High**

TEMPORAL DEMAND

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was that pace slow and leisurely or rapid and frantic?

Low **High**

PERFORMANCE

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Good **Poor**

EFFORT

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low **High**

FRUSTRATION LEVEL

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Low **High**

Post Study Questionnaire

Thank you for your participation in this study. We are trying to improve our system. Your feedback is greatly appreciated.

1. After completing this study, on a scale from 1 to 5, how well do you understand the concept of registration error in Augmented Reality?

   1 -------------------- 2 --------------------- 3 --------------------- 4 --------------------- 5
   Not at all Very well

2. Is this value different than your answer before you participated in this study?

   ___ yes ___ no

3. Why is your answer different now?

4. Did you find any of the placement tasks too easy? Please explain.

5. Did you find any of the placement tasks too difficult? Please explain.

6. Did you use different strategies in the different conditions? If yes, please explain?

7. Did you find the blue context blocks sufficient? Please explain.

8. What other kinds of context might be helpful in this type of system?

9. Did you find the system comfortable or bothersome to use? Please explain.

10. Would you find Augmented Reality instructions useful in a real-world setting? Please explain.

11. Any other comments?

APPENDIX B

USER STUDY 1 DATA ANALYSIS

Perfect No Context Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	0	0	0	0	0	0	0	0	0	0	0	0

Block No.	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
1	10	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	2	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	9	0	0	0	2	0	0	0	0	0	0	0	0

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Fixed No Context Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
1	2	2	10	2	7	3	6	2	1	15	5	3	**5**
2	1	1	3	2	1	1	1	1	1	2	1	14	**1**
3	1	1	2	2	1	1	1	1	1	1	1	6	**1**
4	1	1	8	3	1	1	1	1	1	1	1	2	**1**
5	1	1	1	2	1	1	1	1	1	1	1	1	**1**
6	1	1	1	1	1	1	1	1	1	1	1	1	**1**
7	1	1	1	1	1	1	1	1	1	1	1	1	**1**
8	1	1	1	1	1	1	1	1	1	1	1	1	**1**
9	1	1	1	1	1	1	1	1	1	2	1	1	**1**
10	1	1	1	1	1	1	1	1	1	1	1	1	**1**
11	1	1	1	2	1	1	1	1	1	1	1	1	**1**
12	1	1	1	2	1	1	1	1	1	1	1	1	**1**
13	1	1	1	1	1	1	1	1	1	1	1	1	**1**
14	1	1	1	1	1	1	1	1	1	1	1	1	**1**
15	1	1	1	1	1	1	1	1	1	1	1	1	**1**
16	1	1	1	1	1	1	1	1	1	1	1	1	**1**
17	1	1	1	1	1	1	1	1	1	1	1	1	**1**
18	1	1	1	1	1	1	1	1	1	5	1	1	**1**
No. of Errors per Subject	**1**	**1**	**19**	**8**	**6**	**2**	**5**	**1**	**0**	**20**	**4**	**21**	**4**

Block No.	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
1	19	2	6	4	1	5	6	5	15	7	5	4	**3**
2	8	4	7	1	1	1	2	2	1	1	1	2	**4**
3	7	1	1	1	1	1	1	1	1	1	1	1	**2**
4	2	3	1	1	1	1	5	1	1	1	1	1	**2**
5	2	3	1	1	1	1	1	1	1	1	1	1	**1**
6	1	2	1	1	1	1	2	1	1	1	1	1	**1**
7	1	1	1	1	1	1	1	1	1	1	1	1	**1**
8	1	3	1	1	1	1	1	1	1	1	1	1	**1**
9	1	4	1	1	1	2	1	1	1	1	1	1	**1**
10	1	1	1	1	1	1	1	1	1	1	1	2	**1**
11	1	1	1	1	1	1	1	1	1	1	1	1	**1**
12	1	1	1	1	1	1	1	1	1	1	1	1	**1**
13	1	1	1	1	1	1	1	1	1	1	1	1	**1**
14	1	1	1	1	1	1	1	1	1	1	1	1	**1**
15	1	1	1	1	1	1	1	1	1	1	1	1	**1**
16	1	1	1	1	1	1	1	1	1	1	1	1	**1**
17	1	1	1	1	1	1	1	1	1	1	1	1	**1**
18	1	1	1	1	1	1	1	1	1	1	1	1	**1**
No. of Errors per Subject	**33**	**14**	**11**	**3**	**0**	**5**	**11**	**5**	**14**	**6**	**4**	**5**	**7**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Random No Context Error Data (PILOT DATA)

Block No.	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*
1	1	3	8	4	4	**2**
2	4	2	7	13	7	**4**
3	7	9	1	3	4	**9**
4	6	2	5	2	7	**6**
5	8	10	2	1	7	**1**
6	3	3	7	2	7	**3**
7	2	4	7	21	5	**9**
8	7	6	3	9	1	**2**
9	1	5	2	7	9	**5**
10	7	6	9	6	3	**5**
11	7	8	1	6	2	**1**
12	2	1	2	7	1	**5**
13	4	3	6	8	1	**7**
14	9	3	3	32	2	**2**
15	3	9	10	29	19	**8**
16	4	5	2	11	7	**5**
17	5	4	3	20	7	**9**
18	5	4	5	31	9	**4**
No. of Errors per Subject	**67**	**69**	**65**	**194**	**84**	**69**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Perfect With Context Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	3	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	2	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	2	1	1	1	1	1	1	1	1	1	1
9	1	1	2	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	2	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	0	2	2	0	0	0	0	0	2	0	0	0

Block No.	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	2	2	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	0	0	0	0	0	1	1	0	0	0	0	0

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Fixed With Context Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
1	1	1	1	3	1	1	1	2	1	1	1	1	**2**
2	1	1	1	1	1	1	2	1	1	1	1	1	**1**
3	2	1	1	1	1	1	1	1	1	1	1	1	**1**
4	1	1	1	1	1	1	1	1	2	1	1	1	**1**
5	1	1	1	1	2	1	1	1	1	1	1	1	**1**
6	1	1	1	1	1	1	1	1	1	1	1	1	**1**
7	7	1	5	1	1	1	1	1	1	2	1	1	**1**
8	1	1	1	1	1	1	1	1	1	1	1	1	**1**
9	1	1	1	1	1	1	1	1	1	1	1	1	**1**
10	1	1	1	1	1	1	1	1	1	1	1	1	**1**
11	1	1	1	1	1	1	1	1	1	1	1	1	**1**
12	1	1	1	1	2	1	1	1	1	1	1	1	**1**
13	1	1	1	1	2	1	1	1	1	1	1	1	**1**
14	1	1	1	1	2	1	1	1	1	1	1	1	**1**
15	1	1	2	1	5	1	1	1	1	1	1	2	**1**
16	1	1	1	1	1	1	1	1	1	1	1	1	**1**
17	1	1	1	1	1	1	1	1	1	1	1	1	**1**
18	1	1	1	1	1	1	1	1	1	1	1	1	**1**
No. of Errors per Subject	**7**	**0**	**5**	**2**	**8**	**0**	**1**	**1**	**1**	**1**	**0**	**1**	**1**

Block No.	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
1	1	4	2	1	1	1	1	1	1	1	1	1	**1**
2	1	1	1	1	1	1	1	1	1	1	1	1	**1**
3	1	3	1	1	1	1	1	2	1	1	1	1	**1**
4	1	2	1	2	9	4	1	3	1	1	1	2	**1**
5	2	1	1	1	1	1	2	3	1	1	1	1	**1**
6	1	1	1	1	1	1	1	1	1	1	1	1	**1**
7	3	3	1	1	1	1	1	2	1	1	1	1	**1**
8	1	1	1	2	1	1	2	1	1	1	1	1	**1**
9	1	1	1	1	1	1	1	1	1	1	1	1	**1**
10	1	1	1	1	1	1	1	1	1	1	1	1	**1**
11	1	1	1	1	1	1	1	1	1	1	1	1	**1**
12	1	1	1	1	1	1	1	1	1	1	1	1	**1**
13	2	1	1	3	2	1	3	1	2	1	1	1	**1**
14	1	1	1	1	1	1	1	1	1	1	2	1	**1**
15	2	1	1	1	1	1	1	1	1	2	1	1	**1**
16	1	1	1	1	1	1	1	1	1	1	1	1	**1**
17	2	1	1	1	1	1	1	1	1	1	1	1	**1**
18	1	1	1	2	1	1	1	1	2	1	1	1	**1**
No. of Errors per Subject	**6**	**8**	**1**	**5**	**9**	**3**	**4**	**6**	**2**	**1**	**1**	**1**	**0**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Random With Context Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
1	1	2	1	15	1	1	1	1	1	1	4	1	1
2	1	1	1	1	1	10	1	1	1	1	6	1	1
3	3	1	3	1	1	2	1	1	1	2	1	2	1
4	1	1	1	1	1	1	1	1	1	1	5	1	2
5	1	1	1	1	2	1	1	1	1	2	1	1	1
6	2	1	3	6	1	1	1	1	1	1	4	3	1
7	1	1	2	1	1	1	1	3	1	4	2	2	1
8	1	1	1	2	1	1	1	1	1	1	3	1	1
9	1	1	1	2	1	1	2	1	1	1	2	1	1
10	1	1	1	1	1	1	1	1	2	1	1	1	1
11	2	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	3	1	1	1	1	1	1	2	1	1
13	1	1	1	1	1	1	1	1	2	1	1	3	1
14	1	2	1	1	1	2	1	1	1	1	1	2	1
15	1	1	3	1	2	1	1	1	1	2	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	**4**	**2**	**7**	**23**	**2**	**11**	**1**	**2**	**2**	**6**	**20**	**7**	**1**

Block No.	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
1	5	2	2	1	1	2	3	1	1	3	1	1	3
2	6	2	1	1	1	1	1	1	1	2	1	1	1
3	7	1	1	1	1	1	1	1	7	1	2	1	1
4	1	1	1	1	1	1	1	1	2	1	1	1	1
5	6	2	2	1	1	1	1	1	2	1	1	1	1
6	3	1	1	1	2	1	1	4	2	1	1	1	1
7	1	3	1	1	1	1	1	4	1	1	1	1	1
8	1	2	1	1	1	1	1	1	1	2	1	1	1
9	1	1	1	1	1	1	2	1	1	1	1	2	1
10	1	1	2	1	1	1	1	1	1	1	1	1	1
11	1	2	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1
13	2	1	1	2	1	1	1	1	1	1	2	1	1
14	1	1	1	1	1	1	1	5	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	2	4	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1
17	4	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	2	2	1	1	1	1	1	1
No. of Errors per Subject	**26**	**7**	**3**	**1**	**1**	**2**	**4**	**10**	**9**	**4**	**3**	**4**	**2**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

Perfect No Context Block Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	4.2390	10.5790	9.3710	5.3190	4.5540	6.5840	**10.1290**
2	3.1300	6.7800	4.4480	3.6260	3.7520	4.0380	**4.1970**
3	2.9150	4.4860	5.8850	3.1930	3.7800	3.1450	**3.8760**
4	6.1940	4.6380	5.8180	5.2440	4.3570	5.4860	**9.1770**
5	4.4190	6.3100	6.1740	3.8190	4.0700	4.7400	**7.0490**
6	2.8730	4.9790	4.2320	3.0360	3.7420	4.2730	**5.2540**
7	3.6590	4.5430	5.9460	3.8020	2.6910	4.6400	**4.3430**
8	2.7850	3.6730	5.3340	4.2500	3.4810	4.3970	**4.0800**
9	2.3910	3.0780	5.3340	3.0790	3.0230	2.6630	**5.6430**
10	2.2520	6.1880	4.6880	2.8520	3.2600	2.9210	**3.8630**
11	3.2810	4.2340	5.3900	3.5610	3.4460	5.2890	**7.9610**
12	3.2180	4.0030	6.2010	3.3000	3.7050	4.5230	**5.6060**
13	3.6360	4.4210	4.7020	3.5210	4.0720	4.7280	**0.0700**
14	2.4710	3.9960	4.5580	3.2850	3.6660	4.3690	**5.0510**
15	2.9310	5.8630	6.2170	3.6500	3.8360	3.8030	**4.6160**
16	2.9740	3.2780	3.7600	4.3690	4.1250	3.5560	**10.0620**
17	3.7950	3.6650	5.5490	4.1960	3.0230	3.9100	**6.4480**
18	3.2860	4.0680	4.1960	4.0680	3.0990	3.4140	**3.8560**
Average Time per Subject	**3.3583**	**4.9323**	**5.4335**	**3.7872**	**3.6490**	**4.2488**	**5.6267**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	14.5690	4.7870	9.6510	6.9620	6.5140	5.0390	**55.3610**
2	7.4990	3.0070	6.5700	4.0520	5.0250	3.7390	**4.6650**
3	11.2930	2.9030	3.3330	3.5700	5.5890	2.8710	**4.1350**
4	8.0860	3.5330	4.7300	8.2130	6.6260	4.2790	**4.7910**
5	3.8860	3.9920	3.5250	5.0090	6.2160	3.7760	**5.4130**
6	3.3600	2.9990	12.4490	3.0230	5.5370	2.8760	**6.2850**
7	6.0970	3.5180	5.0020	3.7820	5.6020	3.6640	**4.3770**
8	5.9680	3.3310	3.1210	3.1570	5.0770	3.9360	**4.4250**
9	5.7130	2.6590	8.9240	3.6590	4.3620	2.7390	**3.3260**
10	6.6280	3.7180	4.7970	6.9260	6.0580	2.6180	**14.6540**
11	5.3370	3.1750	4.9260	10.9120	5.5370	4.0900	**2.8600**
12	4.3030	3.4610	2.5230	3.9030	7.0950	3.8730	**4.5310**
13	6.8290	3.8540	2.6220	4.5310	6.4840	4.5630	**4.0210**
14	6.5500	3.2370	4.5170	3.3960	8.8060	3.3340	**2.5560**
15	3.6570	2.9470	2.2720	7.4530	6.8040	6.4580	**2.8710**
16	10.6640	3.5300	2.5940	4.3650	6.8850	2.9400	**3.5240**
17	4.9070	3.2210	2.7380	4.3760	5.6840	3.7990	**3.7430**
18	4.5010	5.4460	4.8200	3.9310	5.2740	3.0810	**3.1190**
Average Time per Subject	**6.6582**	**3.5177**	**4.9508**	**5.0678**	**6.0653**	**3.7597**	**7.4809**

Perfect No Context Block Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	9.7160	5.6870	5.8640	7.9320	6.0440	13.8520	**6.9450**
2	8.5300	3.5670	4.1320	16.0170	4.3560	5.3880	**15.7070**
3	11.7840	4.1560	4.3670	6.7610	3.7940	4.5570	**4.5070**
4	8.8310	5.5380	7.1640	5.6990	4.8690	6.9620	**10.1670**
5	5.0080	4.8170	4.4890	4.8880	5.8170	5.9560	**5.9470**
6	6.4140	3.3250	4.2210	5.4170	4.2490	4.2940	**4.7350**
7	5.9690	4.5110	4.5160	4.4620	4.6750	3.8430	**7.7930**
8	7.5360	4.1590	3.6650	5.4900	4.0660	3.6010	**3.8680**
9	5.7910	3.1310	3.6870	15.9330	4.2320	4.2500	**2.9110**
10	4.4260	4.4960	4.6690	5.4190	4.4310	5.2920	**3.6950**
11	5.5630	3.3460	3.2890	7.6740	4.6190	5.2110	**4.5840**
12	5.8040	3.8220	4.1040	5.4000	4.6520	4.9360	**4.5420**
13	5.5880	4.8680	6.5670	4.8610	5.4880	5.4640	**5.3510**
14	11.2670	3.9330	2.9910	4.7420	4.0250	6.5220	**4.8010**
15	7.1480	6.1570	4.7850	7.8770	5.5040	4.9770	**4.2400**
16	9.2300	4.4630	4.0570	8.2850	5.4680	14.4160	**4.5000**
17	6.4860	3.5330	3.9590	4.7280	4.5100	4.8270	**4.0530**
18	8.0190	3.2060	5.0400	6.4790	4.0560	3.2830	**6.2710**
Average Time per Subject	**7.3950**	**4.2619**	**4.5314**	**7.1147**	**4.7142**	**5.9795**	**5.8121**

Block No.	S22	S23	S24	S25	S26
1	15.7940	3.2750	3.7470	5.7080	**4.9030**
2	10.2970	2.8230	3.6450	4.2780	**4.3350**
3	6.7040	2.7880	2.9220	4.6110	**3.7990**
4	10.5310	3.8330	5.2790	4.2860	**4.5130**
5	6.1990	3.5140	3.0580	5.4980	**4.1660**
6	7.0130	2.3460	2.6880	3.1010	**4.5340**
7	10.1460	2.4590	3.5120	3.2780	**4.5530**
8	10.2270	2.1260	2.2080	4.0330	**3.4690**
9	11.6720	1.7720	2.4610	3.6860	**2.9680**
10	6.7960	2.3790	3.3590	3.6250	**4.6160**
11	11.3080	3.5450	3.0840	3.7430	**3.5810**
12	7.7880	2.5490	2.8750	3.2200	**3.8970**
13	5.5770	2.5310	3.0560	3.7530	**4.4790**
14	6.8320	2.2970	3.0840	3.7710	**3.4190**
15	5.1120	2.0890	3.7090	4.6850	**2.8630**
16	5.1440	1.6690	3.1500	3.1040	**3.8500**
17	5.2440	2.8750	2.2090	4.7320	**3.6800**
18	5.4730	2.8920	2.2360	7.5030	**3.4070**
Average Time per Subject	**8.2143**	**2.6534**	**3.1268**	**4.2564**	**3.9462**

Fixed No Context Block Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	4.6210	10.9380	281.8230	9.1780	33.3750	18.6430	**65.4260**
2	4.1020	4.0850	23.3110	13.1500	4.0120	8.3200	**5.1790**
3	4.8440	4.3990	14.9010	12.9750	5.0840	7.0360	**8.2760**
4	3.0270	3.3920	72.7670	23.2360	3.8800	4.2950	**5.4360**
5	5.1880	3.1430	6.3950	14.1680	4.2370	4.0110	**7.6930**
6	3.5250	4.0480	5.7990	8.0890	3.5310	5.6890	**5.7040**
7	3.2550	3.4000	5.0740	5.9920	3.0350	3.4660	**5.7890**
8	2.9690	2.5140	3.9080	5.6660	3.1410	6.1010	**5.5480**
9	3.2980	2.3700	5.7790	5.5610	2.9130	3.4230	**3.8520**
10	3.3790	3.1150	6.1560	4.8410	3.7650	6.0060	**3.3390**
11	4.9480	3.0200	5.6970	13.9620	0.1620	5.0340	**4.6730**
12	3.7220	3.9420	6.6530	10.3400	4.7830	4.0560	**4.1010**
13	4.4400	2.8560	5.2110	5.5880	3.5680	4.4790	**3.3200**
14	2.7190	3.3170	5.1140	4.6270	3.9540	4.4340	**4.4580**
15	3.2930	2.9020	4.2410	4.6910	3.0230	3.9880	**4.7090**
16	3.8340	2.6740	4.2190	5.6920	4.5760	3.1590	**7.1480**
17	3.0740	2.4520	3.7390	4.9410	3.2400	4.4440	**2.8360**
18	3.4310	2.4920	5.8090	3.9270	3.7010	3.6160	**4.1360**
Average Time per Subject	**3.7594**	**3.6144**	**25.9220**	**8.7013**	**5.2211**	**5.5667**	**8.4235**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	13.0560	3.5320	94.0830	59.7650	34.6850	20.9950	**163.8590**
2	8.4290	3.6300	7.7810	18.6760	199.8920	3.8210	**52.1200**
3	7.8810	5.7120	6.3690	6.2820	44.3680	4.6990	**33.8680**
4	5.0740	3.7460	4.1130	5.2140	19.1000	3.7490	**7.7240**
5	8.0190	3.6100	3.6970	5.7060	5.3210	6.5450	**9.8790**
6	5.3220	4.2970	4.4940	13.2650	6.4470	4.3550	**7.9990**
7	4.5460	10.3260	2.8090	3.4480	6.2510	3.4500	**4.7330**
8	4.1310	3.6210	2.7700	3.7090	4.6190	4.0220	**4.4640**
9	4.6220	2.9110	7.3590	3.3200	4.9250	3.7220	**4.1120**
10	5.2230	3.3130	4.3460	3.9420	4.9060	4.8850	**4.3930**
11	3.8340	2.8310	4.0140	4.9270	4.7820	5.0150	**4.1020**
12	6.0540	2.7720	3.7220	3.9200	7.5190	3.6950	**5.5720**
13	4.3990	3.1080	3.7950	4.1210	11.5500	4.8540	**3.6700**
14	6.4050	3.1370	4.0590	5.2380	5.6530	3.9480	**6.9020**
15	4.4340	3.1020	3.1050	4.8350	4.7850	4.2030	**4.9830**
16	11.7570	3.2950	4.9250	5.2500	4.3480	5.2450	**6.0260**
17	3.7600	3.2330	3.0490	4.1690	6.2910	3.9940	**4.0350**
18	3.7660	3.3170	50.0220	4.1530	6.1860	3.3880	**3.8080**
Average Time per Subject	**6.1507**	**3.8607**	**11.9173**	**8.8856**	**21.2016**	**5.2547**	**18.4583**

