ABSTRACT

CORBETT, BRENDAN V. The Effects of Haptic Feedback and Visual Distraction on Pointing Task Performance in 3D Haptic Virtual Environments. (Under the direction of Dr. Chang Soo Nam and Dr. David B. Kaber).

Virtual environments have grown in use as a tool for a variety of applications. Despite broadening use, previous research has not fully examined the effect of additional sensory feedback, particularly delivered through the haptic modality, on human performance in virtual environments. The primary measure of performance outcome is typically time to complete the task. While completion time does have significant meaning, it does not take into account user behavior. In pointing tasks in a three-dimensional (3D) virtual environment, the path the user takes may have implications regarding efficiency of motion. A wide variety of studies have been conducted on the effect of object features, such as shape and color, in the ability for people to identify a unique target object from a field of distractor objects. However, these studies are often restricted to 2D views, while virtual environments provide a 3D view. This study examined the effect of haptic feedback and visual distraction on pointing task performance.

A total of 33 subjects were recruited to participate in this experiment. Results indicated a strong positive effect of haptic feedback on performance in terms of task time and root-mean square error of motion. Level of similarity between distractor objects and the target object significantly reduced performance, and subjective ratings indicated a sense of increased task difficulty as similarity increased. Subjects produced the best performance in trials where distractor objects had a different color but the same shape as the target object. The worst performance was found in trials where distractor objects were a mix of those with different color but the same shape and those with the same color but different shape. Those

results were expected. However, in trials with distractors of the same color but a different shape from the target, performance was worse. Subjects were more adept at recognizing differences in color than in shape, which contradicts previous research regarding preattentive processing. In prior studies, when only a single feature of distractor objects is distinct from the target object, time to visually identify the target was similar between basic features such as color and shape. In this 3D virtual environment, color resulted in significantly better performance, which is still consistent with other research which does identify color as the most powerful or compelling visual attribute for differentiation. Overall, this study provides insight towards the effect of object features and similarity and the effect of haptic feedback on pointing task performance in 3D virtual environments.

The Effects of Haptic Feedback and Visual Distraction on Pointing Task Performance in 3D Haptic Virtual Environments

by
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BIOGRAPHY

Brendan Corbett was born in Onslow, NC in a military family. He was raised in a variety of places, though many years were spent on Okinawa, Japan and in Stafford, Virginia. Brendan was a recipient of the Park Scholarship and attended North Carolina State University beginning in August 2007, majoring in Industrial and Systems Engineering. During his time as a student, he decided to continue for a master's degree in the same program, with a concentration in human factors and ergonomics. As a NIOSH trainee in the graduate school, Brendan's coursework had additional emphasis on occupational safety and health. He was also involved in two research projects under his advisors; with Dr. Chang Soo Nam he has worked on a project on development of a collaborative, haptic virtual environment for teaching science to visually impaired students, and with Dr. David B. Kaber, he worked on a project investigating the effect of roadway signage on driver behavior

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1. INTRODUCTION

1.1 Rationale

Prior studies have examined a variety of different influential factors on human computer interaction in virtual environments (Bowman, 2002). However, many of these studies are field specific and lack a generalized examination of factors that may influence human performance (ie., Robles-de-la-Torre, 2006; Takavoli, 2006). Many design principles utilized in three-dimensional (3D) virtual environments are based on research examining two-dimensional (2D) visualizations or physical scenarios. Compared to 2D visualizations, 3D visualizations include the addition of depth and increased user visual processing. While usability of virtual environments is a broadening research field (ie., Tromp et al., 1998; Johnson, 1999; Volbrake and Paelk, 2000), examination of performance effects has been examined to a lesser degree. Virtual environments also have capabilities of enhancing user experience through the use of additional sensory feedback (Hu, 2012). This study seeks to examine pointing task performance in a virtual environment with haptic feedback and visual distractions.

1.2 Research Goals

This study sought to examine the effect of sensory feedback, in particular haptic feedback, on human performance when completing a pointing task in a 3D virtual environment. Additionally, the effect of visual distraction, or manipulation of distractor objects in the field of view, was examined. Color and shape were manipulated with varying degrees of similarity to explore the effect of visual distraction on pointing task performance.

The result of this examination was to identify consistency or departure from expectations of human behavior in 3D virtual environments based on results published in previous studies.

1.3 Contents

This thesis is organized as follows. Section 1 presents the introduction, rationale, and research goals of the study. Section 2 presents the literature review, research questions, research model, and hypothesis. Section 3 presents the methods, including subjects, apparatus, and definition of independent and dependent variables. Section 4 presents the results of the experiment. Section 5 presents discussion on the results. Section 6 presents the study conclusion, with recommendations for future work appearing in Section 7.

2. LITERATURE REVIEW

2.1 Haptic Feedback and Virtual Environments

Virtual environments are rapidly becoming a more common platform for human computer interaction with a wide range of potential benefits. These environments provide an easily manipulated and easily controlled workspace, enabling a great degree of control for a variety of tasks ranging from training to rehabilitation (ie., Hu, 2012; Tavakoli, 2006). Providing haptic feedback, defined in the context of this paper as the application of force to user motion, further enhances a user's immersion and improves interaction with a virtual environment (Meijden, 2009). Haptic feedback has the potential to both provide redundant feedback improving saliency of signals as well as providing unique feedback as a new signal to reinforce or improve user understanding (Robles-de-la-Torre, 2006; Vitense, 2003).

In the medical field, haptically enhanced virtual environments have been used for training in a variety of cases. First year dental students and expert dental surgeons completed a basic dental procedure utilizing a haptically enhanced virtual environment (Dinka, 2006). Performance results were analyzed indicating much higher precision, speed, and consistency for the experts. The results were expected and indicative of results in a real world setting, providing support for the efficacy and validity of virtual environments as a training tool for dental students. Similarly, medical training has been conducted using haptically enhanced virtual environments to examine tumor removal from the brain (Tavakoli, 2006), with results being similar to those obtained by Dinka (2006). In the case of brain surgery simulation, however, user ratings were low in terms of their reception and feeling towards haptic feedback. In other medical settings, use of haptics in robot-assisted surgery showed improvements both in speed and precision for the task (Morris, 2007) While user ratings vary on their use experience and sense of realism from the systems, there are strong indications that virtual environments with haptic feedback provide sufficient feedback and realism to replicate real world interaction, with the benefit of low risk, high accessibility, and low cost, especially in medical cases (Meijden, 2009).

Virtual environments and expanded sensory feedback may provide benefits for educational systems as well. Visually impaired learners have shown positive responses to the use of haptic assistive feedback in virtual environments designed for science education (Nam, 2008). Studies regarding a variety of aspects of haptic feedback in education virtual environments for the visually impaired have shown strong support from a performance perspective as well (Johnson, 2010; Kim, 2012; Nam, 2012). The use of an additional modality of feedback enables visually impaired people to develop a clearer understanding of their surroundings in a virtual environment. Application of haptic assistive feedback, or that designed to directly enhance the performance of a user, has further positive value to learning and awareness in virtual environments (Nam, 2007). While this is a specific case in the education domain, the evidence for significant improvement of virtual environment interaction for visually impaired learners should extend to all users (Openshaw, 2006). Providing assistive feedback has the capability to expand a user’s understanding and enhance their performance in virtual environments.

In other cases, virtual environments have proven to be a valuable tool in rehabilitation. In one study examining user rehabilitation of trauma resulting in motor deficiencies (Clamann, 2012), haptic feedback provided significant improvements in assisting user orientation in a virtual environment. The use of virtual environments as an assistive tool in rehabilitation has also been examined for other cases of motor rehabilitation, notably hand function and fine motor skills (Broeren, 2004). Results from these studies show strong support for use of virtual reality combined with haptic feedback, which enable a greater variety of settings for rehabilitation efforts, improving the user experience and recovery.

While there are many benefits of haptic feedback, in certain cases the feedback is not necessarily positive. Vibration feedback, another form of haptics, has been shown to greatly increase user sense of urgency (Lewis, 2012; Pratt, 2012). This indicates that the use of haptic feedback, while potentially positive, should be carefully selected for appropriate cases where the specific kind of feedback will add value and not detract from user performance or comfort. Virtual environments themselves also have other challenges, such depth perception where systems may need to represent a realistic sense of depth in a 2D interface (Bowman, 2012; Gentaz, 2008). Resolving these issues to improve the user experience is one of the main issues in acceptance and use of virtual environments and use of haptic feedback.

Many previous studies emphasize use of haptic feedback as a way to improve immersion through the additional modality, or increase salience of information using haptic feedback as a redundant signal, or use haptic feedback to provide some new information or cues (ie., Robles-de-la-Torre, 2006; Dinka 2006; Hu, 2012). What is rarely examined is use of haptic feedback as a performance improvement tool. A variety of strategies to use haptic feedback, whether through force feedback or vibration as a signal, have potential to enhance performance, especially in complex tasks where visual or auditory modalities may not be the most efficient in addressing task challenges (Meijden, 2009).