Fixed No Context Block Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	25.8760	28.3310	19.1470	10.1760	86.9370	57.2260	**20.6320**
2	46.2040	29.4230	5.8230	4.6980	5.5300	11.9620	**12.9720**
3	19.8360	6.2750	6.4260	6.8860	6.0040	9.6570	**5.3540**
4	31.6620	4.3500	5.6160	6.0130	6.1010	47.8820	**3.0540**
5	36.5570	6.1830	6.1920	5.6490	7.6250	9.1100	**3.4400**
6	19.5950	4.9050	4.8310	8.4020	4.7980	17.9060	**5.4560**
7	8.5470	5.4340	4.2330	5.8290	4.6190	7.6560	**3.3100**
8	21.0660	3.7600	3.9070	4.9080	4.4700	4.7560	**2.9170**
9	36.4950	3.5930	3.0470	3.6230	11.4520	5.3340	**3.3510**
10	7.2840	4.3180	6.3560	4.8390	5.0120	5.6230	**5.4990**
11	8.2690	4.7590	4.8170	5.7300	6.1240	4.9830	**3.4360**
12	5.3560	5.6380	6.2330	4.8080	4.4090	6.7820	**2.9930**
13	5.9150	5.1310	3.0950	5.8570	4.6840	7.8230	**4.7160**
14	4.8390	15.3160	7.0840	4.6520	4.8670	9.7480	**3.7350**
15	4.6930	3.8530	2.7240	5.1800	7.0660	6.2570	**2.9160**
16	8.9790	5.3720	5.5140	5.7310	4.3950	7.3830	**6.0830**
17	4.8090	3.5050	3.4040	5.7540	4.8880	8.6890	**2.5080**
18	5.0080	3.6590	4.4130	5.3940	4.5090	8.9790	**2.3080**
Average Time per Subject	**16.7217**	**7.9892**	**5.7146**	**5.7849**	**10.1939**	**13.2087**	**5.2600**

Block No.	S22	S23	S24	S25	S26
1	318.0650	31.0780	29.1530	17.3520	**19.8360**
2	8.7280	4.7270	4.4330	7.5520	**19.7320**
3	7.5920	4.1510	4.0880	4.8080	**10.3820**
4	4.7330	0.1450	3.2070	3.8640	**8.4690**
5	6.5080	4.1010	2.4070	4.4130	**4.3940**
6	9.4330	3.5950	2.9640	3.1820	**4.8400**
7	4.6410	2.9630	2.2610	6.6960	**5.6740**
8	5.9560	2.8590	2.4450	3.1520	**4.8870**
9	10.9740	2.6990	3.4710	2.8990	**4.1040**
10	9.3850	2.9280	3.0460	7.5520	**4.3850**
11	4.3220	4.0780	2.6480	3.7610	**5.9320**
12	4.9550	3.8330	2.1630	4.6940	**3.8340**
13	6.0310	3.1950	2.1530	6.7100	**4.0850**
14	3.9600	3.4020	4.0340	3.4000	**3.8640**
15	5.8240	2.6300	2.2970	3.1050	**3.3520**
16	4.7830	3.5390	2.3310	4.2470	**4.4200**
17	7.1670	2.8920	1.9190	3.2520	**4.8470**
18	4.3900	2.7110	3.6770	2.8050	**3.4230**
Average Time per Subject	**23.7471**	**4.7514**	**4.3721**	**5.1913**	**6.6922**

Random No Context Block Placement Time Data (PILOT DATA)

Block No.	***S1***	***S2***	***S3***	***S4***	***S5***	***S6***
1	4.7730	23.7720	280.8780	34.9110	25.0260	**24.0620**
2	21.2090	26.0900	78.1100	95.8900	24.5900	**33.9050**
3	30.0640	108.5920	15.1730	30.3330	20.9610	**90.1660**
4	20.1080	16.6550	73.9260	21.3790	20.4500	**44.7980**
5	25.5110	49.3930	44.8550	8.5760	19.7480	**11.9560**
6	11.3950	20.2940	104.8190	15.6770	25.2240	**26.3710**
7	7.3790	24.5720	88.7160	182.3720	33.3230	**59.7390**
8	18.9100	26.7160	21.4000	60.9510	3.7510	**18.5370**
9	3.7310	22.7890	15.4800	40.5030	32.8400	**47.2340**
10	21.4990	28.2520	84.7920	27.8220	14.5780	**26.4000**
11	20.4990	44.8720	7.8660	26.3350	12.1750	**6.1100**
12	7.5190	5.1380	13.3890	32.8460	5.9210	**36.5640**
13	14.4550	13.2900	34.3050	33.7290	11.3750	**28.8060**
14	25.4760	11.6100	25.3790	150.9490	12.1730	**11.4580**
15	10.3540	42.2560	125.2280	173.3520	98.6710	**42.2150**
16	28.4540	37.8530	19.9070	64.9330	29.0960	**22.7140**
17	12.0650	30.4320	55.3190	150.4280	27.6730	**52.5930**
18	17.7420	20.0100	73.4390	224.4590	33.5680	**22.6640**
Average Time per Subject	**16.7302**	**30.6992**	**64.6101**	**76.4136**	**25.0635**	**33.6829**

Perfect With Context Block Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	7.2070	6.6100	5.3690	5.5360	3.0200	6.0200	**7.0810**
2	4.4870	4.4440	4.5360	4.9430	4.4140	5.0880	**7.7360**
3	5.1010	3.3700	4.5280	6.4300	4.1330	4.7530	**6.2840**
4	3.8250	4.3060	6.0100	5.2230	4.7340	5.1640	**10.7590**
5	5.4220	4.0570	6.4210	3.8520	3.5370	4.5070	**5.6870**
6	4.7050	5.6220	3.6860	11.1980	3.0290	4.8830	**5.4280**
7	3.9830	3.9590	4.3450	3.6050	2.0150	5.2440	**4.5470**
8	4.8690	2.8360	7.7100	5.5300	3.2970	4.4950	**8.1140**
9	3.2720	2.5450	12.3410	3.6370	2.4900	4.1420	**8.2370**
10	5.0800	3.5250	5.4590	4.2790	4.0520	4.8320	**5.7590**
11	2.4560	2.7280	5.3860	6.4160	5.1930	4.6800	**5.0680**
12	4.8490	3.0740	4.3240	7.2350	2.9000	4.1130	**5.2940**
13	2.5430	2.7860	5.0510	4.9570	2.9250	4.3920	**3.3080**
14	4.9030	3.2720	5.5480	9.7720	2.6400	10.3170	**3.1240**
15	3.4700	2.4460	3.7460	4.1910	3.7340	4.4430	**3.4690**
16	4.1090	3.1190	4.2320	3.8410	3.8950	4.4420	**5.9910**
17	5.3320	3.8740	5.1380	4.9920	4.6400	6.6860	**5.6490**
18	3.9080	2.5200	4.0460	3.5040	2.6430	5.7730	**5.2680**
Average Time per Subject	**4.4178**	**3.6163**	**5.4376**	**5.5078**	**3.5162**	**5.2208**	**5.9335**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5.4540	3.1650	5.7530	12.9660	8.0300	5.2450	**3.5450**
2	6.0520	3.6470	5.1170	7.0750	6.0390	5.3090	**4.3430**
3	6.8140	4.4350	30.0410	5.1280	5.3290	5.6620	**3.2760**
4	4.5510	4.0090	11.4510	5.7420	7.4040	5.2550	**7.3990**
5	3.7520	3.5340	6.4920	3.9580	7.3230	4.7700	**3.7480**
6	3.5470	3.3600	3.7780	3.9380	5.7950	3.4000	**3.1170**
7	4.5970	3.6050	2.6870	3.4370	5.0950	5.2890	**3.4720**
8	5.0290	4.1680	2.8520	3.4930	5.2110	6.5330	**2.7040**
9	4.4760	2.8680	8.4670	3.7760	6.8080	11.6080	**3.4210**
10	5.8310	4.3580	5.2710	4.0330	4.0570	5.4060	**4.5350**
11	4.2180	3.6560	7.4300	3.5570	3.2000	6.7360	**3.9410**
12	4.1450	4.5900	7.2190	4.2720	4.1230	4.0530	**11.3760**
13	5.0940	3.9730	2.8700	4.0610	2.9260	4.0480	**2.8980**
14	4.2680	3.2390	4.6320	4.3800	4.9170	3.8400	**2.2770**
15	5.1950	3.4520	5.8880	4.3650	3.8470	4.0130	**2.8800**
16	6.2120	3.5410	4.4730	4.0250	5.7700	5.4280	**3.3640**
17	4.6490	3.7700	6.6710	5.2920	6.5150	5.7790	**3.2440**
18	4.5480	3.5750	4.5760	3.9050	3.4780	4.6070	**3.1450**
Average Time per Subject	**4.9129**	**3.7192**	**6.9816**	**4.8557**	**5.3259**	**5.3878**	**4.0381**

Perfect With Context Block Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	8.7460	3.9960	4.4180	7.7470	6.9030	8.8260	**7.2620**
2	7.2250	6.6720	6.0630	5.9200	5.8770	15.4390	**6.9500**
3	7.2030	3.5920	7.6610	7.6010	7.5080	91.4760	**14.6160**
4	10.1830	3.9370	6.2110	6.8120	6.7230	29.4820	**15.6890**
5	4.7330	4.3500	5.3210	5.0280	6.9790	8.5180	**6.3550**
6	10.6100	3.1840	4.1480	4.0300	5.5350	5.2940	**4.8910**
7	5.8140	2.6830	4.4730	4.0940	5.0300	4.5420	**7.3390**
8	4.0990	3.7370	3.8050	6.1260	5.2120	5.7780	**6.0080**
9	4.4520	3.8300	4.2950	6.5820	4.2770	11.2000	**8.4170**
10	6.8300	4.7800	6.6280	6.9510	5.8620	13.2070	**7.3530**
11	8.2830	3.8130	6.5530	5.4990	4.4680	9.0440	**9.5910**
12	11.3740	5.3190	5.2420	8.0130	15.7210	8.9630	**5.4120**
13	4.6160	3.1580	3.9290	5.5220	4.1590	7.3200	**4.6460**
14	3.7240	3.6890	3.4500	8.4630	4.8720	5.1480	**6.5360**
15	3.0460	4.1770	3.6350	5.8640	5.2170	6.7600	**4.8520**
16	5.3000	4.5990	4.4130	4.9230	6.4300	7.2200	**5.6180**
17	5.6640	3.8970	4.7590	6.0810	7.1280	11.9950	**4.7660**
18	4.6610	4.3230	3.4100	5.3210	4.8490	20.9720	**9.2980**
Average Time per Subject	**6.4757**	**4.0964**	**4.9119**	**6.1432**	**6.2639**	**15.0658**	**7.5333**

Block No.	S22	S23	S24	S25	S26
1	11.5260	4.0390	4.5090	6.0000	**3.7010**
2	6.9640	5.1040	3.9760	6.4190	**5.0650**
3	6.9240	3.1430	2.8280	7.0430	**5.3090**
4	12.0060	4.6840	3.7140	4.1250	**3.5210**
5	5.2650	3.2050	3.5360	3.8240	**4.3930**
6	3.7500	3.7690	3.1200	2.8480	**3.4200**
7	3.0380	2.8630	2.6340	3.2740	**4.7480**
8	4.3990	4.4010	2.8470	3.6410	**6.0500**
9	4.6040	4.3160	2.3080	3.1550	**2.8970**
10	5.9950	3.3800	3.4910	3.8220	**5.3860**
11	3.8840	4.1390	2.7780	2.8120	**3.1410**
12	4.9060	3.1180	3.0510	4.2990	**3.7820**
13	3.4880	2.2970	3.0900	2.9880	**4.1240**
14	4.6350	2.5390	3.9060	3.2430	**3.1690**
15	4.5950	2.7610	2.2450	2.8220	**2.1850**
16	4.7930	2.7560	3.3010	3.7330	**2.4200**
17	13.5810	5.9770	3.1560	3.5890	**2.5330**
18	7.6990	2.7210	3.0930	2.6910	**2.7070**
Average Time per Subject	**6.2251**	**3.6229**	**3.1991**	**3.9071**	**3.8084**

Fixed With Context Block Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5.9200	13.7300	5.2380	66.1500	5.6740	6.3530	**14.2850**
2	3.4380	10.8830	3.5090	8.5090	2.7540	4.5820	**14.5000**
3	19.7830	5.8400	3.8400	9.2600	3.4800	4.5030	**12.2040**
4	12.3220	6.2690	14.5310	11.8990	11.4690	4.5080	**34.7940**
5	10.6040	7.7950	8.9220	8.6030	16.5450	6.6310	**21.7510**
6	10.4910	5.4960	4.5490	9.1670	5.1550	4.4990	**9.5470**
7	99.5650	5.9790	55.7300	6.8730	8.8630	4.2170	**22.8340**
8	6.7780	4.8640	14.9140	6.2620	5.7630	4.1610	**22.3690**
9	6.2230	4.3730	5.3480	8.7520	3.8480	3.6630	**9.7540**
10	6.3350	3.2790	5.5800	6.4260	3.7940	3.1050	**12.1140**
11	4.5640	2.7050	4.1120	7.9660	4.3600	3.8270	**4.6810**
12	6.0300	3.3320	9.0800	9.4940	17.5340	4.4880	**8.3840**
13	7.1890	2.2430	10.0800	6.5490	22.9840	3.7090	**12.5200**
14	4.7660	2.8540	11.4060	9.8070	23.0050	3.7440	**15.0740**
15	6.8020	3.4540	32.4450	8.3750	51.1020	3.1690	**18.6790**
16	4.6760	3.7180	4.9980	6.0570	4.2290	4.2100	**5.4450**
17	5.1000	2.8110	11.6890	6.7390	8.9150	3.5810	**11.7590**
18	4.2690	3.5410	7.0450	10.6730	21.8200	4.2400	**11.2840**
Average Time per Subject	**12.4919**	**5.1759**	**11.8342**	**11.5312**	**12.2941**	**4.2883**	**14.5543**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	49.2320	6.8340	3.0630	18.2460	5.8540	22.3290	**4.9290**
2	9.9840	3.8300	2.7590	5.7070	3.6150	5.7880	**2.0980**
3	9.9730	5.4580	5.5530	11.2890	4.0330	6.9650	**5.6630**
4	20.6630	14.5810	20.4010	5.8590	11.5550	12.5890	**25.5420**
5	9.4280	4.4170	10.9080	11.3610	9.1120	5.7560	**38.7630**
6	5.8990	4.4520	3.2100	26.8100	7.7340	8.6610	**3.7680**
7	8.4050	4.9500	17.1870	8.5970	7.7730	6.1610	**46.3800**
8	5.3400	4.0770	11.9190	8.0260	6.8150	6.3270	**13.7070**
9	10.3120	5.1090	3.2680	6.0950	7.1420	4.1040	**5.1270**
10	7.6880	3.2640	6.8800	3.9660	5.9650	3.8130	**22.6010**
11	6.1160	4.1610	4.8830	5.9290	5.1640	4.4040	**4.9890**
12	8.5050	4.1610	7.4510	5.1390	7.4750	4.7910	**17.7130**
13	7.4100	3.2700	10.2120	5.1840	4.3910	4.5860	**18.0490**
14	6.4040	3.0120	11.3070	5.4180	7.5660	4.5110	**11.5330**
15	5.8100	3.8070	6.4770	5.1920	42.1670	2.7610	**32.8070**
16	6.2820	4.1350	3.8000	4.6360	5.6350	4.7770	**3.2710**
17	4.7610	3.1030	8.5040	3.5860	7.6820	4.1220	**28.7110**
18	7.1640	3.2030	6.5040	5.0460	6.9970	7.1520	**13.3160**
Average Time per Subject	**10.5209**	**4.7680**	**8.0159**	**8.1159**	**8.7042**	**6.6443**	**16.6093**

Fixed With Context Block Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	286.4710	10.8000	8.2190	7.0650	6.2170	10.4680	**9.7660**
2	14.9670	4.5690	3.5660	3.8720	4.8630	3.8710	**4.4770**
3	120.4690	3.6440	3.5140	4.5000	5.7170	4.9430	**23.3790**
4	52.6730	6.6310	37.9000	205.6990	66.5390	26.2060	**24.7860**
5	14.1160	4.2610	13.4780	10.2810	24.5950	24.4950	**18.0320**
6	24.9280	5.2030	9.1660	8.0810	12.4300	6.6750	**7.4520**
7	64.9890	6.0570	26.2740	11.0810	11.0430	19.3020	**16.0800**
8	25.1050	4.6040	25.2570	6.0540	10.4130	30.4830	**5.9940**
9	10.1900	5.0160	4.4470	6.2990	7.5280	5.2500	**5.1950**
10	16.1230	5.0240	3.7070	6.2980	7.1910	14.3430	**7.1760**
11	19.4110	3.9210	3.7960	4.5850	5.1520	28.3100	**4.9570**
12	23.2320	4.2300	14.9560	14.6680	9.4520	13.4160	**9.7360**
13	16.0590	3.5780	57.1990	20.1010	9.5840	27.7040	**8.9170**
14	13.3870	3.9620	13.6690	10.0940	5.9850	13.7500	**11.4500**
15	14.3380	4.3180	12.6490	7.5910	14.2420	12.2500	**11.7410**
16	12.9110	4.1780	3.8970	4.7930	5.8300	4.3400	**5.3940**
17	6.7600	3.8430	10.4540	13.5730	5.6490	15.0190	**15.6760**
18	8.8060	3.2410	12.8520	6.4900	4.7610	11.8310	**9.6610**
Average Time per Subject	**41.3853**	**4.8378**	**14.7222**	**19.5069**	**12.0662**	**15.1476**	**11.1038**

Block No.	S22	S23	S24	S25	S26
1	20.9960	4.8420	5.5460	8.9140	**10.2100**
2	6.3810	3.1740	3.1170	9.8390	**9.4200**
3	19.6450	2.8160	4.7510	4.9490	**12.4380**
4	23.7940	6.1340	7.7860	40.7500	**9.7970**
5	76.2550	3.9690	8.5010	8.6760	**8.0030**
6	7.9680	3.7750	3.2910	6.9220	**6.0050**
7	31.2230	2.8420	5.4450	8.7200	**8.0650**
8	19.4860	2.1790	6.4780	4.2550	**8.4160**
9	8.2730	2.4660	2.8080	5.4570	**7.3420**
10	10.6640	2.6130	8.5090	4.4720	**7.3490**
11	21.8370	2.7250	3.3500	5.3430	**14.0460**
12	7.3350	3.0880	10.8300	7.6180	**5.9070**
13	25.2090	2.2350	8.6300	6.5590	**4.9200**
14	10.2750	3.4190	11.9380	7.1450	**3.8480**
15	9.3000	8.0420	4.6420	4.6680	**4.2580**
16	5.6000	5.7050	3.9090	3.2730	**3.6190**
17	10.4560	2.4480	4.2640	5.1950	**4.4790**
18	39.7020	3.2450	4.2850	6.3740	**2.5830**
Average Time per Subject	**19.6888**	**3.6509**	**6.0044**	**8.2849**	**7.2614**

Random With Context Block Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	4.0000	40.0160	8.5700	376.5920	7.0540	5.7170	**6.8240**
2	6.5100	27.8690	11.9550	22.1620	7.3150	170.3420	**4.8730**
3	34.8190	8.8730	34.9210	6.3590	5.3900	33.6930	**10.7950**
4	5.0630	14.3200	5.9600	23.8820	4.4080	14.1330	**6.1110**
5	8.9570	10.3340	8.0120	20.7130	14.1800	8.6070	**8.2320**
6	21.2320	9.8480	35.6640	198.5180	5.3130	16.0470	**14.2820**
7	6.9030	7.1840	50.4080	27.4290	9.2050	9.6980	**17.9960**
8	8.0620	9.2930	7.3630	72.7460	6.0960	9.6410	**10.4800**
9	7.9660	8.7630	9.9500	19.6430	8.0200	5.9720	**16.5870**
10	6.4090	9.6330	4.9890	11.4100	2.8900	12.9320	**5.9660**
11	13.3310	9.3510	17.4010	13.8250	7.7250	8.2970	**18.7010**
12	4.3010	10.5920	9.2850	83.1190	5.8700	10.2410	**12.0740**
13	6.8120	8.5340	8.6310	11.8480	7.0690	6.0790	**8.2160**
14	14.6670	24.5890	7.4700	7.0440	5.7850	41.3460	**9.7240**
15	5.4240	9.3610	38.7830	8.1600	14.3770	7.2410	**8.9280**
16	4.7510	5.7560	8.4540	5.6570	7.0540	6.2960	**7.1580**
17	8.3310	34.9650	16.1250	16.9660	8.2390	8.1660	**9.3220**
18	3.2160	14.2290	10.9780	15.2950	6.2400	6.4820	**10.1130**
Average Time per Subject	**9.4863**	**14.6394**	**16.3844**	**52.2982**	**7.3461**	**21.1628**	**10.3546**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	7.5950	5.1710	4.6990	87.1600	6.7760	6.2060	**29.5310**
2	8.3520	4.7410	5.4740	280.3680	17.5990	20.5450	**53.0140**
3	10.0030	7.4600	15.9840	50.0600	21.5880	7.7510	**125.5720**
4	10.8950	6.1370	5.3170	117.0320	13.5930	40.8970	**9.2120**
5	8.9920	4.4700	9.7220	13.8780	10.8970	5.7590	**107.4260**
6	8.2040	5.3970	16.7220	170.7980	65.5330	5.7140	**78.1910**
7	60.9540	7.7220	28.5970	41.5510	21.4760	5.6510	**12.8170**
8	12.6660	8.9110	6.7420	72.4890	6.4510	7.2150	**7.3640**
9	15.3940	7.0850	5.9510	25.5370	7.7600	15.8170	**9.7380**
10	14.7830	7.1360	2.8350	17.2920	5.7520	7.2930	**3.6780**
11	13.9100	8.6420	10.9810	7.1260	10.0260	5.2690	**21.9880**
12	12.4240	4.5830	5.4990	30.9120	6.1210	6.0530	**10.6690**
13	16.5320	9.6220	4.6890	11.8860	36.4780	5.7750	**23.5680**
14	13.3490	5.7200	4.9090	11.2840	26.9430	3.8900	**9.8240**
15	8.2390	8.3770	9.1110	11.1970	21.5330	4.7490	**4.5870**
16	7.3440	5.4640	4.7460	17.1920	6.6840	5.1590	**5.6250**
17	9.6080	5.2900	6.3520	18.4940	8.5920	6.2300	**56.3780**
18	7.7890	4.4840	6.3230	10.5180	13.2760	4.8810	**28.4910**
Average Time per Subject	**13.7241**	**6.4673**	**8.5918**	**55.2652**	**17.0599**	**9.1586**	**33.2041**

Random With Context Block Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	67.3470	160.6750	3.8940	8.1000	10.6430	42.1530	**5.9640**
2	24.0390	5.2870	4.3860	15.7720	9.2280	21.0410	**7.3750**
3	10.1790	9.5710	13.3320	15.2130	7.3350	18.7270	**17.7870**
4	54.2540	7.5700	4.0650	7.9720	10.6470	11.7590	**5.4640**
5	32.7090	42.7040	5.4730	6.1510	6.5800	13.7370	**13.2510**
6	10.9120	13.2060	7.9020	42.6170	11.0420	14.4100	**35.0450**
7	85.9730	11.9780	8.0270	10.7900	11.1800	33.0790	**50.4950**
8	46.4610	14.0250	5.4390	4.7120	6.5950	10.6160	**8.2330**
9	17.2880	5.9250	4.9690	5.3000	7.7230	22.0180	**5.2080**
10	20.4050	19.9800	4.4310	4.3580	8.0740	7.9520	**5.0850**
11	48.5820	7.3990	10.2730	11.9200	7.9840	21.5810	**9.0950**
12	16.3360	12.5290	5.1820	10.8990	8.2610	15.3090	**5.5200**
13	11.1620	8.0970	14.0700	8.0500	8.7280	19.6800	**5.2970**
14	9.4560	10.8830	5.3480	9.6120	10.5090	10.1860	**32.6450**
15	8.2620	8.2930	6.1900	7.2320	6.3940	14.7640	**9.5270**
16	12.6160	8.1820	5.4700	4.7050	14.9400	10.2970	**4.6350**
17	18.8600	13.5030	12.6530	8.4980	6.1180	16.4660	**10.9220**
18	9.8240	10.5070	7.5870	6.8280	17.4360	29.9280	**6.2460**
Average Time per Subject	**28.0369**	**20.5730**	**7.1495**	**10.4849**	**9.4121**	**18.5391**	**13.2108**

Block No.	S22	S23	S24	S25	S26
1	11.7330	14.9620	15.0340	8.6670	**85.4120**
2	11.5370	6.4280	7.5120	7.8390	**19.8250**
3	161.9250	4.6070	27.7680	8.6350	**7.4080**
4	40.0520	5.4590	9.3490	4.8890	**7.0870**
5	29.9010	4.9600	4.3090	8.5010	**5.7740**
6	46.7300	3.9340	4.1880	11.1340	**6.5860**
7	20.0480	2.8160	8.1530	13.7310	**6.3640**
8	22.5740	9.7610	4.4280	9.9390	**4.6050**
9	31.2990	4.4330	5.8050	11.9490	**7.9070**
10	13.5580	2.9010	6.3210	6.5350	**7.9180**
11	31.8290	8.5160	9.7070	12.0460	**5.5750**
12	27.3350	5.3260	5.2990	7.8690	**8.5190**
13	14.1840	6.8320	11.3570	17.3730	**6.4370**
14	24.2730	4.8450	9.0540	10.8560	**6.2900**
15	13.8530	9.7330	17.8760	37.0990	**11.0520**
16	8.8540	3.1920	4.4000	6.3520	**7.7480**
17	17.0380	7.9130	6.3310	4.1330	**4.2020**
18	22.6690	3.9150	5.5710	15.2280	**8.6710**
Average Time per Subject	**30.5218**	**6.1407**	**9.0257**	**11.2653**	**12.0767**

Perfect No Context Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	2	2	3	3	5	2	1
2	3	3	4	4	5	2	1
3	5	4	4	4	5	5	4
4	5	5	3	4	5	5	4
5	5	5	3	5	5	5	5
6	5	5	4	5	5	5	5
7	5	5	4	5	5	5	5
8	5	5	4	5	5	5	5
9	5	5	4	5	5	5	5
10	5	4	4	5	5	5	5
11	5	5	4	5	5	5	4
12	5	5	4	5	5	5	5
13	5	5	5	5	5	5	5
14	5	5	4	5	5	5	5
15	5	5	5	5	5	5	5
16	5	5	5	5	5	5	3
17	5	5	5	5	5	5	5
18	5	5	5	5	5	5	5
Average Confidence per Subject	4.7222	4.6111	4.1111	4.7222	5.0000	4.6667	4.2778

Block No.	S8	S9	S10	S11	S12	S13	S14
1	4	5	5	5	5	3	2.1
2	5	5	5	5	5	4	2
3	4	5	5	5	4	5	5
4	5	5	5	5	4	5	5
5	5	5	5	5	5	5	5
6	5	5	4	5	5	5	5
7	5	5	5	5	5	5	5
8	5	5	5	5	5	5	5
9	5	5	5	5	4	5	5
10	5	5	5	5	5	5	5
11	5	5	5	5	4	5	5
12	5	5	5	5	4	5	5
13	5	5	5	5	5	5	5
14	5	5	5	5	4	5	5
15	5	5	5	5	4	5	5
16	4	5	5	5	4	5	5
17	5	5	5	5	4	5	5
18	4	4	5	5	5	5	5
Average Confidence per Subject	4.7778	4.9444	4.9444	5.0000	4.5000	4.8333	4.6722

Perfect No Context Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	5	4	3	4	4	4	3
2	5	4	4	4	5	4	2
3	5	5	5	4	5	5	3
4	5	5	5	4	5	5	3
5	5	5	5	5	4	5	4
6	5	5	5	5	5	5	4
7	5	5	5	5	5	5	3
8	5	5	5	5	5	5	4
9	5	5	5	5	5	5	4
10	5	5	5	5	5	5	3
11	5	5	5	4	5	5	3
12	5	5	5	5	5	5	3
13	5	5	5	5	5	5	3
14	4	5	5	5	5	5	4
15	5	5	5	4	5	5	4
16	5	5	5	4	5	5	3
17	5	5	5	5	5	5	4
18	5	5	5	5	5	5	3
Average Confidence per Subject	4.9444	4.8889	4.8333	4.6111	4.8889	4.8889	3.3333

Block No.	S22	S23	S24	S25	S26
1	2	1	3	3	5
2	2	3	4	4	5
3	2	5	5	5	5
4	2	5	5	5	5
5	5	5	5	5	5
6	2	5	5	5	5
7	2	5	5	5	5
8	2	5	5	5	5
9	2	5	5	5	5
10	2	5	5	5	5
11	2	5	5	5	5
12	2	5	5	5	5
13	2	5	5	5	5
14	2	5	5	5	5
15	2	5	5	5	5
16	2	5	5	5	5
17	2	5	5	5	5
18	2	5	5	5	5
Average Confidence per Subject	2.1667	4.6667	4.8333	4.8333	5.0000

Fixed No Context Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	1.5	1	2.9	4	2.8571	1.6667	**2**
2	3	2	2	3.5	2	3	**1**
3	5	3	2	4	2	4	**3**
4	5	4	1.375	3.6667	2	5	**4**
5	3	5	2	3	3	5	**4**
6	5	5	2	3	4	5	**4**
7	5	5	5	4	5	5	**5**
8	5	5	5	3	5	5	**5**
9	5	5	5	4	5	5	**5**
10	5	5	5	4	5	5	**5**
11	5	5	5	3.5	5	5	**5**
12	5	5	5	3.5	5	5	**5**
13	5	5	5	4	5	5	**5**
14	5	5	5	3	5	5	**5**
15	5	5	5	4	5	5	**5**
16	5	5	5	4	5	5	**5**
17	5	5	5	4	5	5	**5**
18	5	5	5	4	5	5	**5**
Average Confidence per Subject	**4.5833**	**4.4444**	**4.0153**	**3.6759**	**4.2143**	**4.6482**	**4.3333**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	2.5	5	1.4667	2.4	3	3.4	**2.1053**
2	3	5	3	3	2	5	**2**
3	4	5	3	5	2.1667	5	**2.1429**
4	4	5	5	5	2.5	5	**4**
5	4	5	5	5	4	5	**1.5**
6	3	5	5	5	4	5	**2**
7	4	5	5	5	4	5	**3**
8	4	5	5	5	5	5	**5**
9	4	5	5	5	5	5	**5**
10	4	5	5	5	5	5	**5**
11	5	5	5	5	5	5	**5**
12	5	5	5	5	5	5	**5**
13	5	5	5	5	5	5	**5**
14	5	5	5	5	5	5	**5**
15	5	5	5	5	5	5	**5**
16	5	5	3	5	5	5	**5**
17	5	5	5	5	5	5	**5**
18	5	5	3.4	5	5	5	**5**
Average Confidence per Subject	**4.2500**	**5.0000**	**4.3815**	**4.7444**	**4.2593**	**4.9111**	**3.9860**

Fixed No Context Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	4.5	2.8333	2.5	3	1.6	4.8333	**1.6**
2	3.5	1.2857	3	4	1	4.8056	**2**
3	3	3	4	4	2	5	**2**
4	2.6667	4	5	4	3	4.25	**2**
5	2	4	5	4	3	4	**3**
6	2.5	5	5	5	4	3.5	**3**
7	3	5	5	5	4	3	**3**
8	2.6667	5	5	5	4	3	**4**
9	1.25	5	5	5	2	4	**4**
10	4	5	5	5	2	5	**4**
11	3	5	5	5	3	5	**4**
12	5	5	5	5	4	5	**4**
13	5	5	5	5	4	5	**4**
14	5	5	5	4	4	5	**3**
15	5	5	5	5	4	5	**4**
16	5	5	5	5	4	5	**4**
17	5	5	5	5	4	5	**4**
18	5	5	5	5	4	5	**4**
Average Confidence per Subject	**3.7269**	**4.4511**	**4.6944**	**4.6111**	**3.2000**	**4.5216**	**3.3111**

Block No.	S22	S23	S24	S25	S26
1	1.2667	2.1429	3	2.75	**2**
2	1	5	4	3	**2.25**
3	2	5	5	3	**4**
4	3	5	5	5	**5**
5	4	5	5	5	**5**
6	4	5	5	5	**5**
7	4	5	5	5	**5**
8	4	5	5	5	**5**
9	4	5	5	5	**5**
10	4	5	5	5	**5**
11	4	5	5	5	**5**
12	4	5	5	5	**5**
13	4	5	5	5	**5**
14	4	5	5	5	**5**
15	4	5	5	5	**5**
16	4	5	5	5	**5**
17	4	5	5	5	**5**
18	4	5	5	5	**5**
Average Confidence per Subject	**3.5148**	**4.8413**	**4.8333**	**4.7778**	**4.6250**

Random No Context Confidence Data (PILOT STUDY)

Block No.	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
1	3	1	2.625	3	1	3	**3**
2	3.25	2	2.4286	3	1.5714	1.25	**3.25**
3	2.1429	1.3333	3	3	1	1.1111	**2.1429**
4	2	1	2.2	3	1	1.5	**2**
5	2	1	2.5	3	1	4	**2**
6	2	1	1.8571	3	1	2	**2**
7	2	1	1.7143	3	1	1.2222	**2**
8	2	1	2.3333	3	1	2	**2**
9	2	1	2	3	1.4444	1	**2**
10	2	1	2	3	2.3333	1	**2**
11	2	1	4	3	1	1	**2**
12	2	1	2.5	3	1	1	**2**
13	2	1	2.8333	3	1	1	**2**
14	1.8889	1	3	3	1	1	**1.8889**
15	2	1	2	3	1	1	**2**
16	2	1	2.5	3	1	1	**2**
17	2	1	2	3	1	1	**2**
18	2	1	2.2	3	1	1	**2**
Average Confidence per Subject	**2.1268**	**1.0741**	**2.4273**	**3.0000**	**1.1305**	**1.4491**	**2.1268**

Perfect With Context Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	4	5	4	5	5	5
2	5	5	5	4	5	5	5
3	5	5	4	4	5	5	5
4	5	5	4	5	5	5	4
5	5	5	4	5	5	5	5
6	5	5	5	5	5	5	5
7	5	5	4	5	5	5	5
8	5	5	4.5	5	5	5	5
9	5	5	4.5	5	5	5	5
10	5	5	4	5	5	5	5
11	5	5	4	5	5	5	5
12	5	5	4	5	5	5	5
13	5	5	4	5	5	5	5
14	5	5	5	5	5	5	5
15	5	5	4	5	5	5	5
16	5	5	5	5	5	5	5
17	5	5	4	5	5	5	5
18	5	5	5	5	5	5	5
Average Confidence per Subject	5.0000	4.9444	4.3889	4.8333	5.0000	5.0000	4.9444

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5	5	5	5	3	5	5
2	5	5	4	5	5	5	5
3	4	5	4	5	5	5	5
4	5	5	4	5	5	5	5
5	5	5	5	5	5	5	5
6	5	5	5	5	5	5	5
7	5	5	5	5	5	5	5
8	5	5	5	5	5	5	5
9	5	5	5	5	5	5	5
10	5	5	5	5	5	5	5
11	5	5	5	5	5	5	5
12	4	5	5	5	5	5	5
13	5	5	5	5	5	5	5
14	4	5	5	5	5	5	5
15	4	5	5	5	5	5	5
16	5	5	5	5	5	5	5
17	5	5	5	5	5	5	5
18	5	5	5	5	5	5	5
Average Confidence per Subject	4.7778	5.0000	4.8333	5.0000	4.8889	5.0000	5.0000

Perfect With Context Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	5	5	5	4	4	5	4
2	5	5	5	5	5	5	5
3	5	5	4	3	4	4	2
4	5	5	5	5	5	4	3
5	5	5	5	5	5	5	4
6	5	5	5	5	5	5	5
7	5	5	5	5	5	5	5
8	5	5	5	5	5	5	4
9	5	5	5	4	5	5	4
10	5	5	5	4	5	5	3
11	5	5	5	5	5	5	3
12	5	5	5	5	5	5	3
13	5	5	5	5	4	5	5
14	5	5	5	5	4	5	5
15	5	5	5	5	4	5	3
16	5	5	5	5	5	5	5
17	5	5	5	5	4	5	3
18	5	5	5	5	5	5	3
Average Confidence per Subject	5.0000	5.0000	4.9444	4.7222	4.6667	4.8889	3.8333

Block No.	S22	S23	S24	S25	S26
1	2	5	3	4	5
2	2	5	5	5	5
3	2	5	5	5	5
4	2	5	5	5	5
5	2	5	5	5	5
6	2	5	5	5	5
7	3	5	5	5	5
8	3	5	5	5	5
9	4	5	5	5	5
10	4	5	5	5	5
11	5	5	5	5	5
12	5	5	5	5	5
13	5	5	5	5	5
14	5	5	5	5	5
15	5	5	5	5	5
16	5	5	5	5	5
17	5	5	5	5	5
18	5	5	5	5	5
Average Confidence per Subject	3.6667	5.0000	4.8889	4.9444	5.0000

Fixed With Context Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	2	5	3	4	5	3
2	5	3	5	3	5	5	4
3	4	3	5	3	5	5	4
4	5	4	3	3	4	5	2
5	5	4	2	4	3	5	3
6	4	5	5	4	5	5	4
7	2.2857	5	2.6	4	5	5	3
8	5	5	4	4	4	5	3
9	5	5	5	4	5	5	4
10	5	5	5	4	5	5	4
11	5	5	5	5	5	5	4
12	5	5	4	4	3.5	5	4
13	5	5	4	4	3	5	4
14	5	5	4	4	2.5	5	4
15	5	4	4	4	3	5	3
16	5	5	5	4	5	5	4
17	5	5	4	4	4	5	3
18	5	5	4	4	4	5	4
Average Confidence per Subject	4.7381	4.4444	4.2000	3.8333	4.1667	5.0000	3.5556

Block No.	S8	S9	S10	S11	S12	S13	S14
1	4	5	5	5	5	3.5	5
2	4	5	5	5	5	5	5
3	5	5	5	5	5	5	5
4	4	5	5	5	4	5	5
5	5	5	4	5	4	5	4.5
6	5	5	5	5	4	5	5
7	5	5	5	5	4	5	3.6667
8	5	5	5	5	4	5	5
9	5	5	5	5	5	5	5
10	5	5	5	5	5	5	5
11	5	5	5	5	5	5	5
12	4	5	5	5	5	5	4
13	4	5	5	5	5	5	4
14	4	5	5	5	5	5	4
15	4	5	5	5	3.5	5	3
16	5	5	5	5	5	5	5
17	4	5	5	5	4	5	5
18	5	5	5	5	4	5	5
Average Confidence per Subject	4.5556	5.0000	4.9444	5.0000	4.5278	4.9167	4.6204

Fixed With Context Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	2.5	5	5	5	3	5	4
2	5	5	5	5	3	5	5
3	3	5	5	5	3	5	4
4	4.5	5	4	3	2.25	5	3.6667
5	5	5	5	4	2	5	2
6	5	5	5	5	3	5	4
7	4.6667	5	4	5	3	5	2.5
8	4	5	4	5	3	5	2
9	5	5	5	5	4	5	4
10	5	5	5	5	3	5	5
11	5	5	5	5	3	5	5
12	5	5	5	5	3	5	4
13	5	5	3.3333	4.5	3	5	3
14	5	5	3	4	4	5	3
15	5	5	4	4	2	5	3
16	5	5	5	5	4	5	4
17	5	5	4	4	3	5	2
18	5	5	4	5	4	5	4
Average Confidence per Subject	4.6481	5.0000	4.4630	4.6389	3.0694	5.0000	3.5648

Block No.	S22	S23	S24	S25	S26
1	5	5	5	4	5
2	5	5	5	4	5
3	5	5	5	5	5
4	5	5	5	4	5
5	2	5	4	4	5
6	5	5	5	5	5
7	2	5	5	5	5
8	2	5	5	5	5
9	5	5	5	5	5
10	5	5	5	5	5
11	5	5	5	5	5
12	5	5	5	5	5
13	4.5	5	5	5	5
14	5	5	5	5	5
15	5	5	5	5	5
16	5	5	5	5	5
17	5	5	5	5	5
18	5	5	5	5	5
Average Confidence per Subject	4.4722	5.0000	4.9444	4.7778	5.0000