2.2 Visualization

The field of information visualization focuses on taking large, abstract quantities of data and converting them into an understandable, usable visual (Liu, 2003). As a result of the visual focus, a great deal research has been conducted related to human information processing through the visual modality. Emphasis has been placed on understanding user ability to detect features with manipulations of shape and color (i.e., Bauer, 1998; Duncan, 1989; Healey, 1996). These studies look at placing a single target object within a field of distractor objects, with a huge range of manipulations on the target object to categorize it as unique from all distractors. From this research, two major types of visual displays were identified. First, there are those in which the target object varies from all distractor objects by only one feature. For instance, the target object may be identical to all other objects in a given space by color, though its shape or orientation may be different. When only a single feature is manipulated, the expectation is for people to visually identify the target in the time necessary to make dedicated eye movements to scan a field of objects (~200ms). Second, there are studies in which distractors differ from the target object by multiple features (ie., Bartram, 2003). For example, a target may be in a field where some distractors have the same color but a different shape, while other distractors have a different color but the same shape. This type of target is considered a conjunction target, and it is expected to take more than 200ms for the visual system to identify the target in a field of objects.

Color is a particularly important feature to control, as approximately 4% of the world population has some degree of color blindness (Ichihara, 2000). Protanope, deuteranope, and tritanope color blindness all vary in the effected color spectrum. To account for this, a variety of guidelines have been developed on design of visual displays and color selection to provide clear visibility to all users (Bergman 1995; Wong, 2011). Application of color blindness principles can enhance the universal usability of visual displays. Furthermore, use of color blindness research for color selection can guarantee clear and distinct colors, which can improve clarity of information can further improve ease of access to non-colorblind people (Ichihara, 2000).

Other factors do influence the ability of people to identify targets in a field of objects. For example, texture of the objects themselves can play a part, where textural similarity or difference between objects and effect the salience and visibility of objects (Aks, 1996). Furthermore, the background of a field of objects can greatly influence ease of identification (Bauer, 1996). Neutral backgrounds help clarify object features, while complex backgrounds or those which share forms, colors, or patterns similar to targets can greatly increase difficulty. This interaction of object form or shape complements the significance of color in visualization.

Recent research further examines human visualization in virtual reality. In a nuclear fusion research facility, use of color was investigated in a variety of interfaces and displays. It was found that color and texture differentiation enabled significant improvements in consistency, time invested interacting with interfaces and models, as well as cost savings (Sanders, 2006). The use of distinct colors and textures for different fundamental groupings enabled easy identification of different functions, as well as rapid and intuitive understanding of new systems presented using the familiar color palette. Other research has found people are sensitive to differences between real and virtual environments, emphasizing a need for replication of realistic lighting and color to preserve immersion in virtual reality (Billger, 2004). Other factors which are difficult to resolve include perception of orientation. Durgin (2010) proposed that a scale-free model for virtual reality be used to maximize user interaction with a virtual reality without placing strain on the realism of the environment. By creating a virtual environment that does not depend on referencing real objects, a viewer can more easily access virtual images and understand their representation without disruption from a lack of, or departure from, real representations. As a result, a virtual reality that utilizes broad or general objects may be an effective tool for experimental studies.

2.3 Multiple Resource Theory

The multiple resource theory states that there are multiple different pools of resources available for humans to process information. The theory describes visual, auditory, tactile and olfactory modalities which are different senses through which information may be received, each operating off of an independent pool of resources (Wickens, 1984). That is to say, watching a display panel requires visual attention, and does not require olfactory resources. The way humans gain and process information is key to understanding the effect of different distraction or assistive feedback on human performance (Wickens, 1992). If a person is completing a task that demands attention in multiple different modalities, it is possible to place such a high load on a single modality that performance in a different modality will decrease (Wickens, 2010).

2.4 Human Performance Assessment

When assessing human performance, time to complete a task is often the primary measure. Fitts' Law is a foundational law that has seen widespread use in a multitude of studies. Originally published in 1954, the model describes a user's one directional movement time between a start location and a target as a function of the target width and distance to the target (Fitts, 1954). This was further expanded by Accot and Zhai to two dimensional tasks (Accot, 2003). A variety of other studies have examined use of Fitts' Law in three dimensions, both in computerized and real environments (Mateo, 2005; Muarata 2001). All of these studies examine human performance and, indirectly, motion as a function of only movement time. A further limitation of Fitts' Law and Accot's adaptation is that they depend on only a single target object or destination being present in a given field. This is unrealistic when compared to many environments in which people now operate, where a multitude of objects may be present at any given time.

While task time or movement time is a common assessment, it does not take into account user behavior. A common measure of cursor motion performance is root mean square error (RMSE). This measure has been used in a wide variety of studies to examine average deviation from an expected or ideal path in cursor and avatar motion (ie., Riley et al., 1988; Contreras-Vidal, 2002; Sheik-Nainar, 2004; Wang et al., 2006). Examining motion path in a virtual environment is well suited to use of root means square error as an evaluation method as the straight line path and user deviations from the path area easily and accurately generated.

2.5 Research Questions

This study seeks to examine the effect of different types of haptic assistive feedback and different types of visual distraction on performance in a 3D virtual environment. In the context of multiple resource theory, by increasing visual distraction the overall difficulty of the task will be increased; completing the pointing task with a highly distracting layout is expected to require greater time and effort to complete than a pointing task with no visual distraction. The application of haptic feedback across a range of visual distractions is expected to improve performance regardless of the degree of distraction due to the feedback effecting only the tactual modality. The study is generalized in nature to examine these effects in a broad scope. Furthermore, subjective ratings on task difficulty and self-assessment of performance were analyzed to assess how people perceive differences based on these factors.

2.6 Research Model

Figure 1 displays the research model for this study, a 3 x 6 within subjects study with three categories of dependent variables:

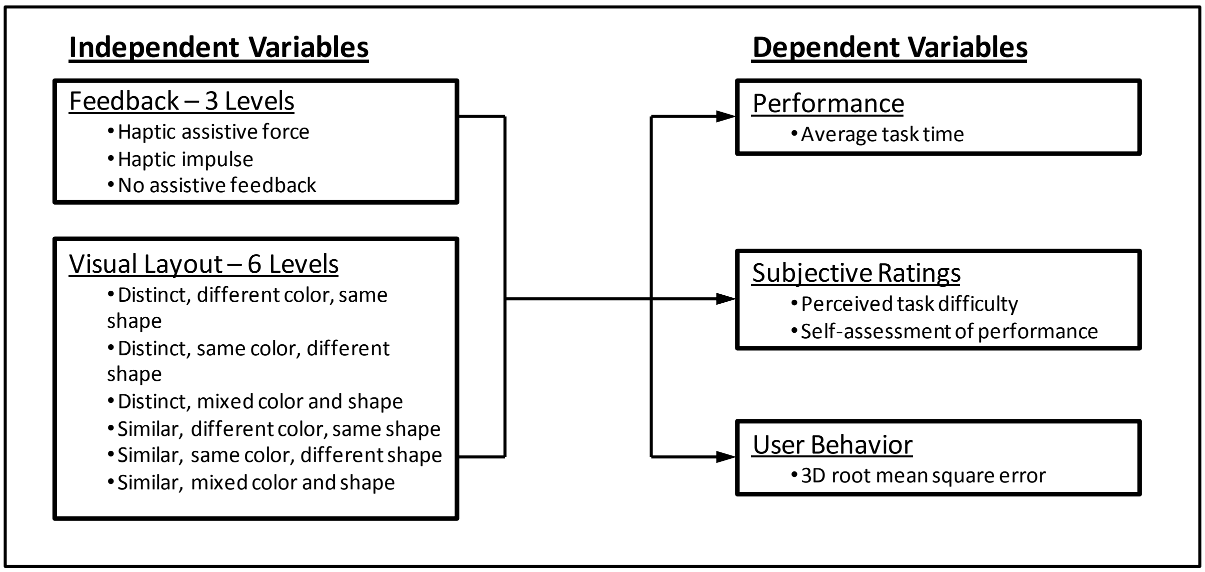

Figure 1: Study Research Model

2.7 Hypotheses

H1: Haptic feedback will significantly reduce average task time by providing a supplement and aid to user motion.

H2: When a target object shape or color is similar to distractor object shape or color in a layout, total task time will increase when compared to layouts with distinct shape or color due to the increase in time needed to identify the target object from the field of distractors.

H3: Haptic feedback will significantly reduce average root mean square error of motion path by reducing motion that is not directed towards the target object.

H4: When a target object shape or color is similar to distractor object shape or color in a layout, average root mean square error of motion path will not increase when compared to layouts with distinct shape or color. The difference in visual task difficulty should not directly influence user motion in the case of a pointing task.

H5: Subjects will rate the task as significantly less difficult in trials with haptic feedback due to the physical assistance while pointing the cursor.

H6: Subjects will self-assess their performance as significantly better in trials with haptic feedback due to the additional support in completing the task.

H7: Subjects will rate task difficulty as significantly greater in trials where distractor objects are similar to the target object in shape or color when compared to trials with distractor objects that are distinctly different in shape or color. The increased similarity will lead to a more challenging visual scanning task resulting in an increased perceived difficulty.

H8: Subjects will self-assess their performance as significantly worse in trials where distractor objects are similar to the target object in shape or color when compared to trials with distractor objects that are distinctly different in shape or color. Due to the increased challenge of visual scanning, subjects will not maintain the same confidence in their performance

3. METHODS

3.1 Subjects

A total of 33 subjects, 17 male and 16 female, were recruited from undergraduate and graduate programs at North Carolina State University to participate in this study. Each subject received course credit for their participation in the experiment. Subjects ranged from 19 to 35 years of age, with a mean of 23.6 years. Subjects reported an average of 32.9 hours per week spent on a computer, ranging from 5 hours to 70 hours. No subject reported colorblindness or any disability, and all subjects were right-handed.

3.2 Apparatus

Haptic Device: The Novint Falcon 3D Touch controller was used for this study. The device has three degrees of freedom, enabling movement along the x-, y-, and z-axis of a virtual environment, and is able to provide haptic feedback or a physical stimulus to users. The device is capable of delivering up to 2lbs. of force at a position resolution of 400 dpi. Users grasp a 1.5" diameter sphere to control the device and the physical range of motion is approximately 8" x 8" x 8". There are four programmable buttons located on the grip; for this study, only the center primary button was activated for use. The device can be seen in use in Figure 2:

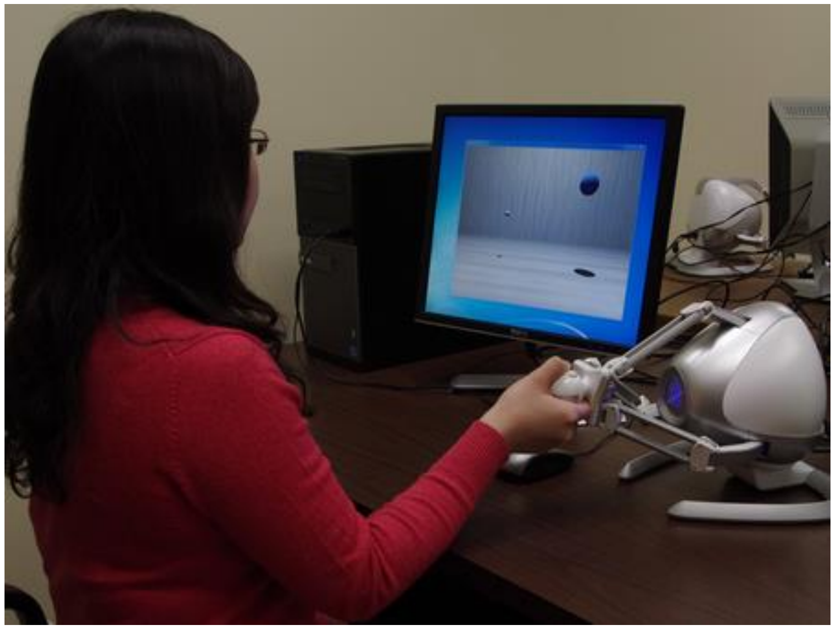

Figure 2: Subject seated with Novint Falcon 3D Touch controller

Haptic Virtual Environment: A custom testing system was developed for this study, utilizing the Novint SDK. The experiment environment had a pale wood-grain texture background to provide a neutral contrast to virtual objects. The virtual environment space was scaled to have a 27cm distance from corner to corner, displayed in a 1366 x 768 window. The system captured data at a rate of 60hz, gathering current trial time, whether or not the user cursor was touching a target object, whether or not the activated button was being pressed, the cursor location in x, y, and z coordinates, and the target object location in x, y, and z coordinates.

Subjects were presented a 6x6 grid of objects in the x-y, or horizontal and vertical, orientation at a set depth, in the z dimension. Every trial included the same number of distractor objects, 35, with one target object meaning a total of 36 objects present in each layout. The x-dimension of the grid ranged from -10 to 10 centimeters, the y-dimension ranged from 2 to 14 centimeters, and the z-depth was 7 centimeters from the start position. The target object would appear in a random location within the grid, with distractor objects populating the other spaces. Objects were also given a random location within their respective grid space. The target object was scaled to have a 1cm diameter. Distractor objects were scaled to have an equivalent maximum dimension, where cubes had a 1cm edge length, and dodecahedrons had a major diameter of 1cm.

Demographic Survey: A brief demographic survey was provided to subjects at the start of each experiment session. They were asked to identify age, gender, vision correction worn (if any), number of hours per week spent using a computer, number of hours per week spent playing video games, any prior experience with virtual environments (i.e., 3D modeling software), any prior experience with haptics, and any disability they may have. Gender, age, and hours per week spent on a computer were all examined using Pearson's product-moment correlation coefficient for any effect on the dependent variables, with no significant effects found.

3.3 Experiment Task

The experiment task was identical for all conditions. A white start object would appear in the foreground, close to the subject. After clicking the start object, it would disappear and the visual array would appear. Subjects were tasked with visually scanning the field to identify the target object, then moving as quickly and accurately as possible to the target and then clicking. Once a target was clicked, the visual field would disappear and the start object would reappear. Data was recorded from the moment the start object was clicked to the moment the target object was clicked.

3.4 Experiment Design and Independent Variables

To examine the effect of haptic feedback on performance in a visually intensive virtual environment, a balanced 3 x 6 within-subjects factorial experiment design was used, which resulted in 18 experiment trials. A summary of the independent variables is in Table 1.

Table 1: Independent variables

Factor	Level	Definition
Feedback	None	No feedback provided to user beyond visual information
	Haptic pulse	A direct force provided from the user's cursor to the target object for a duration of 250ms
	Constant haptic assistive force	A constant, positive force applied to user motion that is directed towards the target object
Visual Layout	Blue sphere distractors	Distractor objects are of a different color but the same shape as the target object
	Red-orange cube distractors	Distractor objects are of the same color but a different shape from the target object
	Red-orange cube and blue sphere distractors	Distractors are a combination of different color but same shape and same color but different shape type of distractors
	Yellow-orange sphere distractors	Distractor objects are of a different color but the same shape as the target object
	Red-orange dodecahedrons	Distractor objects are of the same color but a different shape from the target object
	Yellow-orange sphere and red-orange dodecahedron distractors	Distractors are a combination of different color but same shape and same color but different shape type of distractors

3.4.1 Feedback

Haptic assistive feedback was designed to serve two purposes. First, to improve subject visual scanning by providing a physical cue, relating the direction from a user's cursor to the target object. Second, to improve subject motion by reducing inefficient motion, or that which strays from a straight line path to the target object. The first form of haptic feedback, a haptic pulse for a duration of 250ms, sent the users a direct force towards the target object from their cursor. For 250ms, a 4N force is applied actively to the haptic controller, providing a short impulse of motion towards the target object. This is conceptually similar to how a parent may give a child learning to ride a bike a running start with hands on the bike before allowing the child to ride independently. The second form of haptic feedback, a constant haptic attractive force, provided an additive force to user motion. As the rate of travel for a user moving towards or away from the target object increases, a stronger force up to a maximum of 4N is applied towards the target object. That is to say, if the user moved towards the target, they would feel a boost in the direction towards the target, or if they moved away from the target, they would feel increasing resistance. This sensation can be likened to a rubber band or spring attached from the target object to a user's cursor, except the force is applied only when in motion. When the cursor is far from the target motion towards the target is amplified by up to 4N, which diminishes as the cursor becomes closer to the target similar to the attraction of a rubber band or spring. Motion away from the target receives resistance up to 4N, similar to how a rubber band or spring resists extension away from the resting point.

3.4.2 Visual Layout

A total of six distinct visual layouts were presented, as a combination of the two levels of visual similarity and three levels of distractor features. In every trial, the target object was a red-orange color. Distractor colors were selected based on color blindness research (Ichihara, 2000). The distinct case provided a blue contrast color, which is easily distinguished from the selected red-orange by people with any type of color blindness. The similar case provided a yellow-orange color, which is difficult to distinguish from the red-orange target for any person, regardless of color blindness (Ichihara, 2000).