Random With Context Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	4	3	2.2667	4	4	3
2	5	3	5	2	5	2.5	4
3	3.3333	4	4	3	5	3.5	4
4	5	4	5	3	5	3	4
5	4	4	4	3	3.5	4	4
6	5	5	3.3333	2.3333	5	3	3
7	5	4	3	2	5	4	3
8	5	4	5	2.5	4	4	5
9	5	5	5	3	4	5	4.5
10	5	4	5	3	5	3	4
11	3	4	4	3	4	4	4
12	5	3	4	3	5	4	4
13	5	4	5	3	5	5	4
14	1	4	5	3	4	4	4
15	5	3	3.6667	3	3	5	4
16	5	5	4	4	5	5	5
17	5	4	5	3	5	4	5
18	5	4	4	3	5	5	5
Average Confidence per Subject	**4.5185**	**4.0000**	**4.2778**	**2.8389**	**4.5278**	**4.0000**	**4.0833**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5	5	5	3	5	5	2.6
2	4	5	3	1	4	5	2.1667
3	4	5	5	5	3	5	1.7143
4	5	5	5	3.6	4	3.5	5
5	4	5	5	5	2	5	3
6	4	5	3	1	1.6667	5	2
7	3.6667	5	2.5	4	3	5	4
8	4	5	1	3.6667	4	5	3
9	4	5	5	5	3	5	2
10	5	3	5	3	4	5	5
11	4	5	4	5	4	5	4
12	4	5	5	5	5	5	5
13	3	5	3	5	4.3333	5	4
14	3	5	5	5	3	5	5
15	4	5	5	5	4	5	5
16	4	5	5	5	5	5	5
17	5	5	5	5	5	5	3
18	5	5	5	5	4	5	4
Average Confidence per Subject	**4.1482**	**4.8889**	**4.2500**	**4.1259**	**3.7778**	**4.9167**	**3.6378**

Random With Context Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	4.5	3	5	3	4	4	3
2	4	5	5	4	3	4	4
3	4	5	4	4	3	5	3
4	5	4	5	4	3	4	4
5	4.5	4	5	5	4	5	3
6	5	5	4	3	3	4	1.75
7	5	5	4	4	3	5	1.5
8	4.5	4	5	5	3	5	1
9	5	5	5	5	3	5	1
10	5	5	5	5	2	5	1
11	4	5	4	5	3	5	1
12	5	4	5	5	3	5	1
13	5	5	4	4	2	5	1
14	5	5	5	5	2	5	1.8
15	5	5	4	4	3	5	2
16	5	5	5	5	3	5	4
17	5	5	4	5	4	5	3
18	5	5	4	5	3	5	2
Average Confidence per Subject	4.7500	4.6667	4.5556	4.4444	3.0000	4.7778	2.1694

Block No.	S22	S23	S24	S25	S26
1	4	2.6667	5	4	5
2	5	5	5	5	4
3	3.8571	5	5	5	5
4	3.5	5	5	5	5
5	4.5	5	5	5	5
6	5	5	5	5	5
7	5	5	5	4	5
8	3	5	5	5	5
9	2	5	5	5	5
10	5	5	5	5	5
11	2	5	5	3	5
12	3	5	5	4	5
13	5	5	3	5	5
14	2	5	5	4	5
15	5	5	5	4.5	5
16	5	5	5	5	5
17	4	5	5	5	5
18	2	5	5	5	5
Average Confidence per Subject	3.8254	4.8704	4.8889	4.6389	4.9444

Perfect No Context NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Mental Workload	7	2	1	6	6	1	1	4	3	4	0	4	**0**
Physical Demand	0	2	1	6	1	1	5	2	4	3	0	3	**1**
Temporal Demand	2	2	1	8	6	0	1	3	3	4	0	2	**0**
Performance	0	2	1	3	1	0	1	1	2	1	0	0	**0**
Effort	5	2	1	3	1	3	3	1	3	14	0	2	**1**
Frustration Level	**4**	**2**	**1**	**4**	**1**	**1**	**1**	**1**	**3**	**4**	**0**	**0**	**0**

	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mental Workload	0	3	0	1	8	2	5	10	0	1	5	3	**0**
Physical Demand	0	2	0	1	2	2	2	5	0	1	6	3	**0**
Temporal Demand	0	2	2	3	0	7	0	8	0	0	9	3	**0**
Performance	0	1	0	0	2	1	0	11	0	0	0	0	**0**
Effort	0	2	1	3	0	2	2	12	0	2	5	4	**0**
Frustration Level	**0**	**1**	**0**	**1**	**2**	**1**	**1**	**8**	**6**	**0**	**0**	**1**	**0**

Fixed No Context NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Mental Workload	7	2	1	6	6	1	1	4	3	4	0	4	**0**
Physical Demand	0	2	1	6	1	1	5	2	4	3	0	3	**1**
Temporal Demand	2	2	1	8	6	0	1	3	3	4	0	2	**0**
Performance	0	2	1	3	1	0	1	1	2	1	0	0	**0**
Effort	5	2	1	3	1	3	3	1	3	14	0	2	**1**
Frustration Level	**4**	**2**	**1**	**4**	**1**	**1**	**1**	**1**	**3**	**4**	**0**	**0**	**0**

	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mental Workload	0	3	0	1	8	2	5	10	0	1	5	3	**0**
Physical Demand	0	2	0	1	2	2	2	5	0	1	6	3	**0**
Temporal Demand	0	2	2	3	0	7	0	8	0	0	9	3	**0**
Performance	0	1	0	0	2	1	0	11	0	0	0	0	**0**
Effort	0	2	1	3	0	2	2	12	0	2	5	4	**0**
Frustration Level	**0**	**1**	**0**	**1**	**2**	**1**	**1**	**8**	**6**	**0**	**0**	**1**	**0**

Random No Context NASA TLX Data (PILOT DATA)

	S1	S2	S3	S4	S5	S6
Mental Workload	12	2	13	15	14	**15**
Physical Demand	5	3	9	17	15	**15**
Temporal Demand	6	2	3	18	11	**11**
Performance	10	18	17	16	10	**17**
Effort	12	3	13	16	14	**16**
Frustration Level	**3**	**18**	**17**	**16**	**10**	**16**

Perfect With Context NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Mental Workload	3	0	1	5	1	0	9	1	5	7	0	1	**4**
Physical Demand	0	0	5	2	1	1	3	1	5	9	0	1	**2**
Temporal Demand	0	0	5	3	1	1	7	1	3	13	0	1	**2**
Performance	0	0	5	3	1	1	1	1	2	2	0	2	**0**
Effort	0	0	3	4	1	1	5	1	4	14	0	1	**4**
Frustration Level	**0**	**0**	**1**	**2**	**1**	**0**	**1**	**1**	**5**	**6**	**0**	**0**	**2**

	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mental Workload	0	1	0	5	17	6	2	4	0	2	5	1	**0**
Physical Demand	0	2	0	5	2	1	5	6	0	6	5	2	**0**
Temporal Demand	0	3	1	6	16	7	1	2	0	0	6	2	**0**
Performance	0	3	0	0	1	2	0	2	0	0	1	1	**0**
Effort	0	4	1	3	10	3	2	4	0	4	7	4	**0**
Frustration Level	**0**	**3**	**0**	**1**	**2**	**1**	**0**	**4**	**0**	**3**	**3**	**2**	**0**

Fixed With Context NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Mental Workload	9	2	15	14	8	0	13	7	7	14	0	2	**5**
Physical Demand	0	0	5	8	4	1	5	3	3	12	0	2	**2**
Temporal Demand	0	0	3	11	8	1	5	3	9	14	0	1	**4**
Performance	15	0	5	6	9	1	3	5	5	2	0	2	**3**
Effort	6	3	15	13	10	1	7	7	5	15	0	1	**4**
Frustration Level	**5**	**0**	**5**	**6**	**4**	**0**	**1**	**5**	**6**	**13**	**0**	**0**	**3**

	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mental Workload	13	9	0	12	14	7	0	6	6	4	13	7	**0**
Physical Demand	0	1	0	3	10	8	4	10	0	3	10	4	**0**
Temporal Demand	13	3	1	8	16	7	1	4	6	0	11	3	**0**
Performance	0	6	0	5	4	9	0	4	4	2	1	2	**0**
Effort	10	8	0	8	14	8	3	8	10	4	7	7	**0**
Frustration Level	**4**	**8**	**1**	**5**	**3**	**7**	**0**	**6**	**5**	**2**	**4**	**2**	**0**

Random With Context NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Mental Workload	9	13	13	15	6	16	9	10	9	15	20	10	**7**
Physical Demand	0	13	7	15	4	1	5	2	4	12	0	12	**3**
Temporal Demand	0	10	7	12	4	6	3	3	12	14	0	6	**4**
Performance	14	5	5	13	4	15	3	6	7	4	10	8	**4**
Effort	9	14	13	13	6	14	7	8	7	14	9	10	**8**
Frustration Level	**6**	**6**	**5**	**11**	**2**	**16**	**1**	**7**	**7**	**5**	**15**	**0**	**4**

	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mental Workload	20	7	6	13	18	5	2	18	12	10	17	14	**11**
Physical Demand	12	1	0	4	4	4	5	12	4	2	7	14	**1**
Temporal Demand	5	4	5	6	16	5	3	17	0	0	13	8	**1**
Performance	20	1	2	6	2	7	1	16	6	8	1	3	**0**
Effort	14	7	8	7	18	7	7	16	10	10	17	16	**6**
Frustration Level	**20**	**4**	**4**	**4**	**3**	**7**	**3**	**15**	**13**	**5**	**4**	**6**	**5**

SPSS Data File

Subject	PNC:time	PNC:toterr	PNC:avgerr	PNC:avgcon	FNC:time	FNC:toterr
1	3.358277778	0	0	4.722222	3.759388889	1
2	4.932333333	0	0	4.611111	3.614388889	1
3	5.4335	0	0	4.111111	25.922	19
4	3.787222222	0	0	4.722222	8.701333333	8
5	3.649	0	0	5	5.221111111	6
6	4.248833333	0	0	4.666667	5.566666667	2
7	5.626722222	0	0	4.277778	8.4235	5
8	6.658166667	0	0	4.777778	6.150666667	1
9	3.517666667	0	0	4.944444	3.860722222	0
10	4.950777778	0	0	4.944444	11.91733333	20
11	5.067777778	0	0	5	8.885555556	4
12	6.065277778	0	0	4.5	21.20155556	21
13	3.759722222	0	0	4.833333	5.254722222	4
14	7.480944444	9	0.5	4.672222	18.45827778	33
15	7.395	0	0	4.944444	16.72166667	14
16	4.261944444	0	0	4.888889	7.989166667	11
17	4.531444444	0	0	4.833333	5.714555556	3
18	7.114666667	2	0.111111111	4.611111	5.784944444	0
19	4.714166667	0	0	4.888889	10.19388889	5
20	5.9795	0	0	4.888889	13.20866667	11
21	5.812055556	0	0	3.333333	5.26	5
22	8.214277778	0	0	2.166667	23.74705556	14
23	2.653444444	0	0	4.666667	4.751444444	6
24	3.126777778	0	0	4.833333	4.372055556	4
25	4.256388889	0	0	4.833333	5.191333333	5
26	3.946222222	0	0	5	6.692222222	7

Subject	FNC:avgerr	FNC:avgcon	PC:time	PC:toterr	PC:avgerr	PC:avgcon
1	0.05555556	4.583333	4.417833333	0	0	5
2	0.05555556	4.444444	3.616277778	0	0	4.944444
3	1.05555556	4.015278	5.437555556	2	0.111111111	4.388889
4	0.44444444	3.675928	5.507833333	2	0.111111111	4.833333
5	0.33333333	4.214283	3.516166667	0	0	5
6	0.11111111	4.64815	5.220777778	0	0	5
7	0.27777778	4.333333	5.9335	0	0	4.944444
8	0.05555556	4.25	4.912888889	0	0	4.777778
9	0	5	3.719166667	0	0	5
10	1.11111111	4.381481	6.981555556	2	0.111111111	4.833333
11	0.22222222	4.744444	4.855722222	0	0	5
12	1.16666667	4.259261	5.325944444	0	0	4.888889
13	0.22222222	4.911111	5.387833333	0	0	5
14	1.83333333	3.986007	4.038055556	0	0	5
15	0.77777778	3.726852	6.475722222	0	0	5
16	0.61111111	4.451058	4.096444444	0	0	5
17	0.16666667	4.694444	4.911888889	0	0	4.944444
18	0	4.611111	6.143166667	0	0	4.722222
19	0.27777778	3.2	6.263888889	0	0	4.666667
20	0.61111111	4.521605	15.06577778	1	0.055555556	4.888889
21	0.27777778	3.311111	7.533277778	1	0.055555556	3.833333
22	0.77777778	3.514815	6.225111111	0	0	3.666667
23	0.33333333	4.84127	3.622888889	0	0	5
24	0.22222222	4.833333	3.199055556	0	0	4.888889
25	0.27777778	4.777778	3.907111111	0	0	4.944444
26	0.38888889	4.625	3.808388889	0	0	5

SPSS Data File (cont.)

Subject	SC:time	SC:toterr	SC:avgerr	SC:avgcon	RC:time	RC:toterr
1	12.49194444	7	0.388888889	4.738094	9.486333333	4
2	5.175888889	0	0	4.444444	14.63944444	2
3	11.83422222	5	0.277777778	4.2	16.38438889	7
4	11.53116667	2	0.111111111	3.833333	52.29822222	23
5	12.29411111	8	0.444444444	4.166667	7.346111111	2
6	4.288333333	0	0	5	21.16277778	11
7	14.55433333	1	0.055555556	3.555556	10.35455556	1
8	10.52088889	1	0.055555556	4.555556	13.72405556	2
9	4.768	1	0.055555556	5	6.467333333	2
10	8.015888889	1	0.055555556	4.944444	8.591833333	6
11	8.115888889	0	0	5	55.26522222	20
12	8.704166667	1	0.055555556	4.527778	17.05988889	7
13	6.644277778	1	0.055555556	4.916667	9.158555556	1
14	16.60927778	6	0.333333333	4.620372	33.20405556	26
15	41.38527778	8	0.444444444	4.648148	28.03694444	7
16	4.837777778	1	0.055555556	5	20.573	3
17	14.72222222	5	0.277777778	4.462963	7.1495	1
18	19.50694444	9	0.5	4.638889	10.48494444	1
19	12.06616667	3	0.166666667	3.069444	9.412055556	2
20	15.14755556	4	0.222222222	5	18.53905556	4
21	11.10383333	6	0.333333333	3.564815	13.21077778	10
22	19.68883333	2	0.111111111	4.472222	30.52177778	9
23	3.650944444	1	0.055555556	5	6.140722222	4
24	6.004444444	1	0.055555556	4.944444	9.025666667	3
25	8.284944444	1	0.055555556	4.777778	11.26527778	4
26	7.261388889	0	0	5	12.07666667	2

Subject	RC:avgerr	RC:avgcon	Handedness	SA	SA %	Age
1	0.222222222	4.518517	17	20	95.2381	24
2	0.111111111	4	15	16	76.19048	24
3	0.388888889	4.277778	20	17	80.95238	25
4	1.277777778	2.838889	15	15	71.42857	20
5	0.111111111	4.527778	19	18	85.71429	21
6	0.611111111	4	13	19	90.47619	18
7	0.055555556	4.083333	10	18	85.71429	19
8	0.111111111	4.14815	14	19	90.47619	20
9	0.111111111	4.888889	16	16	76.19048	29
10	0.333333333	4.25	11	14	66.66667	56
11	1.111111111	4.125928	16	6	28.57143	54
12	0.388888889	3.777778	15	10	47.61905	21
13	0.055555556	4.916667	-8	17	80.95238	21
14	1.444444444	3.637831	17	7	33.33333	20
15	0.388888889	4.75	17	8	38.09524	54
16	0.166666667	4.666667	2	19	90.47619	19
17	0.055555556	4.555556	17	18	85.71429	30
18	0.055555556	4.444444	-20	19	90.47619	25
19	0.111111111	3	11	18	85.71429	31
20	0.222222222	4.777778	15	13	61.90476	28
21	0.555555556	2.169444	17	11	52.38095	29
22	0.5	3.825397	10	10	47.61905	31
23	0.222222222	4.87037	17	20	95.2381	29
24	0.166666667	4.888889	10	20	95.2381	30
25	0.222222222	4.638889	18	19	90.47619	25
26	0.111111111	4.944444	13	20	95.2381	28

SPSS Data File (cont.)

Subject	M/F 0/1	PNC TLX Mental	PNC TLX Physical	PNC TLX Temporal	PNC TLX Performance	PNC TLX Effort
1	0	7	0	2	0	5
2	0	2	2	2	2	2
3	0	1	1	1	1	1
4	1	6	6	8	3	3
5	1	6	1	6	1	1
6	0	1	1	0	0	3
7	1	1	5	1	1	3
8	0	4	2	3	1	1
9	0	3	4	3	2	3
10	0	4	3	4	1	14
11	1	0	0	0	0	0
12	0	4	3	2	0	2
13	0	0	1	0	0	1
14	0	0	0	0	0	0
15	1	3	2	2	1	2
16	0	0	0	2	0	1
17	1	1	1	3	0	3
18	1	8	2	0	2	0
19	1	2	2	7	1	2
20	1	5	2	0	0	2
21	1	10	5	8	11	12
22	1	0	0	0	0	0
23	0	1	1	0	0	2
24	0	5	6	9	0	5
25	1	3	3	3	0	4
26	0	0	0	0	0	0

Subject	PNC TLXFrustration	SNC TLX Mental	SNC TLX Physical	SNC TLX Temporal	SNC TLX Performance	SNC TLX Effort
1	4	4	0	0	1	2
2	2	6	3	2	1	3
3	1	5	1	5	7	5
4	4	10	6	10	6	5
5	1	4	2	6	4	4
6	1	7	1	2	2	3
7	1	5	5	3	7	3
8	1	6	2	4	4	4
9	3	2	2	1	0	2
10	4	15	4	10	11	14
11	0	0	0	0	0	0
12	0	6	5	4	8	2
13	0	6	2	2	0	5
14	0	13	15	11	5	7
15	1	8	2	2	8	4
16	0	8	0	5	3	5
17	1	7	3	5	2	4
18	2	17	3	17	1	3
19	1	8	6	6	4	7
20	1	8	8	4	2	10
21	8	15	8	12	12	12
22	6	8	0	0	7	15
23	0	3	2	0	5	6
24	0	15	11	9	2	12
25	1	6	4	2	1	6
26	0	6	0	1	7	8

SPSS Data File (cont.)

Subject	SNC TLXFrustration	PC TLX Menta;	PC TLX Physical	PC TLX Temporal	PC TLX Performance	PC TLX Effort
1	1	3	0	0	0	0
2	0	0	0	0	0	0
3	9	1	5	5	5	3
4	6	5	2	3	3	4
5	4	1	1	1	1	1
6	2	0	1	1	1	1
7	3	9	3	7	1	5
8	4	1	1	1	1	1
9	2	5	5	3	2	4
10	14	7	9	13	2	14
11	0	0	0	0	0	0
12	0	1	1	1	2	1
13	2	4	2	2	0	4
14	7	0	0	0	0	0
15	4	1	2	3	3	4
16	9	0	0	1	0	1
17	3	5	5	6	0	3
18	3	17	2	16	1	10
19	7	6	1	7	2	3
20	9	2	5	1	0	2
21	12	4	6	2	2	4
22	16	0	0	0	0	0
23	4	2	6	0	0	4
24	3	5	5	6	1	7
25	3	1	2	2	1	4
26	7	0	0	0	0	0

Subject	PC TLXFrustration	SC TLX Mental	SC TLX Physical	SC TLX Temporal	SC TLX Performance	SC TLX Effort
1	0	9	0	0	15	6
2	0	2	0	0	0	3
3	1	15	5	3	5	15
4	2	14	8	11	6	13
5	1	8	4	8	9	10
6	0	0	1	1	1	1
7	1	13	5	5	3	7
8	1	7	3	3	5	7
9	5	7	3	9	5	5
10	6	14	12	14	2	15
11	0	0	0	0	0	0
12	0	2	2	1	2	1
13	2	5	2	4	3	4
14	0	13	0	13	0	10
15	3	9	1	3	6	8
16	0	0	0	1	0	0
17	1	12	3	8	5	8
18	2	14	10	16	4	14
19	1	7	8	7	9	8
20	0	0	4	1	0	3
21	4	6	10	4	4	8
22	0	6	0	6	4	10
23	3	4	3	0	2	4
24	3	13	10	11	1	7
25	2	7	4	3	2	7
26	0	0	0	0	0	0

SPSS Data File (cont.)

Subject	*SC TLX Frustration*	*RC TLX Mental*	*RC TLX Physical*	*RC TLX Temporal*	*RC TLX Performance*	*RC TLX Effort*	*RC TLX Frustration*
1	5	9	0	0	14	9	**6**
2	0	13	13	10	5	14	**6**
3	5	13	7	7	5	13	**5**
4	6	15	15	12	13	13	**11**
5	4	6	4	4	4	6	**2**
6	0	16	1	6	15	14	**16**
7	1	9	5	3	3	7	**1**
8	5	10	2	3	6	8	**7**
9	6	9	4	12	7	7	**7**
10	13	15	12	14	4	14	**5**
11	0	20	0	0	10	9	**15**
12	0	10	12	6	8	10	**0**
13	3	7	3	4	4	8	**4**
14	4	20	12	5	20	14	**20**
15	8	7	1	4	1	7	**4**
16	1	6	0	5	2	8	**4**
17	5	13	4	6	6	7	**4**
18	3	18	4	16	2	18	**3**
19	7	5	4	5	7	7	**7**
20	0	2	5	3	1	7	**3**
21	6	18	12	17	16	16	**15**
22	5	12	4	0	6	10	**13**
23	2	10	2	0	8	10	**5**
24	4	17	7	13	1	17	**4**
25	2	14	14	8	3	16	**6**
26	**0**	**11**	**1**	**1**	**0**	**6**	**5**

SPSS Block Distance Data File

Block #	PC error total	PC error avg	PC time total	PC time avg	FC error total	FC error avg	FC time total	FC time avg
1	0	1.285714	132.899	6.328524	8	0.380952	566.843	**26.99252**
2	0	0.952381	127.376	6.065524	1	0.047619	122.141	**5.816238**
3	4	0.619048	234.941	11.18767	4	0.190476	274.01	**13.0481**
4	0	0.238095	164.869	7.850905	16	0.761905	627.416	**29.87695**
5	0	0.428571	108.344	5.159238	5	0.238095	279.854	**13.32638**
6	1	0.904762	103.178	4.913238	0	0	183.373	**8.732048**
7	0	0.619048	89.855	4.27881	16	0.761905	458.34	**21.82571**
8	1	0.190476	101.606	4.838381	2	0.095238	229.232	**10.91581**
9	1	0.190476	121.141	5.768619	0	0	127.043	**6.049667**
10	0	0.095238	118.088	5.623238	0	0	154.672	**7.365333**
11	0	0.095238	111.916	5.329333	0	0	137.993	**6.571095**
12	0	0.142857	131.611	6.26719	1	0.047619	203.267	**9.679381**
13	0	0.238095	85.182	4.056286	7	0.333333	261.518	**12.45324**
14	1	0.333333	103.011	4.905286	1	0.047619	192.704	**9.176381**
15	0	0.190476	88.69	4.223333	7	0.333333	300.176	**14.2941**
16	0	0	100.945	4.806905	0	0	107.212	**5.105333**
17	0	0.142857	116.521	5.548619	1	0.047619	182.037	**8.668429**
18	**0**	**0.095238**	**108.33**	**5.158571**	**1**	**0.047619**	**169.896**	**8.090286**

Block #	RC error total	RC error avg	RC time total	RC time avg	PC Distance	SC Distance	RC Distance
1	27	0	894.687	42.60414	2	0	**1**
2	20	0	728.247	34.67843	1	0	**0**
3	13	0.190476	465.412	22.16248	2	1	**2**
4	5	0	378.691	18.0329	2	2	**0**
5	9	0	360.784	17.18019	1	2	**1**
6	19	0.047619	786.597	37.457	0	0	**2**
7	13	0	519.113	24.71967	0	2	**1**
8	4	0.047619	341.6	16.26667	1	2	**1**
9	4	0.047619	232.614	11.07686	2	0	**1**
10	2	0	183.283	8.727762	2	1	**0**
11	2	0	283.407	13.49557	1	0	**2**
12	3	0	285.779	13.60852	2	2	**2**
13	5	0	240.823	11.46776	0	2	**1**
14	7	0.047619	275.183	13.10395	1	2	**1**
15	4	0	220.729	10.5109	1	2	**1**
16	0	0	158.185	7.532619	1	0	**0**
17	3	0	300.078	14.28943	2	1	**2**
18	**2**	**0**	**230.671**	**10.98433**	**2**	**1**	**2**

SPSS Analyses

1. To compare Error and Block Placement Time Data between the cases:
    - General Linear Model > Repeated Measures
        - Within Subjects Factor – case(4)
        - Measure Name – Average Error and Average Time
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

2. To compare NASA TLX Data between the cases:
    - General Linear Model > Repeated Measures
        - Within Subjects Factor – case(4)
        - Measure Name – NASA TLX measures
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

3. To look at correlations between all of the data
    - Correlate > Bivariate
        - Pearson
        - Two-tailed

4. To compare Block Distance Data
    - General Linear Model > Univariate (ANOVA)
        - Dependent Variable – error or time
        - Random Factor – distance
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

APPENDIX C

USER STUDY 2 DOCUMENTS AND QUESTIONNAIRES

Research Consent Form for
Adaptive Intent-Based Augmentation System Study

Project Title: Adaptive Intent-Based Augmentation System Study
Investigators: *Blair MacIntyre, Cindy Robertson,*
Georgia Institute of Technology

You are being asked to be a volunteer in a research study.

Purpose:

"Augmented Reality" is a variation of Virtual Reality that uses see-through displays (usually see-through goggles worn on the head) to draw graphics on top of the wearer's view of the world around them. For example, the "1st and 10" system used during football games on TV is an augmented reality system that draws the 1st down line on the field for the TV audience. Another example would be a car repair system that draws maintenance instructions directly on a repairperson's view of the engine when they look at it. A major problem with creating augmented reality systems is that it is hard to make the graphics line up ("register") with the user's view of the world, primarily because it is hard for the computer to know exactly where the user and the objects in the world are.

However, we believe that it is not always necessary that the graphics precisely line up with the real world for users to understand what the computer is telling them. We have designed a set of AR graphical displays that we think should be understandable by people even when they do not line up with the physical world.

The purpose of this study is to test one of these graphical drawing techniques, virtual context, in an augmented reality system. This experiment will help us understand how well context helps to reduce the effects of graphical misalignments in Augmented Reality. This is the first step in creating a general-purpose graphics toolkit of AR drawing techniques that help programmers to create AR systems that function in the presence of registration error.

Procedures:

If you decide to be in this study, you will be asked to complete a series of tasks while immersed in an Augmented Reality Environment. You will be asked to wear a head-mounted display that is being tracked by the computer, and follow a set of instructions in order to complete a set of building tasks using Lego building blocks. You will be instructed to pick up a particular block and place it on a building platform. If the block is not placed correctly, you will be asked to try again. The series of tasks will test how different kinds of graphical instructions help you to complete the task when there are different types of misalignment between the graphics and the real world. .

Your time commitment will be approximately 90 minutes. During that time, the researcher will give you instructions on how to complete the experiment you are about to participate in. You will be asked to fill out an introductory questionnaire. You will then be asked to perform a series of block placement tasks. After each task, you will be asked to fill out a trial survey and after completing all of the tasks, you will be asked to fill out a survey about your entire experience.

Three types of data will be recorded during this study. First, data will be recorded while you are going through the experiment. This type of data will include, for example, how long you take to complete each block placement, how many incorrect blocks you placed, etc. The second type of data is your survey responses. The third type of data will be a video-taped record of your session. All of these types of data will be stored for analysis which may extend over several years of research. We will use this data to assess the types of visualizations that may be useful for inclusion in our toolkits. We will keep the video locked in our lab in TSRB and will destroy it after our research has been completed. You consent to the capture of data and the use of it for these research purposes.

Risks/Discomforts

You may face some risks or discomforts due to being part of this study. Some people may experience dizziness and/or headaches while wearing a head-mounted display.

Benefits

If you are a volunteer from the psychology pool, you will receive study credits. If you are not from the psychology pool, you will be compensated $10 per hour for participating in this study. Also, results from the study will help to design better graphics for augmented reality environments.

Compensation to You

If you are a volunteer from the psychology pool, you will receive 1.5 study credits. If you are not from the psychology pool, we will compensate you $10 per hour rounded to the nearest half hour. (For example, if your study lasts for 1 hour and 35 minutes, you will be paid $15, but if your study lasts for 1 hour and 45 minutes, you will be paid $20.)

Confidentiality

The following procedures will be followed to keep your personal information confidential in this study: Your identity will be coded, and all data will be kept in a secured, limited access location. Your identity will not be revealed in any publication or presentation of the results of this research. However, confidentiality cannot be guaranteed; your personal information may be disclosed if required by law. To ensure that this research activity is being conducted properly, Georgia Institute of Technology and Governmental agencies (I.e. Office of Human Research Protections), have the right to review study records, but confidentiality will be maintained to the extent allowed by law.

Costs to You

You shall incur no costs by participating in this study.

In Case of Injury/Harm

If you are injured as a result of being in this study, please contact Blair MacIntyre at (404) 894-5224. Neither the Principal Investigator nor the Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting form participation in this study.

Subject Rights

Your participation in this study is voluntary. You do not have to be in this study if you do not want to be. You have the right to change your mind and leave the study at any time without giving any reason, and without penalty. Any new information that may make you change your mind about being in this study will be given to you. You will be given a copy of this consent form to keep. You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject

If you have any questions about the study, you may contact Cindy Robertson at telephone (404) 385-1104 or Blair MacIntyre at telephone (4040) 894-5224. If you have any questions about your rights as a research subject, you may contact Melanie Clark, Georgia Institute of Technology at (404) 894-6942.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

Subject's Name: ____

Subject's Signature: ______________________________ Date:____________

Person Obtaining Consent Signature: ___________________ Date:____________

We would like to be able to contact you if we have any follow-up questions. If you consent to us contacting you in the future, please provide your email address.

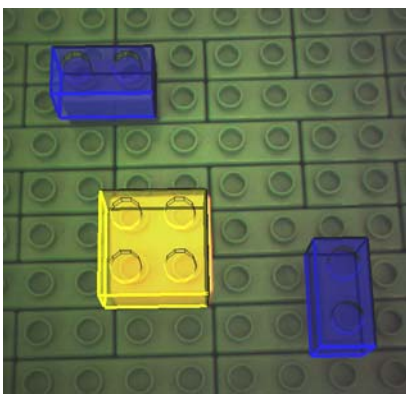
Email address: ____

Training

This study is designed to test your ability to complete a Lego placement task where you will be shown a yellow virtual block on the Head Mounted Display (HMD) telling you where to place a yellow Lego piece on the green Lego base plate. In addition to the yellow virtual target block, some virtual context will be displayed on your head mounted display. For the purposes of this study, the context will take the form of two virtual blue Lego blocks that represent two physical blue Lego blocks that exists on the Lego base plate.

These instructions will be shown in 4 different ways: fully registered graphics, the graphics will be located off to the left side of the Lego base plate, the graphics will always be located on your HMD in your field of view but they will be transparent enough so that you can see the real world through the graphics, and graphics that will be located in your field of view but you have to turn your head to the left or the right to see them. For each set of 18 Lego blocks you place, the virtual blocks shown on the Head Mounted Display will be shown using the same method.

Fully registered graphics: When the graphical world and the physical world align properly, there is little to no registration error present in the system. Figure 1(a) is an example of the graphical world and the physical world aligning almost perfectly. Figure 1(a) also shows both the physical blue blocks and the virtual blue context blocks that will be provided on the head-mounted display in the fully registered case.


(a)

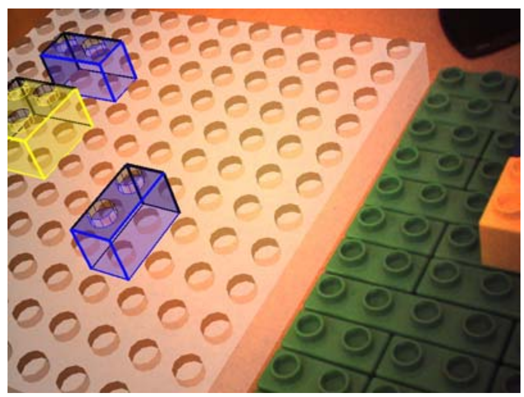
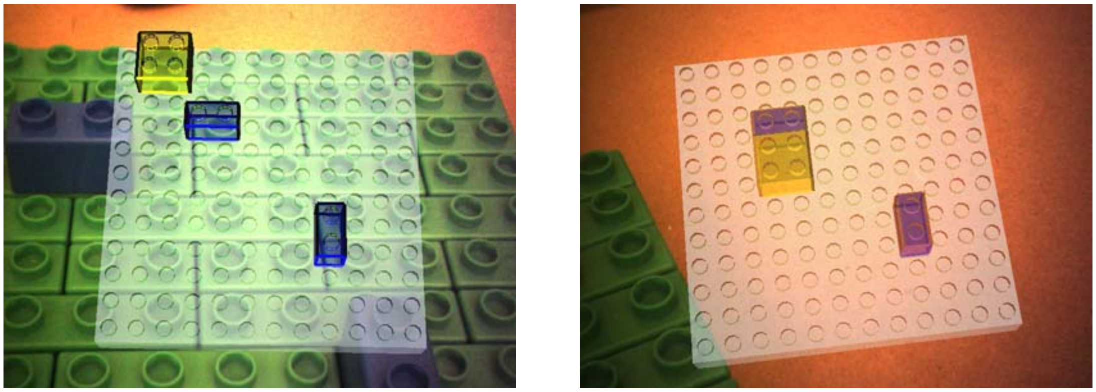

(b)

Figure 1: (a) Fully Registered Graphics, (b) Context off to the side

Context off to the side: In this case the graphical world and the physical world do not align. Instead, the graphics are located off to the left side of the physical base plate. Figure 1(b) shows an example of the graphics located off to the side.

Graphics attached to the head which are always visible: In this case the graphics will be located within your field of view and they will constantly remain there. They will be transparent enough so that you can see through them to see the physical board located beneath. Figure 2(a) shows an example of the graphics you will experience in this block of trials.



(a) (b)

Figure 2: (a) Graphics attached to the head which are always visible, (b) Graphics attached to the head which are NOT always visible

Graphics attached to the head which are NOT always visible: In this case the graphics will be located within your field of view, but you have to turn your head to the left or the right to see them. Again, they will be transparent enough so that you can see through them to see the physical board located beneath. Figure 2(b) shows the graphics that you will see when you turn your head to the side in this block.

This study: In this study, you will be asked to complete 4 sets of tasks. You will be asked to complete these tasks using the 4 instruction methods described above. In each of these cases, a yellow virtual block representing the target is shown on the display, as well as blue virtual blocks representing some existing blue context Lego blocks are also shown. The 4 tasks are as follows:

1. place 18 blocks when the graphics are fully registered
2. place 18 blocks when the graphics are located off to the side
3. place 18 blocks when the graphics are always located in your field of view
4. place 18 blocks when you have to turn your head to see the graphics

While completing this study, we will evaluate you based on two different metrics: the amount of time that it takes you to place each block and the number of errors you make in placing each block. Therefore, it is important to perform this task as **quickly** and as **accurately** as possible!

Intro Questionnaire

Thank you for your participation in this experiment.

1. Age: _______

2. Gender: M / F

3. Are your right-handed or left-handed? ___ right-handed ___ left-handed

4. Education level:
   ___ High school
   ___ Undergraduate degree
   ___ Graduate degree
   Other: ______________________

   If you are still in college, how many semesters have you been at your university? ____

   What is/was your major? _____________________________________

5. Occupation: ________________________________

6. Hobbies:
   ___ Jigsaw Puzzles
   ___ Lego blocks
   ___ Building toys
   Other similar hobbies: __________________

7. Experience using computers:

Never use	Occasional	Everyday	Expert User

1 ------------ 2 ------------ 3 ------------4 ------------5 ------------6 ------------ 7

8. Do you have any experience with video games? (check all that apply)

   ___ I do not own a video game machine
   ___ I own a video game machine

   ___ I have never played video games
   ___ I have played video games a few times
   ___ I play video games occasionally
   ___ I play video games weekly
   ___ I play video games daily

   Estimated hours playing video games per week: ___

9. What are your favorite kinds of games? (check all that apply)
   - ___ Action Adventure
   - ___ Role-Playing
   - ___ First Person Shooters
   - ___ Strategy Games Including Real-Time Strategy
   - ___ Adventure
   - ___ Sports
   - ___ Puzzle
   - ___ Sim series games (e.g. Simcity, Sims roller-coaster)
   - ___ Massively Multiplayer
   - ___ Casual games (web based)
   - ___ Other __________________________

10. Do you have any experience in Augmented or Virtual Environments?

    ___ yes ___ no

    Please explain:

11. Do you have any experience using a Head Mounted Display? (check all that apply)
    - ___ None
    - ___ One time
    - ___ Two times
    - ___ More than two times
    - ___ Some in courses
    - ___ Some in research
    - ___ Some commercial
    - ___Other (Please explain)

12. On a scale from 1 to 5, how well do you understand the concept of registration error in Augmented Reality?

    1 ------------------- 2 -------------------- 3 -------------------- 4 -------------------- 5

    Not at all Very well

13. Do you wear glasses or contact lenses? ___ yes ___ no

14. Is your vision corrected right now?

    ___ no ___ yes, glasses ___ yes, contact lenses

15. Are you aware of any other vision problems you might have? ___yes ___ no

    If yes, what? _____________________

16. After having read the training document, please rate each of the conditions you read about with respect to how easy you think they will be in relation to each other? Using the numbers 1-4 (one being the easiest and 4 being the most difficult), label the conditions below in order for their ease of use.

    _____ Fully registered (graphics on real board)
    _____ Graphics located off to the side of the base plate
    _____ Graphics attached to the head – always visible in your field of view
    _____ Graphics attached to the head – look to the side to see it

Post Block Questionnaire

1. On a scale from 1 to 5, how successful do you think you were at completing the task?

   1 -------------------- 2 --------------------- 3 --------------------- 4 --------------------- 5
   Not successful Successful

   Please explain:

2. On a scale from 1 to 5, rate the difficulty level of completing the task given the way in which the information was displayed on the Head Mounted Display?

   1 -------------------- 2 --------------------- 3 --------------------- 4 --------------------- 5
   Easy Hard

   Please explain:

3. On a scale from 1 to 5, did you feel that there was enough information displayed on the Head Mounted Display, too much information, or not enough information?

   1 -------------------- 2 --------------------- 3 --------------------- 4 --------------------- 5
   Not enough Just right Too much

   Please explain:

4. What particular strategy or strategies did you have for completing the task in this set?

5. How did the way in which the information was provided to you play a role in formulating your strategies? Please explain.

Please consider only the block that you have just completed while answering these questions.

MENTAL DEMAND
How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Low **High**

PHYSICAL DEMAND
How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low **High**

TEMPORAL DEMAND
How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was that pace slow and leisurely or rapid and frantic?

Low **High**

PERFORMANCE
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Good **Poor**

EFFORT
How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low **High**

FRUSTRATION LEVEL
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Low **High**

Post Study Questionnaire

Thank you for your participation in this study. We are trying to improve our system. Your feedback is greatly appreciated.

1. Did you find any of the placement tasks too easy? Please explain.

2. Did you find any of the placement tasks too difficult? Please explain.

3. Did you use different strategies in the different conditions? If yes, please explain?

4. How would you rate the ease of use for each of the conditions you experienced in relation to each other? Using the numbers 1-4 (one being the easiest and 4 being the most difficult), label the conditions below in order for their ease of use.

    _____ Fully registered (graphics on real board)

    _____ Graphics located off to the side of the base plate

    _____ Graphics attached to the head – always visible in your field of view

    _____ Graphics attached to the head – look to the side to see it

5. Why did you rate the above conditions as you did?

6. Did you find the movement of the base plate with respect to your body in the cases where the graphics were attached to your head useful or distracting? Please explain your answer.

7. What other ways of displaying information might be helpful in this type of system?

8. Did you find the system comfortable or bothersome to use? Please explain.

9. Would you find Augmented Reality instructions useful in a real-world setting? Please explain.

10. Any other comments?

APPENDIX D

USER STUDY 2 DATA ANALYSIS

AR-Registered Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Block No.	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	2	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	2	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	2	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	0	0	0	0	0	0	0	1	0	2	0	0	0

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

AR-Off-to-Side Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	2	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	2	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	0	1	0	0	0	0	0	0	0	0	0	1	0	0

Block No.	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
2	2	2	1	1	1	1	2	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	2	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	2	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	1	2	0	1	0	0	1	0	0	0	0	0	0	1

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

HUD-Visible Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	2	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	2	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	2	1	1	1	1	1
15	1	1	1	2	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**0**

Block No.	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	2	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	2	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

HUD-Side Error Data

Block No.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	2
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	2	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	2	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	2	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**

Block No.	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	2	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	2	1	1	1	1	3	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	2	2	2	1	1	1	1	1	1	1	2	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	2	1	1	1	1	1	1	1	1	1	1	1	1	1
No. of Errors per Subject	**2**	**0**	**1**	**2**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**1**	**0**

*Numbers in the fields indicate number of attempts to place the block, so the number of errors equals the number in the box-1.