A sphere was selected for the target object shape to be direction neutral. Similar to the common use of a circle in two-dimensional human-computer interaction studies (i.e., Jagacinski, 1985; Mottet, 1994), the sphere provides the same features to a person regardless of their direction of approach. To contrast this, cubes were used for the distinct distractor shape. Increasing the number of faces of a cube by a magnitude of two, an octahedron has two-dimensional profiles which are functionally similar to that of a cube, presenting four edges. Decahedrons, an increase of the number of faces of an octahedron by two, also have potential to present a two-dimensional cross section with four sides. Dodecahedrons were selected as the similar distractor shape, an increase of the number of faces of a decahedron by two, as dodecahedrons share no two-dimensional cross section with cubes. Furthermore, all angles of a dodecahedron are greater than 90 degrees, while octahedrons and decahedrons both have angles of less than 90 degrees. Displaying any acute angles would provide a distinct and easily identified geometric form, not increasing the similarity when compared to a cube which contains only 90 degree angles.

The combination of color and shape manipulation of distractor objects resulted in the six different layouts falling into three categories. In the first category, the distractor objects were of a different color but the same shape as the target object (blue-sphere and yellow-orange-sphere). In the second category, the distractor objects were of the same color but a different shape than the target object (red-orange-cube and red-orange-dodecahedron). These layouts are considered preattentive (Heijden 1996), differing from the target object by only one feature. Finally, in the mixed layout, both first and second category distractors were included. In the final case, the target object was considered a conjunction target as it shared both shape and color features with the distractors (blue-sphere and red-orange-cube in the same trial, yellow-orange-sphere and red-orange-dodecahedron in the same trial). The six combinations of visual layout and similarity of features can be seen in Figures 3 to 8.

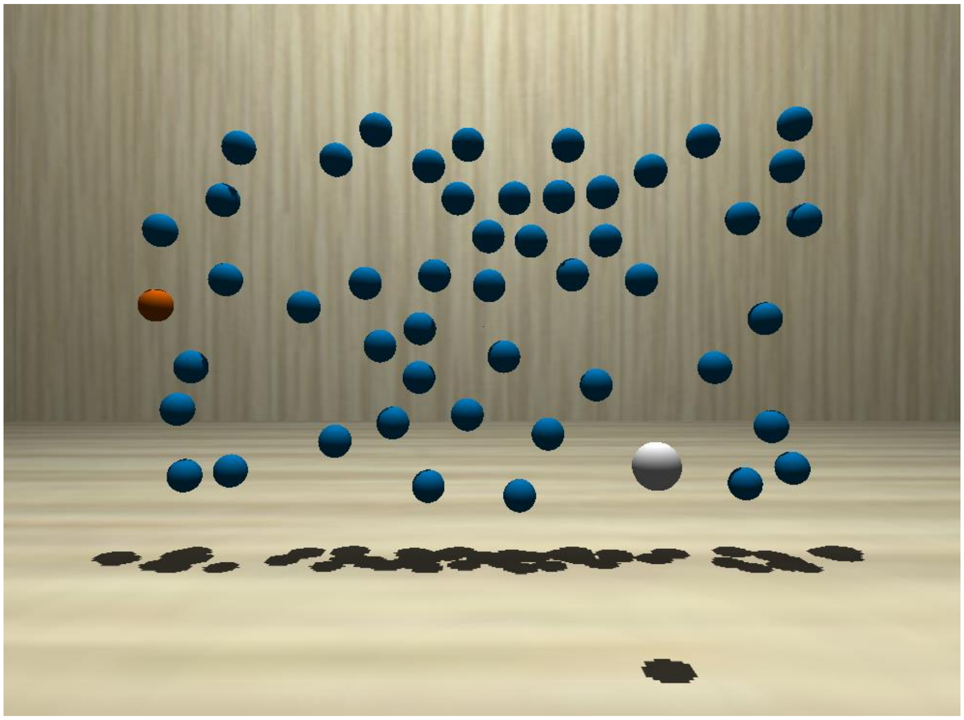
Figure 3: Distinct distractors with different color but same shape, blue spheres

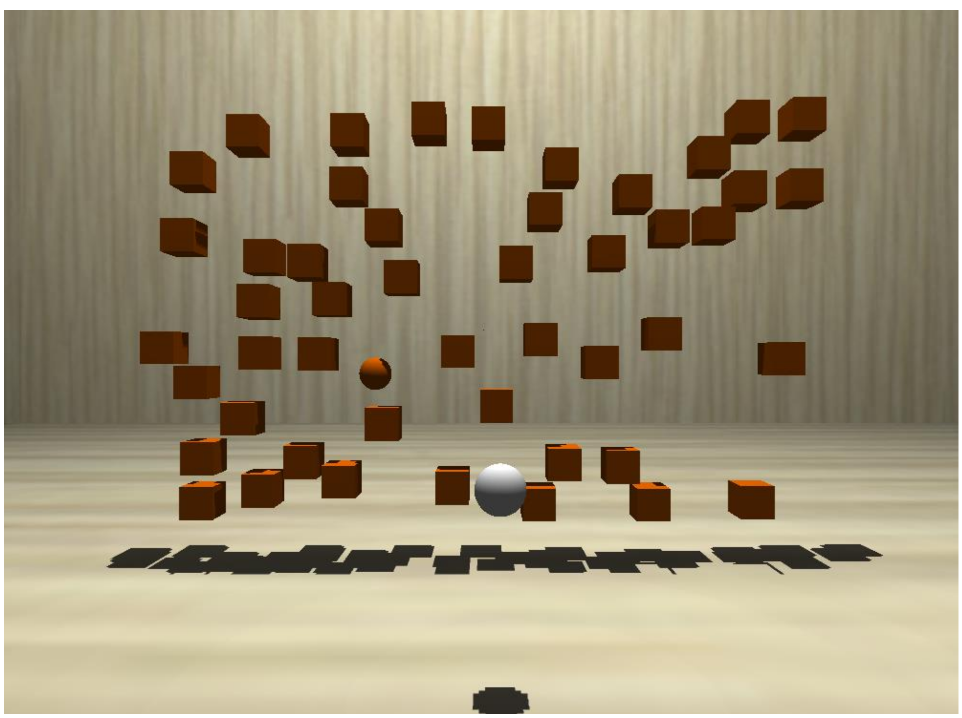
Figure 4: Distinct distractors with same color but different shape, red-orange cubes

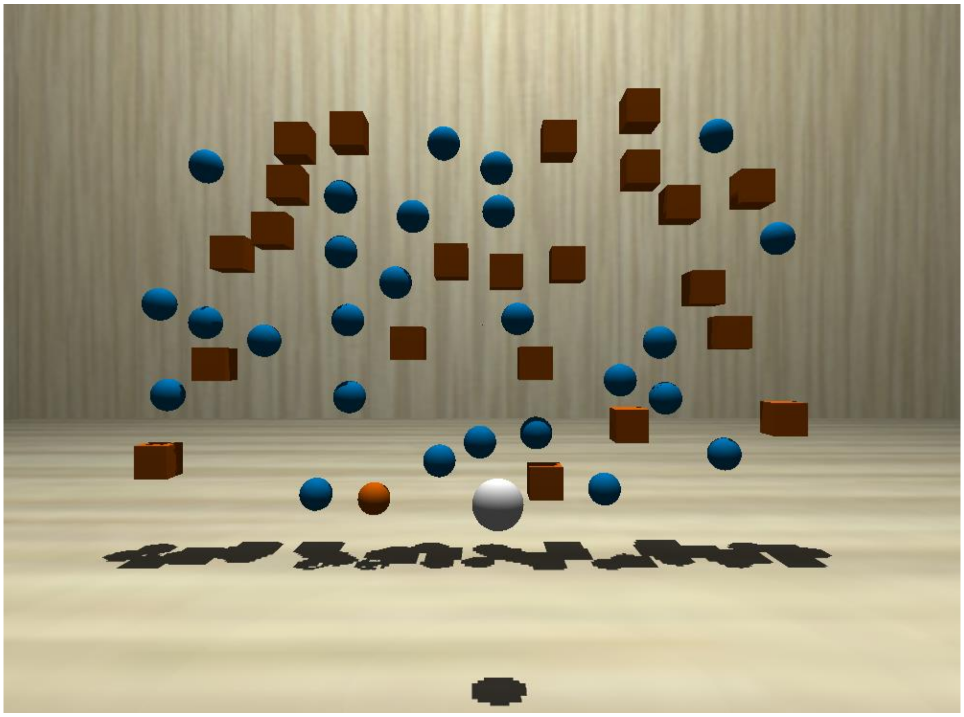

Figure 5: Distinct distractors, mixed color and shape, blue spheres and red-orange cubes