AR-Registered Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5.285	6.491	5.173	9.316	4.792	4.747	**7.666**
2	3.998	5.116	3.311	4.696	5.068	4.553	**5.747**
3	4.391	4.819	3.655	7.664	4.273	3.324	**6.471**
4	4.307	6.172	3.174	9.795	3.936	6.524	**8.472**
5	4.223	5.195	5.976	9.549	4.373	3.565	**6.208**
6	3.354	4.266	3.601	5.356	4.913	3.697	**6.3**
7	3.118	4.125	2.704	5.642	4.789	3.401	**3.88**
8	3.341	4.733	3.66	6.353	4.297	3.679	**5.015**
9	3.787	4.962	4.039	6.504	4.651	5.002	**4.966**
10	2.861	5.011	4.219	5.695	3.901	3.326	**5.414**
11	3.717	4.163	3.067	4.483	3.788	2.989	**5.141**
12	4.18	4.453	3.796	24.273	4.526	3.184	**7.034**
13	3.308	5.172	3.567	3.828	4.48	3.694	**4.718**
14	3.373	4.357	3.855	6.536	3.722	3.784	**6.162**
15	3.135	4.034	4.062	5.783	4.003	2.556	**4.508**
16	3.454	5.707	3.421	8.487	4.357	5.029	**4.062**
17	3.446	3.93	3.695	6.083	5.483	3.311	**5.13**
18	2.944	4.675	3.737	9.231	4.919	2.579	**7.446**
Average Time per Subject	**3.679**	**4.8545**	**3.8173**	**7.7374**	**4.4595**	**3.8302**	**5.7967**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	12.342	4.73	14.356	6.377	5.409	3.847	**4.789**
2	8.104	3.384	4.681	4.276	3.646	4.753	**4.897**
3	3.997	4.133	5.067	3.649	3.715	4.555	**5.318**
4	8.838	4.341	6.294	6.443	3.958	5.251	**10.062**
5	6.925	4.108	6.237	4.428	4.289	4.026	**4.992**
6	4.609	3.473	4.308	5.479	3.27	3.543	**5.336**
7	3.748	3.973	4.804	4.347	2.467	4.326	**4.509**
8	12.362	3.078	7.213	6.757	2.8	5.041	**4.345**
9	4.279	4.928	3.933	5.567	3.39	4.892	**4.5**
10	4.781	3.917	4.672	4.382	2.547	4.367	**3.97**
11	4.414	4.047	4.794	6.115	2.458	3.693	**3.875**
12	4.349	3.787	9.675	4.527	2.587	4.822	**4.479**
13	6.316	4.558	4.391	4.932	2.835	3.934	**7.935**
14	4.707	4.135	7.377	5.415	3.621	4.248	**4.607**
15	4.777	2.821	4.404	4.014	2.809	3.504	**3.988**
16	6.589	3.707	5.311	7.342	2.472	3.284	**3.423**
17	4.446	3.161	5.208	4.937	3.269	3.952	**4.161**
18	4.694	2.833	5.851	6.108	2.588	3.169	**3.985**
Average Time per Subject	**6.1265**	**3.8397**	**6.032**	**5.2831**	**3.2294**	**4.1782**	**4.9539**

AR-Registered Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	4.735	4.006	4.713	3.839	6.02	10.844	**3.855**
2	3.999	3.226	3.816	3.691	4.853	4.902	**3.524**
3	3.886	3.535	3.194	3.989	5.165	4.563	**3.155**
4	4.58	5.488	6.957	3.784	4.624	5.65	**7.273**
5	3.896	5.82	4.659	3.783	6.232	6.16	**5.56**
6	4.202	5.158	3.578	3.983	6.183	7.038	**4.719**
7	3.656	4.048	3.681	3.152	4.654	4.203	**3.277**
8	3.236	5.067	3.092	4.38	5.207	3.9	**4.14**
9	4.021	6.529	4.495	4.263	6.057	5.368	**4.4**
10	3.805	5.729	3.239	5.702	3.521	4.306	**2.619**
11	4.972	3.049	3.546	3.839	3.681	4.447	**3.972**
12	3.223	5.683	3.603	3.304	5.166	4.511	**4.16**
13	2.679	3.648	3.792	3.484	5.271	5.78	**3.113**
14	3.476	5.277	4.076	3.775	6.716	7.596	**3.78**
15	2.553	4.168	2.655	3.445	4.683	3.223	**4.419**
16	3.922	4.29	3.027	3.311	4.446	6.865	**3.016**
17	2.947	3.202	2.899	5.318	4.757	5.129	**3.872**
18	2.571	5.608	2.611	3.15	4.203	3.958	**2.439**
Average Time per Subject	**3.6866**	**4.6406**	**3.7574**	**3.8996**	**5.0799**	**5.4691**	**3.9607**

Block No.	S22	S23	S24	S25	S26	S27	S28
1	3.93	19.581	7.207	8.944	7.285	4.951	**7.752**
2	4.487	4.365	4.279	9.847	5.259	3.198	**5.766**
3	3.762	3.398	7.512	5.414	4.71	4.036	**4.45**
4	5.098	7.038	4.117	8.656	6.257	3.746	**7.513**
5	5.467	4.931	5.072	10.185	3.753	3.731	**6.207**
6	2.932	4.161	4.786	4.226	5.337	3.276	**4.818**
7	3.473	2.882	4.45	3.952	4.394	2.911	**3.926**
8	3.307	4.421	5.954	20.229	4.288	5.406	**3.771**
9	7.525	4.392	5.071	4.714	3.94	3.803	**6.127**
10	2.898	3.266	6.318	3.391	4.417	2.676	**4.41**
11	3.086	3.397	3.403	3.491	3.788	2.52	**3.47**
12	3.665	5.214	4.344	4.459	5.823	3.84	**4.15**
13	4.607	4.002	3.933	3.316	5.262	3.892	**3.577**
14	5.8	3.837	4.273	6.238	4.211	3.463	**4.585**
15	3.547	3.099	4.582	3.075	6.028	3.145	**4.267**
16	3.009	2.687	3.685	3.468	4.404	3.047	**3.412**
17	2.744	3.287	3.453	3.47	5.744	2.985	**4.889**
18	3.275	2.475	4.626	3.877	5.46	2.403	**4.116**
Average Time per Subject	**4.034**	**4.8018**	**4.8369**	**6.164**	**5.02**	**3.5016**	**4.8448**

AR-Off-to-Side Placement Time Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	3.793	7.505	4.441	18.633	4.877	5.492	**17.319**
2	6.469	14.887	11.428	15.187	8.6	6.1	**10.408**
3	3.534	4.712	3.742	6.879	5.454	3.439	**5.943**
4	5.714	4.785	3.893	6.763	4.356	3.191	**7.452**
5	6.115	7.048	3.917	6.149	7.295	3.895	**5.654**
6	5.39	10.032	5.18	7.57	9.147	4.187	**9.683**
7	6.173	9.255	6.624	9.602	12.977	4.681	**12.026**
8	5.181	4.973	3.893	9.157	5.825	4.053	**9.244**
9	5.75	7.474	6.282	7.551	6.577	4.665	**9.328**
10	3.322	6.015	4.937	10.439	4.329	4.152	**7.789**
11	3.137	6.218	6.124	10.955	8.204	4.797	**13.671**
12	4.756	7.717	4.799	7.162	5.31	4.918	**7.039**
13	6.757	9.793	10.467	17.534	10.543	6.104	**9.116**
14	3.446	6.409	5.387	10.365	4.921	3.724	**6.06**
15	3.565	4.926	4.255	5.687	5.242	3.672	**6.623**
16	4.682	9.782	4.051	10.68	5.868	4.154	**6.685**
17	4.025	4.869	3.766	5.145	5.515	3.863	**6.805**
18	3.394	4.502	5.424	6.976	5.234	3.206	**8.562**
Average Time per Subject	**4.7335**	**7.272333**	**5.4783**	**9.5797**	**6.6819**	**4.3496**	**8.8559**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	12.09	4.602	4.83	6	7.201	5.271	**4.894**
2	10.906	7.326	8.556	6.982	10.499	6.459	**6.878**
3	7.103	4.402	5.11	3.186	5.773	4.119	**6.762**
4	6.562	4.114	4.155	4.468	5.089	5.953	**5.063**
5	7.97	5.345	4.845	4.888	5.514	4.34	**4.45**
6	13.432	5.114	6.128	4.143	11.52	5.366	**10.468**
7	7.077	5.147	6.988	5.499	8.201	9.663	**7.303**
8	8.784	4.802	6.215	4.628	5.96	5.129	**8.007**
9	6.555	4.056	5.106	5.726	5.522	6.864	**7.894**
10	4.999	4.245	3.932	4.746	6.138	3.972	**4.835**
11	13.609	5.953	7.942	10.32	9.931	5.594	**8.64**
12	6.548	4.904	6.305	5.379	5.137	4.534	**5.279**
13	9.957	8.05	8.861	6.904	6.864	9.093	**8.643**
14	5.936	4.519	5.372	6.618	6.071	4.819	**5.078**
15	5.479	3.843	4.884	6.512	6.898	3.533	**4.382**
16	5.987	3.983	6.109	9.945	5.4	5.098	**8.394**
17	7.241	4.654	4.019	3.703	5.858	3.685	**4.307**
18	5.879	3.44	3.777	5.176	5.024	4.478	**6.189**
Average Time per Subject	**8.1174**	**4.9166**	**5.7297**	**5.8235**	**6.8111**	**5.4428**	**6.5259**

AR-Off-to-Side Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	5.844	5.297	3.846	7.742	6.189	6.79	**5.52**
2	14.682	13.566	6.795	11.17	9.655	9.153	**26.11**
3	5.526	4.512	5.377	4.982	5.516	6.269	**4.433**
4	4.061	5.358	3.755	7.088	5.685	5.034	**4.597**
5	6.22	8.002	3.714	6.617	13.639	7.927	**4.544**
6	4.549	13.938	4.815	6.479	8.807	7.207	**6.35**
7	6.258	8.164	5.917	11.924	11.065	9.478	**7.193**
8	5.063	7.078	5.4	7.416	5.767	6.777	**5.909**
9	4.795	5.565	5.803	9.644	10.195	6.927	**6.773**
10	4.48	6.192	4.157	6.425	5.191	5.6	**4.088**
11	3.89	5.85	5.329	5.837	10.131	5.343	**13.601**
12	4.169	5.991	4.639	6.315	10.668	5.27	**3.877**
13	5.042	6.846	8.783	7.13	15.48	7.198	**8.798**
14	4.19	5.628	5.513	6.396	8.626	7.276	**4.245**
15	5.749	7.341	4.459	6.712	4.978	6.549	**4.118**
16	4.688	5.734	12.812	11.746	8.203	6.069	**6.105**
17	4.209	4.522	5.116	6.295	5.306	5.286	**3.635**
18	4.565	7.539	3.511	7.103	6.531	6.263	**3.408**
Average Time per Subject	**5.4433**	**7.0624**	**5.5412**	**7.6123**	**8.424**	**6.6898**	**6.8502**

Block No.	S22	S23	S24	S25	S26	S27	S28
1	4.03	6.021	9.1	4.806	4.263	6.617	**15.636**
2	4.964	7.567	8.893	7.771	4.659	8.335	**9.151**
3	2.981	3.542	5.16	3.89	3.965	3.951	**8.399**
4	3.569	4.279	5.52	4.992	3.499	4.642	**10.711**
5	3.739	4.236	6.339	3.925	4.326	3.803	**6.719**
6	4.37	4.654	6.586	6.123	4.454	4.299	**7.481**
7	4.51	3.918	7.761	12.16	5.239	7.093	**8.944**
8	3.749	4.236	8.214	4.502	4.026	6.089	**7.643**
9	5.129	5.732	8.637	6.518	3.961	5.553	**8.953**
10	3.372	3.18	3.91	4.364	2.559	3.492	**6.414**
11	4.505	7.334	16.999	5.019	4.65	8.255	**8.991**
12	3.868	3.462	5.321	8.41	3.48	4.989	**5.783**
13	5.431	4.989	6.888	6.488	6.03	8.503	**11.963**
14	4.356	3.678	6.026	4.444	3.112	3.61	**5.044**
15	3.852	3.636	5.729	3.462	3.444	4.231	**7.06**
16	4.446	7.454	6.166	6.589	5.878	5.824	**8.005**
17	4.76	3.063	4.372	3.708	2.67	3.799	**6.634**
18	4.396	3.096	4.778	4.824	3.257	6.362	**6.104**
Average Time per Subject	**4.2237**	**4.6709**	**7.0222**	**5.6664**	**4.0818**	**5.5248**	**8.3131**

HUD-Visible Placement Time Data

Block No.	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
1	4.128	10.408	4.159	22.77	8.416	7.476	**35.784**
2	4.329	4.821	3.346	5.223	3.922	3.174	**5.964**
3	5.538	4.744	5.489	8.251	5.038	3.824	**10.831**
4	5.059	8.588	6.822	14.005	8.774	5.844	**11.267**
5	4.192	4.216	2.79	5.447	5.426	4.805	**3.833**
6	5.021	4.098	3.709	5.369	4.565	6.735	**6.48**
7	3.86	4.676	3.736	4.138	4.234	3.506	**7.056**
8	5.8	7.559	7.626	7.51	5.4	7.483	**8.105**
9	4.164	6.473	4.979	6.526	4.648	5.048	**12.513**
10	5.17	7.765	5.487	5.88	4.816	5.194	**8.013**
11	3.499	4.144	4.387	5.405	3.828	2.819	**7.603**
12	4.835	5.254	4.826	12.939	5.866	4.028	**10.872**
13	4.107	4.431	3.983	8.04	4.441	4.878	**6.689**
14	5.231	6.629	5.186	7.013	6.585	4.487	**10.511**
15	4.871	8.998	5.645	17.047	7.004	5.928	**10.315**
16	4.26	5.402	5.396	10.383	7.425	4.504	**11.229**
17	5.83	12.649	8.773	12.013	9.43	8.58	**12.155**
18	3.09	3.492	3.755	3.032	3.677	2.393	**3.996**
Average Time per Subject	**4.610222**	**6.352611**	**5.0052**	**8.9439**	**5.7497**	**5.0392**	**10.179**

Block No.	*S8*	*S9*	*S10*	*S11*	*S12*	*S13*	*S14*
1	9.048	4.453	7.45	16.942	13.573	5.174	**7.558**
2	6.627	3.132	5.825	5.605	4.422	3.683	**3.847**
3	5.152	4.738	11.678	6.704	5.984	5.896	**5.763**
4	15.447	6.288	9.72	7.607	6.714	7.901	**6.606**
5	4.283	3.266	3.52	4.688	4.024	3.474	**4.482**
6	6.543	3.43	3.945	5.331	4.199	4.398	**5.36**
7	4.413	2.92	3.461	9.499	4.107	4.199	**4.415**
8	10.55	5.187	7.815	6.648	6.279	6.803	**5.912**
9	12.597	6.811	9.328	6.309	5.459	4.568	**4.866**
10	6.925	3.635	4.173	6.322	5.788	4.669	**3.962**
11	4.845	2.982	3.686	5.708	3.347	4.759	**4.202**
12	9.948	3.79	6.445	6.153	6.81	6.172	**4.728**
13	5.774	3.375	3.59	5.252	3.709	3.566	**3.595**
14	14.239	13.31	7.974	9.02	5.051	5.144	**5.941**
15	10.419	7.573	14.266	7.616	6.779	5.847	**9.146**
16	11.933	4.793	6.99	11.987	4.294	6.037	**3.572**
17	16.895	7.36	11.053	8.274	7.07	10.71	**6.152**
18	4.87	3.735	4.103	3.551	2.864	3.208	**3.405**
Average Time per Subject	**8.9171**	**5.0432**	**6.9457**	**7.4009**	**5.5818**	**5.3449**	**5.1951**

HUD-Visible Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	6.074	6.769	3.723	6.553	6.913	5.239	**6.52**
2	4.244	4.109	3.176	4.352	4.257	6.904	**3.325**
3	4.92	6.941	3.899	3.58	7.973	5.845	**4.541**
4	6.929	6.634	6.597	6.401	10.249	8.446	**4.485**
5	4.743	5.007	4.582	4.282	5.345	5.678	**3.231**
6	4.108	4.444	3.237	3.729	8.617	5.72	**3.134**
7	4.47	4.178	3.544	3.733	6.266	4.547	**2.952**
8	6.936	8.324	6.383	5.605	6.087	7.471	**4.154**
9	4.809	4.889	4.376	7.092	5.667	8.281	**5.68**
10	4.17	4.337	8.061	4.678	12.219	7.957	**3.738**
11	3.778	4.401	3.453	3.274	4.885	5.787	**3.01**
12	4.138	6.21	9.647	4.155	9.126	6.299	**4.222**
13	4.455	3.603	3.278	4.176	5.319	7.126	**3.573**
14	11.156	5.494	7.065	6.144	6.796	8.799	**4.141**
15	6.775	8.096	6.306	5.522	7.776	6.367	**4.65**
16	6.637	5.338	4.332	5.956	3.954	5.385	**4.317**
17	8.104	8.671	11.125	6.269	12.07	8.106	**5.516**
18	3.868	3.084	3.342	3.769	5.596	4.351	**3.331**
Average Time per Subject	**5.573**	**5.5849**	**5.3403**	**4.9594**	**7.1731**	**6.5727**	**4.14**

Block No.	S22	S23	S24	S25	S26	S27	S28
1	6.321	6.116	7.268	4.184	7.869	4.99	**7.977**
2	2.772	3.659	4.069	4.526	3.51	4.297	**5.05**
3	3.204	4.173	6.305	3.336	4.06	7.251	**6.12**
4	4.133	8.71	11.259	6.199	5.294	6.854	**8.445**
5	2.518	2.884	4.82	3.483	3.502	3.622	**4.119**
6	2.804	3.376	6.614	3.462	4.051	4.118	**5.281**
7	2.533	7.135	5.46	3.404	4.029	4.565	**4.244**
8	8.532	6.888	5.225	4.678	5.429	5.729	**5.94**
9	3.364	5.445	5.97	10.658	4.954	5.211	**6.761**
10	3.751	4.702	5.576	7.082	4.13	6.264	**4.858**
11	2.338	5.15	3.983	3.573	3.425	3.162	**4.677**
12	5.451	4.942	6.135	6.378	4.361	4.185	**6.422**
13	2.881	4.773	4.07	3.054	3.291	3.749	**5.118**
14	5.608	5.493	5.573	6.005	6.018	4.528	**5.017**
15	3.503	6.649	7.965	8.663	5.884	10.054	**9.926**
16	3.471	4.888	6.72	8.032	4.255	5.454	**4.152**
17	4.751	7.957	9.322	4.61	5.941	8.658	**5.581**
18	2.427	3.252	3.374	3.013	2.945	3.038	**3.182**
Average Time per Subject	**3.909**	**5.344**	**6.0949**	**5.2411**	**4.6082**	**5.3183**	**5.715**

HUD-Side Placement Time Data

Block No.	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
1	6.534	7.013	4.35	7.23	5.656	4.944	**9.815**
2	5.128	6.328	3.166	9.126	5.92	4.677	**5.391**
3	8.9	7.729	5.678	10.596	14.841	5.457	**8.235**
4	6.84	5.468	4.814	12.312	10.239	7.491	**9.681**
5	5.18	5.245	3.534	10.251	5.7	3.283	**7.359**
6	8.815	8.323	14.827	47.721	10.346	5.499	**11.884**
7	5.837	5.644	4.764	10.494	10.299	4.62	**6.399**
8	6.989	16.002	8.828	12.439	8.956	4.888	**7.694**
9	5.868	5.609	3.992	4.832	6.148	8.059	**5.069**
10	5.624	7.611	8.405	11.301	15.112	5.008	**13.875**
11	4.576	5.254	4.148	5.32	7.075	3.503	**7.047**
12	4.338	5.427	3.381	5.144	5.24	3.505	**5.93**
13	5.893	7.69	7.35	10.057	14.235	12.714	**11.611**
14	5.907	5.086	3.793	4.659	5.847	4.646	**5.841**
15	4.919	5.331	4.101	13.236	9.138	3.368	**7.746**
16	4.814	4.533	3.388	5.067	4.728	3.623	**4.564**
17	6.568	8.359	9.152	25.145	6.95	10.176	**8.361**
18	7.219	8.021	7.098	13.142	12.6	5.708	**10.853**
Average Time per Subject	**6.108278**	**6.926278**	**5.8205**	**12.115**	**8.835**	**5.6205**	**8.1864**

Block No.	*S8*	*S9*	*S10*	*S11*	*S12*	*S13*	*S14*
1	5.879	6.436	3.528	3.868	6.406	7.801	**6.541**
2	6.483	5.556	2.986	8.209	5.314	5.59	**6.601**
3	15.085	6.717	5.628	9.595	16.052	5.794	**16.541**
4	21.139	6.59	9.617	6.584	6.312	5.217	**8.206**
5	5.999	6.376	6.865	4.048	4.172	4.795	**5.592**
6	11.277	6.396	8.099	7.448	7.188	6.09	**38.516**
7	7.49	5.761	8.271	8.82	5.562	8.008	**6.916**
8	13.392	12.415	8.808	6.94	6.947	6.658	**12.758**
9	7.734	5.702	5.061	4.331	4.088	4.73	**5.786**
10	13.199	6.901	11.035	4.909	6.505	10.574	**6.559**
11	6.665	6.38	6.418	3.26	4.67	4.276	**5.829**
12	5.335	5.011	6.636	3.494	3.795	4.451	**6.947**
13	14.477	6.075	9.377	4.904	6.283	5.803	**8.438**
14	6.246	5.312	4.464	4.346	5.237	4.934	**5.75**
15	9.136	5.617	7.001	6.835	5.221	5.96	**5.559**
16	4.875	4.373	6.265	2.974	3.82	3.935	**5.119**
17	9.752	6.458	8.6	6.786	6.75	6.965	**7.086**
18	10.305	6.124	9.925	5.507	9.565	13.004	**7.175**
Average Time per Subject	**9.6927**	**6.3444**	**7.1436**	**5.7143**	**6.3271**	**6.3658**	**9.2177**