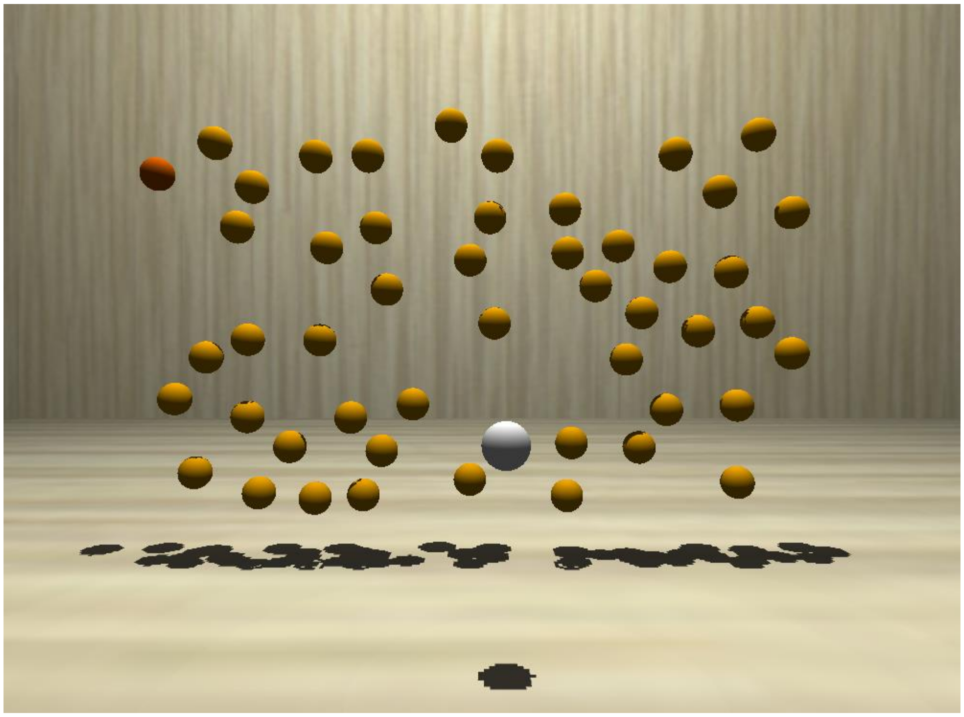

Figure 6: Similar distractors with different color but same shape, yellow-orange spheres

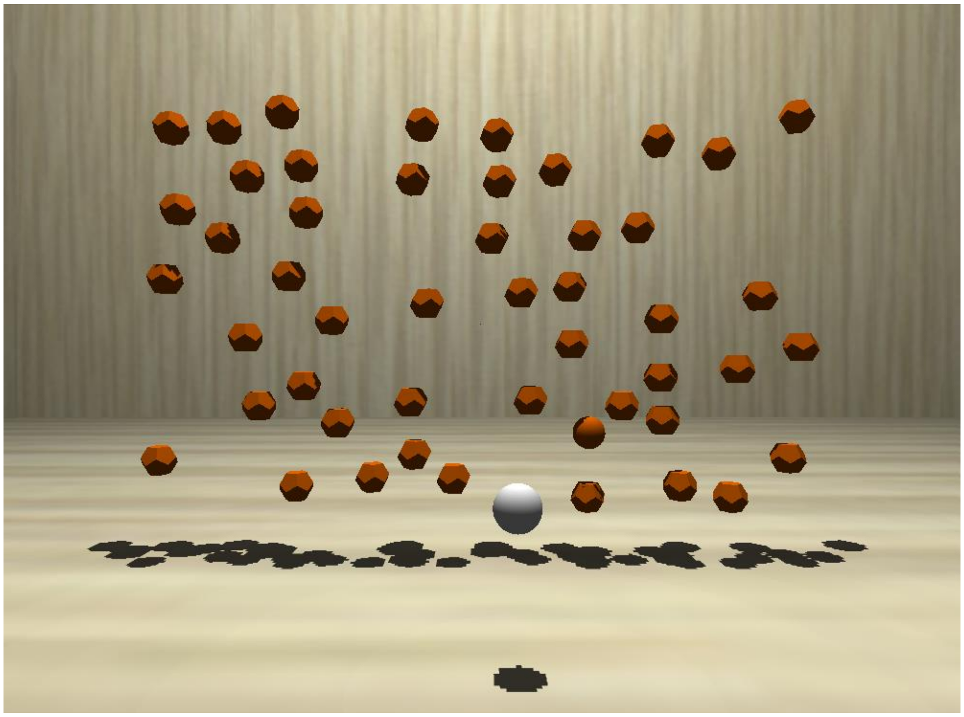

Figure 7: Similar distractors with same color but different shape, red-orange dodecahedrons

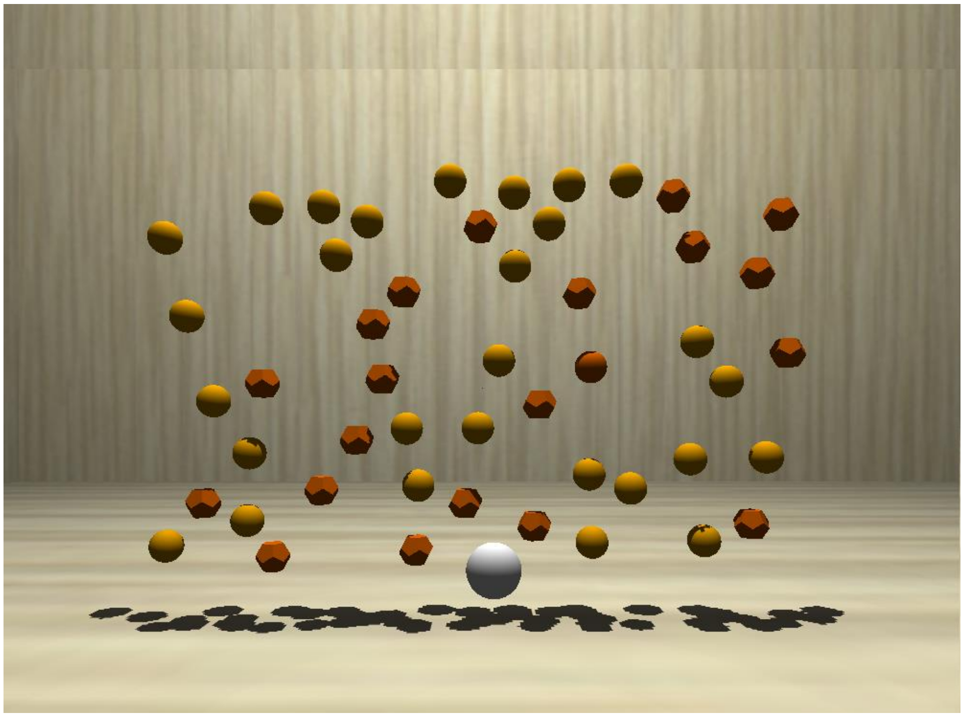

Figure 8: Similar distractors with mixed color and shape, yellow-orange spheres and red-orange dodecahedrons

3.5 Dependent Variables

This study examined three groups of dependent variables. First, average task time was analyzed as the main measure of performance. Task time was defined as the time from when a subject clicked the start object to the moment they touch and clicked a target object, with the time for each type of trial for each subject being averaged.

User behavior measurement was focused on the motion path of the cursor as controlled by a user through the virtual environment. The average root mean square error of user motion path, referencing the straight line path from the cursor to the target object, was used. The root mean square error calculation is based on the most direct path from the cursor to the target, the straight line path. As a user moves away from the path, the perpendicular distance from the cursor position to the straight line path is used to generate values for the root mean square error calculation. Each time the user started the task by clicking the start object, a linear function was generated for the straight line from the cursor center to the target center. Deviations greater than 1cm from the straight line path were recorded then used for the root mean square error. The 1cm buffer was applied to account for the radius of the cursor, 0.5cm, as well as the diameter of the target object, also 0.5cm. This means the maximum distance from the straight line path the cursor could stray was 1cm while still having the possibility of intersecting.

Subjective measures of task difficulty and self-assessment of performance were also examined. Difficulty was rated on a scale from 1 to 10, where 1 indicated a very easy or trivial task, while 10 indicated an extremely challenging or highly effortful task. Self-assessment of performance also occurred on a scale from 1 to 10, with 1 indicating very poor performance, while 10 indicated a near perfect performance. Perfect performance was defined for subjects as a single, direct, and rapid motion to the target object with a single click. These ratings, adapted from Davis, 1989 and Bowman et al., 2002, were designed to focus on how haptic feedback changed user perception of the task based on the visual layout.

A summary of the response measures and their definitions is in Table 2:

Table 2: Summary of response measures

Category	Parameter	Definition
Performance	Average task time	Time from the moment the a start object is clicked to when a target object is clicked
Subjective Rating	Difficulty	User rating of overall task difficulty
	Self-assessment of performance	User rating of their performance
User Behavior	Root mean square error	Measurement of deviation of motion path compared to the straight line from cursor origin to target

3.7 Experiment Procedure

The experiment took place in the Cognitive Ergonomics Laboratory at North Carolina State University, a light, sound and temperature controlled environment, as seen in Figure 3. Subjects first read and signed an informed consent then completed the demographic survey.