HUD-Side Placement Time Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	4.604	8.941	8.658	5.623	8.966	10.912	**10.082**
2	4.152	4.626	12.566	5.243	7.815	7.213	**5.414**
3	9.012	8.191	13.762	8.078	7.369	11.681	**8.139**
4	5.222	5.713	8.676	5.778	6.725	9.246	**7.125**
5	3.73	3.585	7.182	5.934	5.096	4.447	**4.154**
6	7.836	6.407	10.907	17.706	8.872	6.9	**16.838**
7	4.326	5.433	8.064	6.11	5.914	6.13	**5.73**
8	6.078	8.537	19.104	18.37	14.529	6.627	**7.579**
9	4.966	4.174	5.383	5.519	5.742	4.344	**5.09**
10	5.141	5.396	12.83	10.209	8.751	8.32	**8.739**
11	4.198	4.645	5.303	6.718	5.115	5.891	**5.64**
12	4.761	4.473	4.901	6.134	5.208	3.801	**4.868**
13	5.159	5.93	10.266	12.811	7.023	5.808	**9.778**
14	3.404	4.207	8.006	5.93	5.603	5.165	**6.461**
15	4.128	4.552	7.141	6.923	10.752	4.881	**7.435**
16	5.117	3.068	4.786	4.743	4.643	4.342	**3.98**
17	5.257	8.071	5.419	9.993	13.568	8.568	**7.183**
18	12.636	12.319	7.561	8.201	10.271	6.651	**9.141**
Average Time per Subject	**5.5404**	**6.0149**	**8.9175**	**8.3346**	**7.8868**	**6.7182**	**7.4098**

Block No.	S22	S23	S24	S25	S26	S27	S28
1	7.595	5.357	5.487	8.859	6.904	7.362	**5.773**
2	4.187	4.232	4.63	4.937	5.208	3.848	**5.8**
3	4.431	5.829	5.6	6.84	6.143	5.111	**6.513**
4	5.744	8.537	5.825	5.466	9.06	5.325	**5.356**
5	3.958	2.982	4.563	4.594	4.408	3.755	**4.637**
6	7.286	17.427	8.494	8.41	9.816	4.096	**13.2**
7	4.067	10.897	5.615	5.382	10.589	5.171	**5.107**
8	8.779	8.327	7.65	5.654	7.386	13.544	**6.616**
9	3.244	3.278	4.396	3.965	2.827	5.625	**6.008**
10	4.54	4.927	11.912	8.641	6.841	10.499	**6.723**
11	3.863	2.888	5.536	4.407	3.183	5.16	**6.325**
12	3.64	2.803	5.355	3.658	4.024	3.255	**5.348**
13	8.638	6.777	6.181	5.95	7.217	10.738	**7.135**
14	4.621	2.973	5.618	4.317	7.859	3.64	**6.683**
15	4.355	3.38	8.116	5.797	8.748	6.337	**5.614**
16	3.629	2.485	4.305	3.313	2.678	4.134	**4.433**
17	5.766	7.744	10.114	7.297	6.108	14.883	**6.193**
18	4.8	6.427	6.927	6.079	6.094	9.538	**8.558**
Average Time per Subject	**5.1746**	**5.9594**	**6.4624**	**5.7537**	**6.3941**	**6.7789**	**6.4457**

AR-Registered Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	5	5	5	5	5	4
2	5	5	5	5	5	5	4
3	5	5	5	5	5	5	4
4	4	5	5	5	5	5	4
5	5	5	5	4	5	5	4
6	5	5	5	5	5	5	4
7	5	5	5	5	5	5	4
8	5	5	5	5	5	5	4
9	5	5	5	5	5	5	4
10	5	5	5	5	5	5	4
11	5	5	5	5	5	5	4
12	5	5	5	5	5	4	4
13	5	5	5	5	5	5	4
14	5	5	5	5	5	5	4
15	5	5	5	5	5	5	4
16	5	5	5	5	5	5	4
17	5	5	5	5	5	5	4
18	5	5	5	5	5	5	4
Average Confidence per Subject	4.9444	5	5	4.9444	5	4.9444	4
Median Confidence per Subject	5	5	5	5	5	5	4

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5	5	5	5	4	5	5
2	5	5	5	5	5	5	5
3	5	5	5	5	5	5	5
4	5	4	5	5	4	4	5
5	5	5	5	5	4	5	5
6	5	5	5	5	4	5	5
7	5	5	5	5	4	4	5
8	5	5	5	5	4	4	5
9	5	5	5	5	4	4	5
10	5	5	5	5	4	5	5
11	5	5	5	5	4	5	5
12	5	5	5	5	4	4	5
13	5	4	5	5	4	5	5
14	5	5	5	5	4	5	5
15	5	5	5	5	4	5	5
16	5	5	5	5	4	5	5
17	5	5	5	5	5	5	5
18	5	5	5	5	5	5	5
Average Confidence per Subject	5	4.8889	5	5	4.2222	4.7222	5
Median Confidence per Subject	5	5	5	5	4	5	5

AR-Registered Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	5	4	5	5	5	5	5
2	5	5	5	5	5	5	5
3	5	5	5	5	4	5	5
4	4	5	5	5	5	5	5
5	5	5	5	5	5	5	5
6	5	5	5	5	4	5	5
7	5	5	5	5	5	5	5
8	5	5	5	5	4	5	5
9	5	5	5	5	5	5	5
10	5	5	5	5	5	5	5
11	5	5	5	5	5	5	5
12	5	5	5	5	4	5	5
13	5	5	5	5	4	5	5
14	5	5	5	5	4	5	5
15	5	5	5	5	5	5	5
16	5	5	5	5	5	5	5
17	5	5	5	5	5	5	5
18	5	5	5	5	5	5	5
Average Confidence per Subject	4.9444	4.9444	5	5	4.6667	5	5
Median Confidence per Subject	5	5	5	5	5	5	5

Block No.	S22	S23	S24	S25	S26	S27	S28
1	5	5	4	2	5	5	5
2	5	5	4	3	5	5	5
3	5	5	5	5	5	5	5
4	4	5	4	4	5	5	5
5	5	5	4	4	5	5	5
6	5	5	5	5	5	5	5
7	5	5	5	5	5	5	5
8	4	5	4	4.5	5	5	5
9	4	5	4	5	5	5	5
10	5	5	4	5	5	5	5
11	4	5	5	5	5	5	5
12	4	5	4	5	5	5	5
13	5	5	4	5	5	5	5
14	4	5	4	5	5	5	5
15	5	5	4	5	5	5	5
16	5	5	4	5	5	5	5
17	5	5	5	5	5	5	5
18	4	5	4	5	5	5	5
Average Confidence per Subject	4.6111	5	4.2778	4.5833	5	5	5
Median Confidence per Subject	5	5	4	5	5	5	5

AR-Off-to-Side Confidence Data

Block No.	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
1	5	5	5	5	5	5	**4**
2	5	5	5	5	4	4	**4**
3	5	5	5	5	5	5	**5**
4	5	5	5	5	5	5	**5**
5	5	5	5	5	5	5	**5**
6	5	5	5	5	4	4	**5**
7	5	5	5	5	4	4	**4**
8	5	5	5	5	5	5	**5**
9	5	5	5	5	5	5	**4**
10	5	5	5	5	5	5	**4**
11	5	5	5	5	5	4	**4**
12	5	5	5	5	5	5	**4**
13	5	4	5	5	4	4	**4**
14	5	5	5	5	5	5	**5**
15	5	5	5	5	5	5	**5**
16	5	3	5	5	5	5	**5**
17	5	5	5	5	5	5	**5**
18	5	5	5	5	5	5	**4**
Average Confidence per Subject	5	4.8333	5	5	4.7778	4.7222	**4.5**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**5**	**5**	**4.5**

Block No.	*S8*	*S9*	*S10*	*S11*	*S12*	*S13*	*S14*
1	5	5	5	4	4	5	**5**
2	5	3	5	5	3	5	**5**
3	5	5	5	5	4	5	**5**
4	5	5	5	5	4	5	**5**
5	5	4	5	5	4	5	**5**
6	5	4	5	5	4.5	5	**4**
7	5	4	5	5	4	5	**5**
8	5	5	5	5	4	5	**5**
9	5	5	5	5	4	5	**5**
10	5	5	5	5	4	5	**5**
11	5	3	5	4	4	5	**5**
12	5	4	5	5	4	5	**5**
13	5	3	5	5	4	5	**5**
14	5	4	5	5	4	5	**5**
15	5	5	5	5	4	5	**5**
16	5	5	4	5	4	5	**5**
17	5	5	5	5	4	5	**5**
18	5	5	5	5	4	5	**5**
Average Confidence per Subject	5	4.3889	4.9444	4.8889	3.9722	5	**4.9444**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**4**	**5**	**5**

AR-Off-to-Side Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	4	5	5	5	3	4	5
2	4	3.5	5	5	4	4	5
3	5	5	5	5	4	4	5
4	5	5	5	5	5	4	5
5	4	5	5	5	3	5	5
6	5	5	5	5	4	5	5
7	5	4	5	5	3	5	5
8	5	5	5	5	5	5	5
9	5	5	5	5	4	5	5
10	5	5	5	5	5	5	5
11	4	5	5	5	3	5	5
12	5	5	5	5	2	5	5
13	4	4	5	5	3	5	5
14	4	5	5	5	2	5	5
15	5	5	5	5	5	5	5
16	4	4	5	5	4	5	5
17	5	5	5	5	5	5	5
18	5	5	5	5	4	5	5
Average Confidence per Subject	4.6111	4.75	5	5	3.7778	4.7778	5
Median Confidence per Subject	5	5	5	5	4	5	5

Block No.	S22	S23	S24	S25	S26	S27	S28
1	5	5	4	5	5	5	5
2	4	5	4	4	5	5	5
3	5	5	5	5	5	5	5
4	5	5	5	5	5	5	5
5	4	5	4	5	5	5	5
6	5	5	4	4	4	5	5
7	4	5	3	5	5	5	5
8	5	5	4	5	5	5	5
9	4	5	5	5	5	5	5
10	5	5	5	5	5	5	5
11	4	5	4	5	5	5	5
12	5	5	4	5	5	5	5
13	4	5	4	5	5	5	5
14	5	5	4	5	5	5	5
15	5	5	5	5	5	5	5
16	4	5	4	5	5	5	5
17	4	5	5	5	5	5	5
18	4	5	5	5	5	5	5
Average Confidence per Subject	4.5	5	4.3333	4.6667	4.9444	5	5
Median Confidence per Subject	4.5	5	4	5	5	5	5

HUD-Visible Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	4	5	3	5	4	**3**
2	5	5	5	5	5	5	**5**
3	5	5	5	5	5	5	**4**
4	5	5	5	4	4	4	**3**
5	5	5	5	5	5	5	**5**
6	5	5	5	5	5	4	**4**
7	5	5	5	5	5	5	**4**
8	5	4	5	5	5	4	**4**
9	5	5	5	5	5	5	**3**
10	5	5	5	5	5	5	**4**
11	5	5	5	5	5	5	**5**
12	5	5	5	4	5	4	**4**
13	5	5	5	5	5	5	**5**
14	5	4	5	5	5	4	**4**
15	5	4	5	4.5	5	4	**4**
16	5	4	5	5	5	4	**3**
17	5	4	5	5	5	5	**4**
18	5	5	5	5	5	5	**5**
Average Confidence per Subject	5	4.6667	5	4.75	4.9444	4.5556	**4.0556**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**5**	**5**	**4**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5	5	5	5	3	5	**5**
2	5	5	5	5	4	5	**5**
3	5	5	5	5	4	5	**5**
4	5	4	5	5	4	5	**5**
5	5	5	5	5	5	5	**5**
6	5	5	5	5	4	5	**5**
7	5	5	5	5	4	5	**5**
8	5	5	4	5	3	5	**5**
9	5	4	5	5	4	5	**5**
10	5	5	5	5	4	5	**5**
11	5	5	5	5	5	5	**5**
12	5	4	5	5	4	5	**5**
13	5	5	5	5	4	5	**5**
14	5	4	5	5	4	5	**5**
15	5	4	5	5	3	5	**5**
16	5	5	5	5	4	5	**5**
17	5	4	5	5	4	5	**5**
18	5	5	5	5	5	5	**5**
Average Confidence per Subject	5	4.6667	4.9444	5	4	5	**5**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**4**	**5**	**5**

HUD-Visible Confidence Data (cont.)

Block No.	*S15*	*S16*	*S17*	*S18*	*S19*	*S20*	*S21*
1	5	4	5	5	3	5	**5**
2	5	5	5	5	5	5	**5**
3	5	5	5	5	3	5	**5**
4	5	4	5	5	2	5	**5**
5	5	5	5	5	3	5	**5**
6	5	5	5	5	2	5	**5**
7	5	5	5	5	1	5	**5**
8	5	4	5	5	4	5	**5**
9	5	4	5	5	3	5	**5**
10	5	5	5	5	3	5	**5**
11	5	5	5	5	4	5	**5**
12	5	4	5	5	2	5	**5**
13	5	5	5	5	5	5	**5**
14	5	4	5	5	4	5	**5**
15	5	4	5	5	3	5	**5**
16	4	4	5	5	4	5	**5**
17	5	4	5	5	3	5	**5**
18	5	5	5	5	3	5	**5**
Average Confidence per Subject	4.9444	4.5	5	5	3.1667	5	**5**
Median Confidence per Subject	**5**	**4.5**	**5**	**5**	**3**	**5**	**5**

Block No.	*S22*	*S23*	*S24*	*S25*	*S26*	*S27*	*S28*
1	5	5	4	5	5	5	**5**
2	5	5	5	5	5	5	**5**
3	5	5	5	5	5	3	**5**
4	5	5	4	5	5	5	**5**
5	5	5	5	5	5	5	**5**
6	5	5	5	5	5	5	**5**
7	5	5	4	5	5	5	**5**
8	5	5	4	5	5	5	**5**
9	5	5	4	5	5	5	**5**
10	5	5	4	5	5	5	**5**
11	5	5	5	5	5	5	**5**
12	5	5	4	5	5	5	**5**
13	5	5	5	5	5	5	**5**
14	5	5	4	5	5	5	**5**
15	5	5	4	5	5	3	**5**
16	5	5	4	5	5	5	**5**
17	5	5	4	5	5	5	**5**
18	5	5	5	5	5	5	**5**
Average Confidence per Subject	5	5	4.3889	5	5	4.7778	**5**
Median Confidence per Subject	**5**	**5**	**4**	**5**	**5**	**5**	**5**

HUD-Side Confidence Data

Block No.	S1	S2	S3	S4	S5	S6	S7
1	5	5	5	5	5	5	**5**
2	5	5	5	5	5	5	**4**
3	4	5	5	5	5	5	**5**
4	5	5	5	5	4	5	**4**
5	5	5	5	5	5	5	**4**
6	5	4	5	4	4	4	**3**
7	5	5	5	5	4	5	**4**
8	5	4	5	5	4	4	**4**
9	5	5	5	5	5	5	**4**
10	5	2	5	5	4	4	**4**
11	5	5	5	5	5	5	**4**
12	5	5	5	5	5	5	**4**
13	4	4	5	5	5	3	**4**
14	4	5	5	5	5	5	**4**
15	5	5	5	5	5	5	**4**
16	5	5	5	5	5	5	**5**
17	5	5	5	4	5	5	**4**
18	5	5	5	5	4	4	**3**
Average Confidence per Subject	4.8333	4.6667	5	4.8889	4.6667	4.6667	**4.0556**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**5**	**5**	**4**

Block No.	S8	S9	S10	S11	S12	S13	S14
1	5	5	5	5	5	5	**5**
2	5	5	5	5	5	5	**5**
3	5	5	5	5	4	5	**4.5**
4	5	5	5	5	4	5	**5**
5	5	5	5	5	5	5	**5**
6	5	3	5	5	3	5	**4**
7	5	5	5	5	4	5	**4**
8	5	4	5	5	4	5	**5**
9	5	5	5	5	5	5	**5**
10	5	4	5	5	4	5	**5**
11	5	5	5	5	4	5	**5**
12	5	5	5	5	4	5	**5**
13	5	5	5	5	4	5	**5**
14	5	5	5	5	4	5	**5**
15	5	5	5	5	4	5	**5**
16	5	5	5	5	5	5	**5**
17	5	4	4	5	4	5	**5**
18	5	4	5	5	3	5	**5**
Average Confidence per Subject	5	4.6667	4.9444	5	4.1667	5	**4.8611**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**4**	**5**	**5**

HUD-Side Confidence Data (cont.)

Block No.	S15	S16	S17	S18	S19	S20	S21
1	5	5	5	5	4	5	**5**
2	5	5	5	5	4	5	**5**
3	3.5	5	5	5	2	5	**5**
4	4	4	5	5	2	5	**5**
5	5	5	5	5	4	5	**5**
6	4	5	5	5	3	5	**5**
7	5	5	5	5	3	5	**5**
8	4	4	4	5	2.5	5	**5**
9	5	5	5	5	4	5	**5**
10	4	4	5	5	4	4	**5**
11	5	5	5	5	3	5	**5**
12	5	5	5	5	4	5	**5**
13	5	4	5	5	4	5	**5**
14	5	5	5	5	4	5	**5**
15	5	4	5	5	4	5	**5**
16	5	5	5	5	5	5	**5**
17	4	4	5	5	4	5	**5**
18	4	3	5	5	5	5	**5**
Average Confidence per Subject	4.5833	4.5556	4.9444	5	3.6389	4.9444	**5**
Median Confidence per Subject	**5**	**5**	**5**	**5**	**4**	**5**	**5**

Block No.	S22	S23	S24	S25	S26	S27	S28
1	5	5	5	5	5	5	**5**
2	5	5	4	5	5	5	**5**
3	5	5	4	5	5	5	**5**
4	5	5	4	5	5	5	**5**
5	5	5	5	5	5	5	**5**
6	5	5	4	4	5	5	**5**
7	5	5	4	5	5	5	**5**
8	4	5	4	4	5	5	**5**
9	5	5	5	5	5	5	**5**
10	5	5	3	3	5	5	**5**
11	5	5	5	5	5	5	**5**
12	5	5	5	5	5	5	**5**
13	4	5	4	5	5	5	**5**
14	5	5	4	5	5	5	**5**
15	5	5	4	5	5	5	**5**
16	5	5	5	5	5	5	**5**
17	5	5	4	4	5	5	**5**
18	5	5	4	4	4	5	**5**
Average Confidence per Subject	4.8889	5	4.2778	4.6667	4.9444	5	**5**
Median Confidence per Subject	**5**	**5**	**4**	**5**	**5**	**5**	**5**

AR-Registered NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mental Workload	3	3	0	1	0	6	4	1	18	2	5	1	6	**5**
Physical Demand	5	3	0	1	2	2	2	0	6	4	5	12	15	**5**
Temporal Demand	3	4	1	1	0	12	6	0	16	9	3	5	6	**13**
Performance	2	2	0	1	0	1	6	0	5	5	4	2	3	**1**
Effort	5	2	0	1	0	6	5	0	16	6	3	0	11	**5**
Frustration Level	**3**	**2**	**0**	**1**	**0**	**1**	**3**	**1**	**16**	**5**	**1**	**0**	**4**	**15**

	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
Mental Workload	10	6	3	2	5	1	1	12	2	10	7	4	3	**1**
Physical Demand	3	9	3	4	2	7	1	3	2	8	15	4	3	**1**
Temporal Demand	16	4	17	14	4	1	1	7	8	7	7	6	3	**1**
Performance	2	4	1	3	2	1	1	5	8	6	11	1	1	**1**
Effort	16	6	3	6	4	1	15	11	10	9	13	9	3	**1**
Frustration Level	**13**	**6**	**11**	**2**	**3**	**1**	**1**	**2**	**10**	**13**	**14**	**1**	**1**	**1**

AR-Off-to-Side NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mental Workload	7	8	1	3	10	8	6	0	18	9	7	10	17	**5**
Physical Demand	11	13	2	1	2	2	2	0	8	5	5	3	10	**9**
Temporal Demand	3	10	1	3	5	6	8	0	18	12	7	9	8	**7**
Performance	2	8	1	1	3	2	14	0	14	1	4	2	3	**6**
Effort	5	7	1	3	8	7	8	0	16	8	8	7	17	**7**
Frustration Level	**5**	**7**	**0**	**1**	**4**	**2**	**4**	**0**	**16**	**2**	**1**	**0**	**17**	**12**

	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
Mental Workload	18	14	15	4	15	5	6	13	6	5	11	2	13	**14**
Physical Demand	3	18	19	2	6	9	12	4	12	6	5	1	13	**4**
Temporal Demand	16	10	19	3	13	2	1	8	6	7	9	1	7	**4**
Performance	4	14	6	5	7	1	2	9	4	3	5	1	1	**1**
Effort	16	14	19	4	12	1	14	12	8	13	7	5	11	**2**
Frustration Level	**14**	**13**	**11**	**5**	**15**	**4**	**1**	**11**	**14**	**16**	**5**	**1**	**2**	**1**

HUD-Visible NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mental Workload	9	14	3	6	5	8	6	5	20	17	5	11	18	9
Physical Demand	11	7	1	1	2	2	2	0	5	17	11	5	8	4
Temporal Demand	12	11	2	4	2	10	10	1	14	7	5	7	6	5
Performance	5	5	2	4	3	2	6	5	16	5	5	5	3	8
Effort	10	12	1	7	5	8	6	5	16	17	5	11	18	7
Frustration Level	9	9	0	6	2	12	8	12	14	10	1	12	14	11

	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
Mental Workload	14	18	16	4	14	5	1	7	3	10	11	3	7	11
Physical Demand	1	12	9	3	5	7	1	5	4	6	7	1	1	1
Temporal Demand	15	10	7	4	12	2	1	3	6	10	7	2	11	1
Performance	2	8	2	3	3	1	1	17	6	9	10	1	3	1
Effort	14	14	15	3	10	2	12	4	14	7	15	7	7	3
Frustration Level	2	10	13	3	8	4	2	2	18	12	19	1	1	1

HUD-Side NASA TLX Data

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Mental Workload	8	8	1	6	7	8	6	1	16	15	7	7	13	12
Physical Demand	12	3	2	1	2	2	2	4	16	20	3	7	10	11
Temporal Demand	4	5	1	2	6	13	10	0	20	7	9	8	6	10
Performance	3	6	0	3	0	2	14	0	5	7	5	4	3	7
Effort	5	7	1	4	6	8	8	2	16	18	3	7	11	10
Frustration Level	6	7	1	2	1	4	5	3	18	9	1	6	4	6

	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	S28
Mental Workload	14	14	17	7	16	4	6	12	14	14	7	10	11	4
Physical Demand	3	15	17	3	4	7	4	6	14	7	10	1	5	12
Temporal Demand	16	18	19	4	10	2	1	5	10	8	13	7	5	2
Performance	3	8	2	7	13	1	1	6	12	6	4	1	5	1
Effort	16	16	17	7	14	2	14	12	12	8	14	9	7	3
Frustration Level	13	9	15	7	16	2	1	6	12	8	16	1	5	1

Ease Data

Subject	REG - before	OTS - before	HV – before	HS - before	REG - after	OTS - after	HV - after	HS - after
1	4	1	3	2	2	1	4	3
2	1	3	2	4	1	2	4	3
3	1	4	2	3	1	2	3	4
4	4	1	3	2	1	2	4	3
5	1	3	2	4	1	4	3	2
6	1	2	4	3	1	2	4	3
7	1	3	2	4	1	4	3	2
8	1	2	4	3	1	2	4	3
9	1	3	2	4	1	2	4	3
10	1	3	2	4	1	3	4	2
11	1	2	3	4	1	3	2	4
12	1	3	2	4	1	2	4	3
13	2	1	4	3	1	3	4	2
14	2	4	1	3	1	2	4	3
15	1	3	2	4	3	2	1	4
16	1	4	3	2	1	2	4	3
17	1	3	2	4	1	3	2	4
18	1	2	3	4	1	3	2	4
19	1	4	2	3	3	2	1	4
20	1	3	4	2	1	3	4	2
21	1	3	2	4	1	2	4	3
22	3	4	1	2	2	4	1	3
23	1	3	2	4	2	3	1	4
24	3	4	2	1	3	1	4	2
25	2	3	1	4	4	2	3	1
26	3	4	1	2	2	3	4	1
27	1	4	2	3	1	3	2	4
28	**1**	**4**	**2**	**3**	**1**	**2**	**3**	**4**

*In the above table, the subjects were asked to rate how easy they thought each of the cases would be before they completed the tasks and how easy they were after the tasks. They were asked to rate the conditions from 1 to 4, with 1 being the easiest and 4 being the hardest.

SPSS Data File

Subject	REG:time	REG:toterr	REG:avgerr	REG:avgcon	OTS:time	OTS:toterr
1	3.679	0	0	4.944444	4.7335	**0**
2	4.8545	0	0	5	7.272333333	**1**
3	3.817333333	0	0	5	5.478333333	**0**
4	7.737444444	0	0	4.944444	9.579666667	**0**
5	4.4595	0	0	5	6.681888889	**0**
6	3.830222222	0	0	4.944444	4.349611111	**0**
7	5.796666667	0	0	4	8.855944444	**0**
8	6.1265	0	0	5	8.117444444	**0**
9	3.839666667	0	0	4.888889	4.916611111	**0**
10	6.032	1	0.055555556	5	5.729666667	**0**
11	5.283055556	0	0	5	5.8235	**0**
12	3.229444444	0	0	4.222222	6.811111111	**1**
13	4.178166667	0	0	4.722222	5.442777778	**0**
14	4.953944444	0	0	5	6.525888889	**0**
15	3.686611111	0	0	4.944444	5.443333333	**1**
16	4.640611111	0	0	4.944444	7.062388889	**2**
17	3.757388889	0	0	5	5.541166667	**0**
18	3.899555556	0	0	5	7.612277778	**1**
19	5.079944444	0	0	4.666667	8.424	**0**
20	5.469055556	0	0	5	6.689777778	**0**
21	3.960722222	0	0	5	6.850222222	**1**
22	4.034	0	0	4.611111	4.223722222	**0**
23	4.801833333	1	0.055555556	5	4.670944444	**0**
24	4.836944444	0	0	4.277778	7.022166667	**0**
25	6.164	2	0.111111111	4.583333	5.666388889	**1**
26	5.02	0	0	5	4.081777778	**0**
27	3.501611111	0	0	5	5.524833333	**0**
28	**4.844777778**	**0**	**0**	**5**	**8.313055556**	**1**

Subject	OTS:avgerr	OTS:avgcon	HV:time	HV:toterr	HV:avgerr	HV:avgcon
1	0	5	4.610222222	0	0	**5**
2	0.05555556	4.833333	6.352611111	0	0	**4.666667**
3	0	5	5.005222222	0	0	**5**
4	0	5	8.943944444	1	0.055555556	**4.75**
5	0	4.777778	5.749722222	0	0	**4.944444**
6	0	4.722222	5.039222222	0	0	**4.555556**
7	0	4.5	10.17866667	0	0	**4.055556**
8	0	5	8.917111111	2	0.111111111	**5**
9	0	4.388889	5.043222222	1	0.055555556	**4.666667**
10	0	4.944444	6.945666667	0	0	**4.944444**
11	0	4.888889	7.400888889	0	0	**5**
12	0.05555556	3.972222	5.581833333	0	0	**4**
13	0	5	5.344888889	0	0	**5**
14	0	4.944444	5.195111111	0	0	**5**
15	0.05555556	4.611111	5.573	1	0.055555556	**4.944444**
16	0.11111111	4.75	5.584944444	0	0	**4.5**
17	0	5	5.340333333	0	0	**5**
18	0.05555556	5	4.959444444	0	0	**5**
19	0	3.777778	7.173055556	0	0	**3.166667**
20	0	4.777778	6.572666667	0	0	**5**
21	0.05555556	5	4.14	0	0	**5**
22	0	4.5	3.909	0	0	**5**
23	0	5	5.344	0	0	**5**
24	0	4.333333	6.094888889	0	0	**4.388889**
25	0.05555556	4.666667	5.241111111	0	0	**5**
26	0	4.944444	4.608222222	0	0	**5**
27	0	5	5.318277778	1	0.055555556	**4.777778**
28	**0.05555556**	**5**	**5.715**	**0**	**0**	**5**

SPSS Data File (cont.)

Subject	HS:time	HS:toterr	HS:avgerr	HS:avgcon	Handedness	SA
1	6.108277778	0	0	4.833333	16	**20**
2	6.926277778	0	0	4.666667	17	**19**
3	5.8205	0	0	5	16	**19**
4	12.11511111	1	0.055555556	4.888889	15	**6**
5	8.835	0	0	4.666667	17	**19**
6	5.6205	1	0.055555556	4.666667	18	**20**
7	8.186388889	0	0	4.055556	12	**18**
8	9.692666667	0	0	5	13	**18**
9	6.344444444	0	0	4.666667	16	**20**
10	7.143555556	0	0	4.944444	0	**12**
11	5.714333333	0	0	5	18	**18**
12	6.327055556	0	0	4.166667	17	**14**
13	6.365833333	0	0	5	19	**19**
14	9.217722222	1	0.055555556	4.861111	15	**20**
15	5.540388889	2	0.111111111	4.583333	14	**16**
16	6.014888889	0	0	4.555556	16	**20**
17	8.9175	1	0.055555556	4.944444	15	**20**
18	8.334611111	2	0.111111111	5	-16	**18**
19	7.886777778	1	0.055555556	3.638889	13	**15**
20	6.718166667	0	0	4.944444	11	**20**
21	7.409777778	0	0	5	17	**13**
22	5.174611111	0	0	4.888889	13	**20**
23	5.959444444	2	0.111111111	5	14	**20**
24	6.462444444	0	0	4.277778	20	**17**
25	5.753666667	0	0	4.666667	17	**20**
26	6.394055556	0	0	4.944444	11	**18**
27	6.778944444	1	0.055555556	5	17	**17**
28	**6.445666667**	**0**	**0**	**5**	**17**	**16**

Subject	SA %	Age	M/F 0/1	REG TLX M	REG TLX Physical	REG TLX Temporal
1	95.2381	24	0	3	5	**3**
2	90.47619	26	1	3	3	**4**
3	90.47619	22	0	0	0	**1**
4	27.27273	21	1	1	1	**1**
5	90.47619	18	1	0	2	**0**
6	95.2381	28	0	6	2	**12**
7	85.71429	21	0	4	2	**6**
8	85.71429	23	0	1	0	**0**
9	95.2381	27	0	18	6	**16**
10	57.14286	24	1	2	4	**9**
11	85.71429	24	1	5	5	**3**
12	66.66667	19	1	1	12	**5**
13	90.47619	23	1	6	15	**6**
14	95.2381	19	0	5	5	**13**
15	76.19048	21	1	10	3	**16**
16	95.2381	25	1	6	9	**4**
17	95.2381	29	1	3	3	**17**
18	85.71429	23	0	2	4	**14**
19	71.42857	18	1	5	2	**4**
20	95.2381	22	0	1	7	**1**
21	61.90476	20	1	1	1	**1**
22	95.2381	19	1	12	3	**7**
23	95.2381	20	1	2	2	**8**
24	80.95238	20	1	10	8	**7**
25	95.2381	20	1	7	15	**7**
26	85.71429	18	0	4	4	**6**
27	80.95238	22	0	3	3	**3**
28	**76.19048**	**25**	**0**	**1**	**1**	**1**

SPSS Data File (cont.)

Subject	REG TLX Performance	REG TLX Effort	REG TLXFrustration	OTS TLX Mental	OTS TLX Physical	OTS TLX Temporal
1	2	5	3	7	11	3
2	2	2	2	8	13	10
3	0	0	0	2	2	1
4	1	1	1	3	1	3
5	0	0	0	10	2	5
6	1	6	1	8	2	6
7	6	5	3	6	2	8
8	0	0	1	0	0	0
9	5	16	16	18	8	18
10	5	6	5	9	5	12
11	4	3	1	7	5	7
12	2	0	0	10	3	9
13	3	11	4	17	10	8
14	1	5	15	5	9	7
15	2	16	13	18	3	16
16	4	6	6	14	18	10
17	1	3	11	15	19	19
18	3	6	2	4	2	3
19	2	4	3	15	6	13
20	1	1	1	5	9	2
21	1	15	1	6	12	1
22	5	11	2	13	4	8
23	8	10	10	6	12	6
24	6	9	13	5	6	7
25	11	13	14	11	5	9
26	1	9	1	2	1	1
27	1	3	1	13	13	7
28	1	1	1	14	4	4

Subject	OTS TLX Performance	OTS TLX Effort	OTS TLXFrustration	HV TLX Mental	HV TLX Physical	HV TLX Temporal
1	2	5	5	9	11	12
2	8	7	7	14	7	11
3	1	1	0	3	1	2
4	1	3	1	6	1	4
5	3	8	4	5	2	2
6	2	7	2	8	2	10
7	14	8	4	6	2	10
8	0	0	0	5	0	1
9	14	16	16	20	5	14
10	1	8	2	17	17	7
11	4	8	1	5	11	5
12	2	7	0	11	5	7
13	3	17	17	18	8	6
14	6	7	12	9	4	5
15	4	16	14	14	1	15
16	14	14	13	18	12	10
17	6	19	11	16	9	7
18	5	4	5	4	3	4
19	7	12	15	14	5	12
20	1	1	4	5	7	2
21	2	14	1	1	1	1
22	9	12	11	7	5	3
23	4	8	14	3	4	6
24	3	13	16	10	6	10
25	5	7	5	11	7	7
26	1	5	1	3	1	2
27	1	11	2	7	1	11
28	1	2	1	11	1	1

SPSS Data File (cont.)

Subject	HV TLX Performance	HV TLX Effort	HV TLXFrustration	HS TLX Mental	HS TLX Physical	HS TLX Temporal
1	5	10	9	8	12	4
2	5	12	9	8	3	5
3	2	1	0	1	2	1
4	4	7	6	6	1	2
5	3	5	2	7	2	6
6	2	8	12	8	2	13
7	6	6	8	6	2	10
8	5	5	12	1	4	0
9	16	16	14	16	16	20
10	5	17	10	15	20	7
11	5	5	1	7	3	9
12	5	11	12	7	7	8
13	3	18	14	13	10	6
14	8	7	11	12	11	10
15	2	14	2	14	3	16
16	8	14	10	14	15	18
17	2	15	13	17	17	19
18	3	3	3	7	3	4
19	3	10	8	16	4	10
20	1	2	4	4	7	2
21	1	12	2	6	4	1
22	17	4	2	12	6	5
23	6	14	18	14	14	10
24	9	7	12	14	7	8
25	10	15	19	7	10	13
26	1	7	1	10	1	7
27	3	7	1	11	5	5
28	1	3	1	4	12	2

Subject	HS TLX Performance	HS TLX Effort	HS TLXFrustration	REG Median Conf	OTS Median Conf	HV Median Conf	HS Median Conf
1	3	5	6	5	5	5	5
2	6	7	7	5	5	5	5
3	0	1	1	5	5	5	5
4	3	4	2	5	5	5	5
5	0	6	1	5	5	5	5
6	2	8	4	5	5	5	5
7	14	8	5	4	4.5	4	4
8	0	2	3	5	5	5	5
9	5	16	18	5	5	5	5
10	7	18	9	5	5	5	5
11	5	3	1	5	5	5	5
12	4	7	6	4	4	4	4
13	3	11	4	5	5	5	5
14	7	10	6	5	5	5	5
15	3	16	13	5	5	5	5
16	8	16	9	5	5	4.5	5
17	2	17	15	5	5	5	5
18	7	7	7	5	5	5	5
19	13	14	16	5	4	3	4
20	1	2	2	5	5	5	5
21	1	14	1	5	5	5	5
22	6	12	6	5	4.5	5	5
23	12	12	12	5	5	5	5
24	6	8	8	4	4	4	4
25	4	14	16	5	5	5	5
26	1	9	1	5	5	5	5
27	5	7	5	5	5	5	5
28	1	3	1	5	5	5	5

SPSS Block Distance Data File

Block #	REG error total	REG error avg	REG time total	REG time avg	OTS error total	OTS error avg	OTS time total	OTS time avg
1	1	0.166667	192.982	6.892214	1	0.166667	198.649	**7.094607**
2	1	0.166667	131.442	4.694357	3	0.5	255.67	**9.755571**
3	0	0	125.8	4.492857	0	0	138.661	**4.952179**
4	1	0.166667	168.348	6.012429	0	0	144.348	**5.155286**
5	0	0	149.55	5.341071	0	0	161.175	**5.75625**
6	0	0	125.902	4.4965	2	0.333333	197.472	**7.052571**
7	0	0	108.492	3.874714	1	0.166667	220.84	**7.887143**
8	1	0.166667	149.072	5.324	0	0	167.72	**5.99**
9	0	0	136.105	4.860893	0	0	183.535	**6.554821**
10	0	0	115.36	4.12	0	0	137.274	**4.902643**
11	0	0	107.405	3.835893	0	0	220.829	**7.88675**
12	0	0	146.817	5.243464	0	0	156.029	**5.572464**
13	0	0	120.024	4.286571	0	0	238.255	**8.509107**
14	0	0	133.002	4.750071	0	0	150.869	**5.388179**
15	0	0	107.287	3.831679	0	0	140.821	**5.029321**
16	0	0	119.234	4.258357	1	0.166667	190.537	**6.804893**
17	0	0	114.908	4.103857	0	0	130.83	**4.6725**
18	**0**	**0**	**115.531**	**4.126107**	**0**	**0**	**142.998**	**5.107071**

Block #	HV error total	HV error avg	HV time total	HV time avg	HS error total	HS error avg	HS time total
1	0	0	243.855	8.709107	0	0	**191.124**
2	0	0	122.17	4.363214	0	0	**160.346**
3	0	0	161.778	5.777786	2	0.333333	**243.547**
4	1	0.166667	221.277	7.90275	0	0	**214.308**
5	0	0	116.262	4.152214	0	0	**141.424**
6	0	0	131.878	4.709929	4	0.666667	**336.624**
7	0	0	125.28	4.474286	0	0	**187.42**
8	0	0	186.058	6.644929	5	0.833333	**272.494**
9	0	0	177.446	6.337357	0	0	**141.57**
10	0	0	159.322	5.690071	0	0	**240.087**
11	0	0	116.11	4.146786	0	0	**143.293**
12	1	0.166667	174.337	6.226321	0	0	**130.863**
13	0	0	123.896	4.424857	1	0.166667	**234.318**
14	2	0.333333	194.158	6.934214	0	0	**146.555**
15	2	0.333333	219.59	7.8425	0	0	**181.327**
16	0	0	171.096	6.110571	0	0	**117.734**
17	0	0	243.625	8.700893	0	0	**243.272**
18	**0**	**0**	**97.743**	**3.490821**	**1**	**0.166667**	**241.449**

SPSS Block Distance Data File (cont.)

Block #	*REG Distance*	*OTS Distance*	*HV Distance*	*HS Distance*
1	2	1	2	**0**
2	0	2	0	**1**
3	1	0	1	**2**
4	1	0	1	**2**
5	2	1	2	**0**
6	0	2	0	**1**
7	0	2	0	**1**
8	1	0	1	**2**
9	2	1	2	**0**
10	1	0	1	**2**
11	0	2	0	**1**
12	2	1	2	**0**
13	0	2	0	**1**
14	2	1	2	**0**
15	1	0	1	**2**
16	2	1	2	**0**
17	1	0	1	**2**
18	**0**	**2**	**0**	**1**

*In the distance columns above 0 = adjacent, 1 = lined up in X or Y, 2 = niether

SPSS Analyses

1. To compare Error and Block Placement Time Data between the cases:
    - General Linear Model > Repeated Measures
        - Within Subjects Factor – case(4)
        - Measure Name – Average Error and Average Time
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

2. To compare NASA TLX Data between the cases:
    - General Linear Model > Repeated Measures
        - Within Subjects Factor – case(4)
        - Measure Name – NASA TLX measures
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

3. To look at correlations between all of the data
    - Correlate > Bivariate
        - Pearson
        - Two-tailed

4. To compare Block Distance Data
    - General Linear Model > Univariate (ANOVA)
        - Dependent Variable – error or time
        - Random Factor – distance (both overall and within the cases)
        - Options:
            - Descriptive Statistics
            - Display Means, Compare Mean Effects (LSD none)
        - Contrasts:
            - Simple Last

5. To compare Confidence Levels
    - Descriptive Statistics > Frequencies

6. To compare the Ease Data before and after
    - Descriptive Statistics > Frequencies

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VITA

CINDY M. ROBERTSON

ROBERTSON was born Cindy Marie Leistner in Sault Ste. Marie, Ontario, Canada. She received a B.S. in Computer Engineering from the University of South Carolina, Columbia, South Carolina in 1997 and a M.S. in Computer Science from the Georgia Institute of Technology, Atlanta, Georgia in 2000 before pursuing a doctorate in Computer Science at the Georgia Institute of Technology as well. When she is not working on her research, Mrs. Robertson enjoys spending time with her family. Her hobbies include water sports and photography.