After completion of the introduction paperwork, three short training sessions were completed to familiarize subjects with use of the haptic controller and interacting with the virtual environment. The first session provided practice with the simplest form of the experiment task, with only a single object present. In this case, all objects were of a uniform size and distance from the cursor. Subjects were informed of their goal to move as quickly and accurately to each target, then click. The second training session was identical to the first, but included the haptic assistive feedback. The final training session was a visual display, differing from the main experiment trials by providing only a 5x5 grid of objects, with colors and shapes distinct from those present in the main trials.

Following the training sessions, the experiment trials began. Each subject completed 18 trials in a randomized order, with each trial consisting of 18 target objects. For each trial, they were prompted to scan and identify the target object, then move as quickly and accurately to the target and click. After each trial, they were asked to rate the difficulty of the trial on a scale from 1 to 10, where 1 indicated the trial was extremely easy or trivial, and a 10 indicated the task was very challenging, requiring a high degree of effort. They were also asked to subjectively rate their own performance, also on a scale of 1 to 10, where a 1 indicated extremely poor performance while a 10 indicated perfect performance. A breakdown of the experiment procedure can be seen in Figure 9:

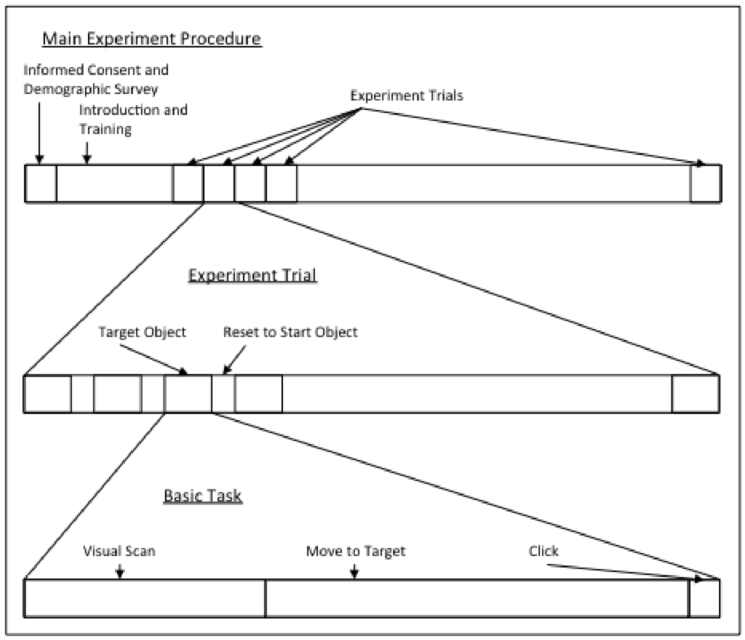

Figure 9: Experiment procedure

4. RESULTS

The data was filtered to remove outliers, only for instances where there subjects were distracted or their task was interrupted (ie. sneezing or momentarily releasing the device); these outliers accounted for less than 1% of the total data set. This process was repeated for each response measure. Following this process, the data was examined to assess compliance with the assumptions of the Analysis of Variance (ANOVA) statistical model.

Initial visual assessment of task time showed appearance of non-normal data, which was confirmed by Shapiro-Wilks evaluation for normality. A log transformation was applied, which resulted in a more linear appearance. Following this, the Shapiro-Wilks Test returned satisfactory results for compliance with normality. Feedback (none: $p = 0.828$, pulse: $p = 0.054$, constant: $p = 0.17$) and visual layout (DDS: $p = 0.616$, DSD: $p = 0.229$, DMM: $p = 0.070$, SDS: $p = 0.556$, SSD: $p = 0.074$, SMM: $p = 0.557$) have p-values which fail to reject the null hypothesis, indicating normal data. The Fligner-Killeen Test was then used to examine homogeneity of variance for each independent variable. Feedback type ($p = 0.862$) and visual layout ($p = 0.629$) resulted in a failure to reject the null hypothesis, indicating homogeneity of variance.

Subjective ratings, initially taken on a scale from 0 to 10 for perceived difficulty and self-assessment of performance, were converted to z-scores for analysis to account for internal rating systems of subjects. The same tests were used for these response measures to ensure ANOVA assumptions were satisfied. For self-assessment of performance, Shapiro-Wilks test (feedback: none: $p = 0.117$, pulse: $p = 0.052$, constant: $p = 0.074$; visual layout:

DDS: $p = 0.064$, DSD: $p = 0.068$, DMM: $p = 0.084$, SDS: $p = 0.055$, SSD: $p = 0.189$, SMM: $p = 0.345$) and Fligner-Killeen test (feedback type: $p = 0.442$, visual layout: $p = 0.378$) satisfy the assumptions of normality and homogeneity of variance. Subjective rating of difficulty results also satisfied both the Shapiro-Wilks (feedback: none: $p = 0.073$, pulse: $p = 0.054$, constant: $p = 0.092$; visual layout: DDS: $p = 0.053$, DSD: $p = 0.112$, DMM: $p = 0.542$, SDS: $p = 0.136$, SSD: $p = 0.649$, SMM: $p = 0.403$) and Fligner-Killeen test (feedback type: $p = 0.665$; visual layout: $p = 0.196$) were satisfied.

Average root mean square error results also satisfied the ANOVA assumptions in passing the Shapiro-Wilks test (feedback: none: $p = 0.182$, pulse: $p = 0.091$, constant: $p = 0.113$; visual layout: DDS: $p = 0.068$, DSD: $p = 0.174$, DMM: $p = 0.418$, SDS: $p = 0.391$, SSD: $p = 0.205$, SMM: $p = 0.113$) and Fligner-Killeen test (feedback type: $p = 0.482$, visual layout: $p = 0.341$).

With all assumptions satisfied, including independence of observations by nature of the experiment design, a two-way ANOVA was used to examine the results for task time, rating of difficulty, self-assessment of performance, and average root mean square error. Subject ID number and trial number, representing the order in which trials were presented, were used as a blocking factors in the model. Main effects of feedback type and visual layout were examined, as well as the interaction effect between feedback type and visual layout. Tukey's Honest Significant Difference test (HSD) was applied to identify significantly different means. For Tukey's HSD, the data passed the requirements for independence of observations and homogeneity of variance. A summary of the ANOVA results can be seen in Table 3:

Table 3: Effects on performance and subjective ratings

Parameter	Effect	F-Value	p-Value
Average Task Time	Feedback	$F_{2,555} = 17.76$	$p < 0.0001$*
	Visual Layout	$F_{5,555} = 44.33$	$p < 0.0001$*
	Feedback*Visual Layout	$F_{5,555} = 28.44$	$p = 0.396$
Self-Assessment of Performance	Feedback	$F_{2,555} = 10.43$	$p < 0.0001$*
	Visual Layout	$F_{5,555} = 29.88$	$p < 0.0001$*
	Feedback*Visual Layout	$F_{5,555} = 21.09$	$p = 0.227$
Subjective Rating of Difficulty	Feedback	$F_{2,555} = 13.00$	$p < 0.0001$*
	Visual Layout	$F_{5,555} = 66.12$	$p < 0.0001$*
	Feedback*Visual Layout	$F_{5,555} = 16.43$	$p = 0.485$
Average Root Mean Square Error	Feedback	$F_{2,555} = 9.81$	$p < 0.0001$*
	Visual Layout	$F_{5,555} = 41.60$	$p = 0.523$
	Feedback*Visual Layout	$F_{5,555} = 19.46$	$p = 0.381$

4.1 Average Task Time

4.1.1 Effect of Haptic Feedback

The ANOVA results indicated a significant difference between the levels of haptic feedback, $F_{2,555} = 17.76$, $p < 0.0001$. Examining the Tukey groupings, no significant difference occurs between the 250ms haptic pulse ($M = 3.42$s, $SD = 0.70$s) and the no feedback condition ($M = 3.35$s, $SD = 0.83$s). However, there is a significant difference between the constant haptic assistive force feedback ($M = 2.93$s, $SD = 0.69$s) and the no feedback and 250ms haptic pulse. These results and the Tukey groupings can be seen in Figure 10:

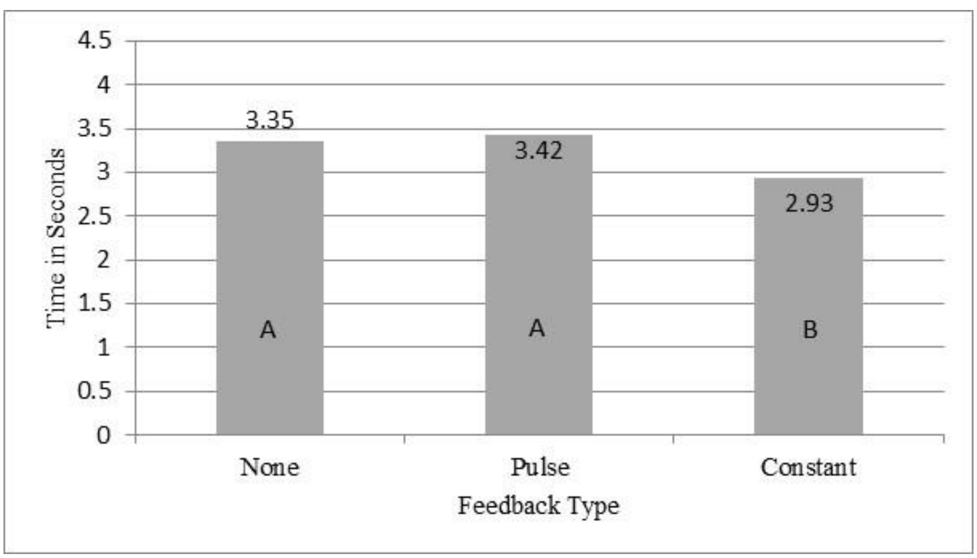

Figure 10: Effect of haptic feedback on average task time

4.1.2 Effect of Visual Layout

A significant difference was found between the distractor object types under different visual layouts, $F_{5,555} = 44.33$, $p < 0.0001$. Examination of the results showed two distinct Tukey groups. The first group contains the layouts with both yellow-orange spheres and red-orange dodecahedrons (M = 4.12s, SD = 0.66s) and trials with only red-orange dodecahedrons (M = 3.96s, SD = 0.66s). The second group, with a lower average task time, included blue sphere distractors (M = 2.82s, SD = 0.68s), red-orange cube distractors (M = 2.90s, SD = 0.81s), both blue sphere and red-orange cube distractors (M = 3.00s, SD = 0.72s), and red-orange dodecahedron distractors (M = 2.86s, SD = 0.85s). These results and the Tukey groupings can be seen in Figure 11:

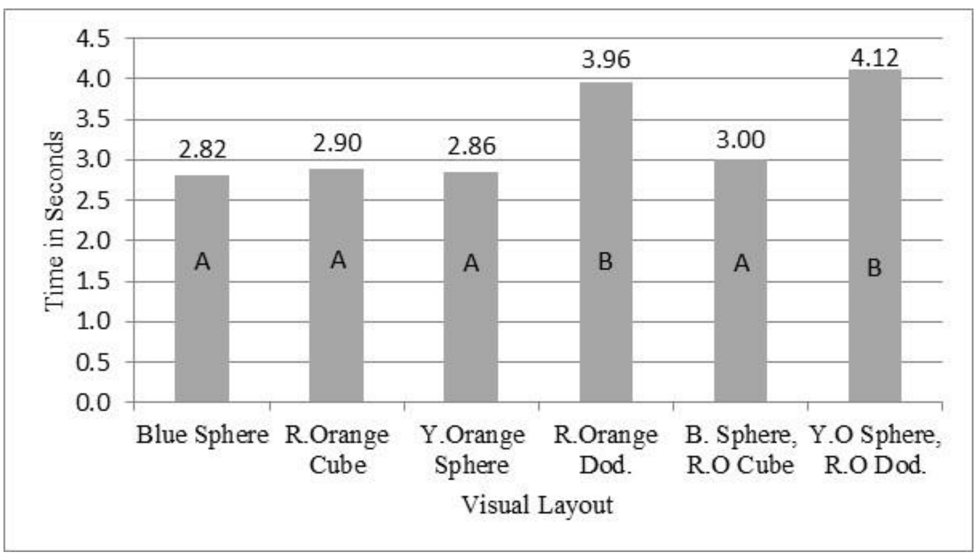

Figure 11: Effect of visual layout on average task time

4.2 Average Root Mean Square Error

A significant main effect was found for the average maximum inflection by feedback type, $F_{2,10} = 9.81$, $p < 0.0001$. Examination of the Tukey groupings showed that the haptic constant haptic force ($M = 1.31$cm, $SD = 0.98$) resulted in a significantly lower average root mean square error than the no-feedback ($M = 2.64$cm, $SD = 1.12$) and haptic pulse ($M = 2.43$cm, $SD = 1.14$) conditions. There was no significant effect of visual layout on the average root mean square error in this case. The results related to haptic feedback can be seen in figure 12:

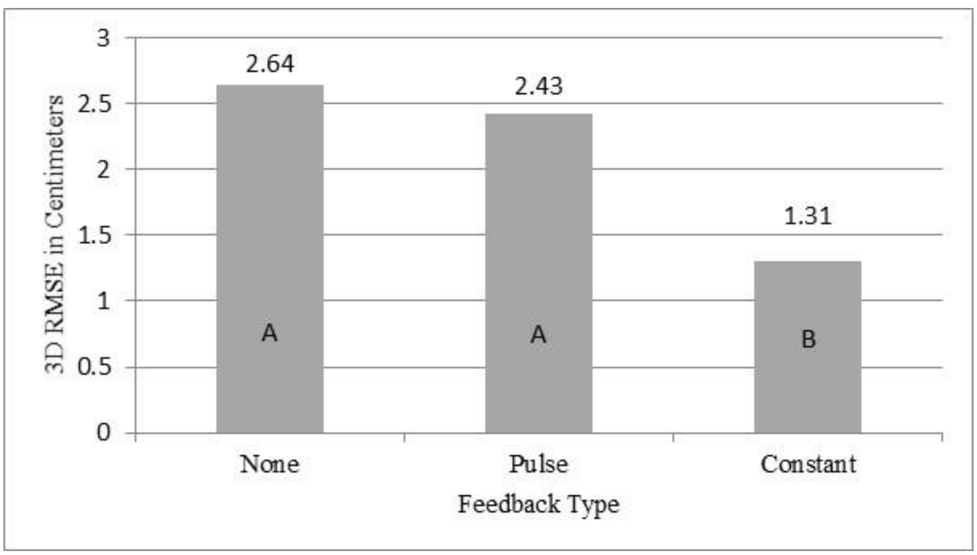

Figure 12: Effect of haptic feedback on average root mean square error

4.3 Subjective Ratings

4.3.1 Task Difficulty

ANOVA results showed two significant effects, one for feedback, $F_{2,555} = 13.00$ and $p < 0.0001$, and one for visual layout, $F_{5,555} = 66.12$ and $p < 0.0001$. No interaction effects were found. Examining the Tukey groupings for feedback type, there was a significant difference with subjects identifying the constant haptic assistive force feedback ($M = 4.40$, $SD = 0.91$) as less difficult than the no feedback ($M = 4.86$, $SD = 0.96$) condition. The 250ms haptic pulse ($M = 4.67$, $SD = 0.97$) had no significant difference compared to the other conditions. These results can be seen in Figure 13:

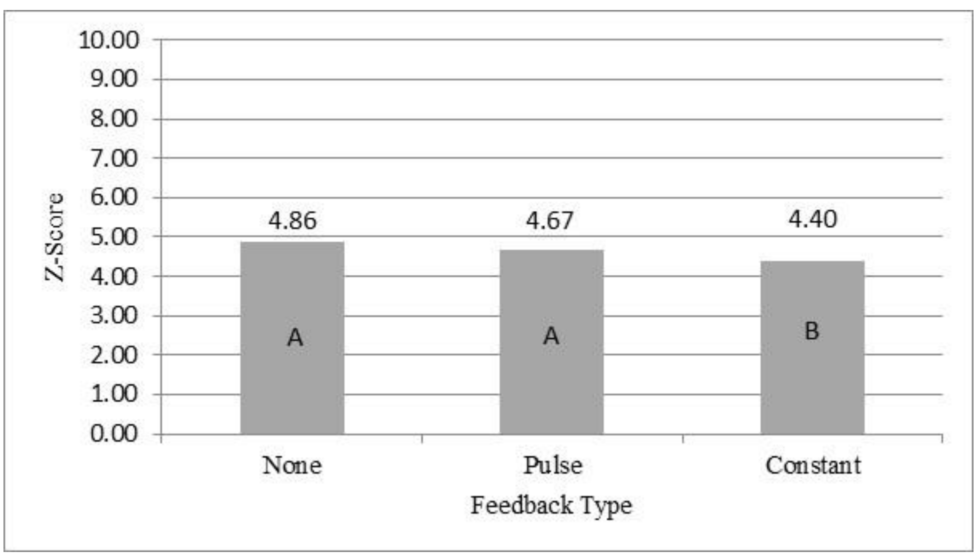

Figure 13: Effect of haptic feedback on subjective rating of task difficulty

Two Tukey groupings were found for visual layout. The first group, with higher rating of perceived difficulty, included the layouts with both yellow-orange spheres and red-orange dodecahedron distractors (*M* = 5.98, *SD* = 0.83) and those with just red-orange dodecahedrons distractors (*M* = 5.25, *SD* = 0.91). The second group, with a lower rating of perceived difficulty, included blue sphere distractors (*M* = 3.84, *SD* = 0.73), red-orange cube distractors (*M* = 4.15, *SD* = 0.82), trials with both blue sphere and red-orange cube distractors (*M* = 4.49, *SD* = 0.68), and yellow-orange sphere distractors (*M* = 4.14, *SD* = 0.66). These results can be seen in Figure 14:

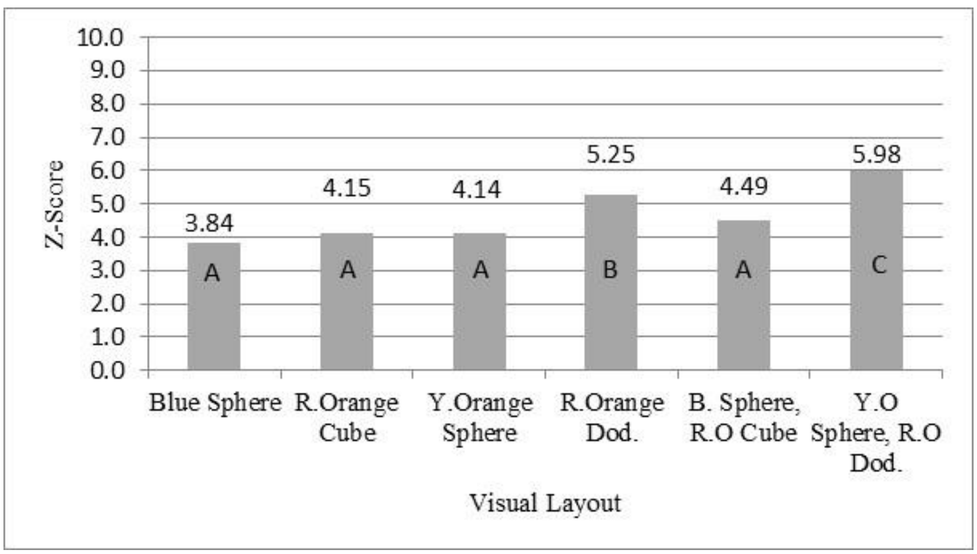

Figure 14: The effect of visual layout on subjective rating of task difficulty

4.3.2 Self-Assessment of Performance

Significant effects were found for feedback, $F_{2,555} = 10.43$ and $p < 0.0001$, and visual layout, $F_{5,555} = 29.88$ and $p < 0.0001$. Subjects rated their performance as significantly higher with constant haptic assistive force feedback (*M* = 7.36, *SD* = 0.91) compared to the no feedback (*M* = 7.07, *SD* = 1.02) and 250ms haptic pulse (*M* = 6.98, *SD* = 0.99) conditions. These results can be seen in Figure 15:

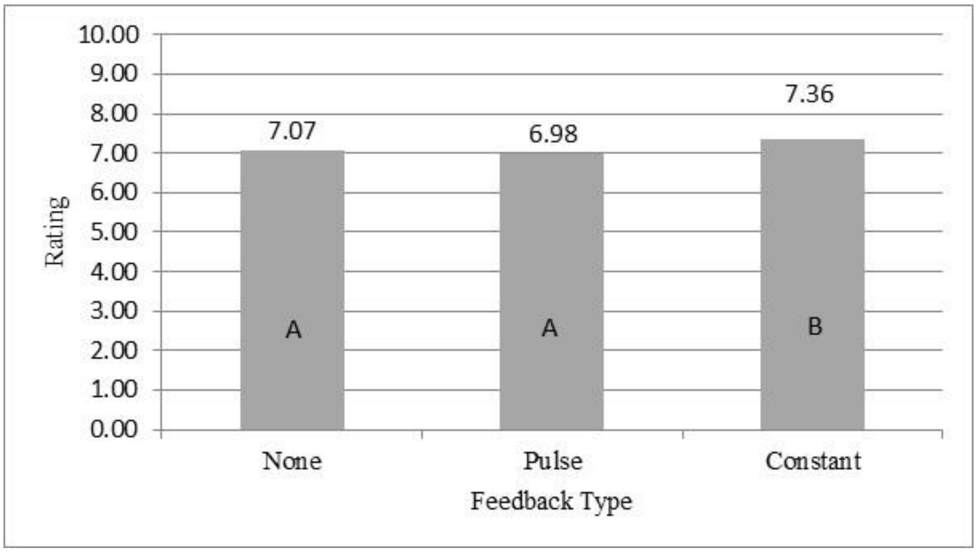

Figure 15: The effect of haptic feedback on self-assessment of performance

Two groups were found for visual layout. The first group consisted of layouts with both yellow-orange spheres and red-orange dodecahedron distractors (*M* = 6.38, *SD* = 0.95) and red-orange dodecahedron distractors (*M* = 6.77, *SD* = 0.89). The second group, with a lower rating of perceived difficulty, included blue sphere distractors (*M* = 7.46, *SD* = 0.99), red-orange cube distractors (*M* = 7.37, *SD* = 0.84), trials with both blue-sphere and red-orange cube distractors (*M* = 7.34, *SD* = 0.87), and yellow-orange distractors (*M* = 7.49, *SD* = 0.87). These results can be seen in Figure 16:

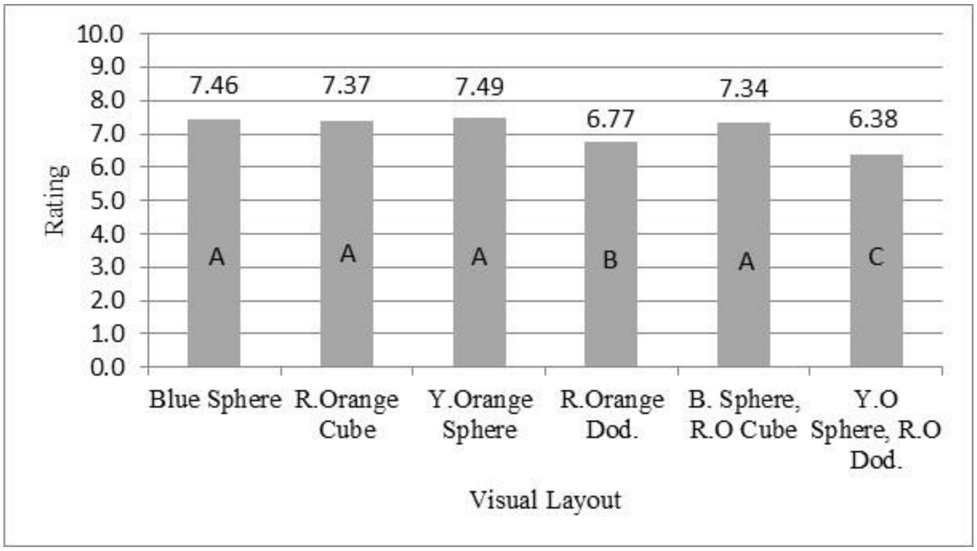

Figure 16: The effect of visual layout on self-assessment of performance

5. DISCUSSION

5.1 Average Task Time

Hypothesis 1, which stated that haptic feedback would significantly reduce task time, was partially supported. The improved task time under the condition of constant haptic assistive force feedback shows strong support for implementation of this assistive feedback and did support this hypothesis. By providing constant feedback, subjects could easily tell whether or not they were moving in the appropriate direction. This provided users a constant update signal in addition to their own visual scanning. Research in multi-modal feedback and signal redundancy suggest improvements in performance when additional modalities are used to enhance or support user activities (Ellis, 2005; Lee, 2009). In this case, the additional modality has shown performance improvements in a similar manner.

The case of the 250ms haptic pulse having no significant difference from the no feedback condition was unexpected, countering the belief that performance would improve with this style of feedback. The lack of improvement indicates that the 250ms pulse was either insufficient in duration or perceptibility for users to properly utilize the haptic signal to direct hand motion. It was believed this pulse would provide a directional cue and reduce task time, however this was not the case. While a 250ms pulse is supported by literature to be a sufficient time for physical detection (Lecuyer, 2002), in a case where there is competing visual information the pulse is insufficient to effect performance, resulting in no significant improvement in performance. These results confirm previous studies regarding the importance of selecting appropriate feedback based on the task design and load on a system user (i.e., Pitts 2012). In this case, while the 250ms pulse was detected by subjects, it was not used in a meaningful way.

The results indicate support for Hypothesis 2, which stated that increasing the similarity of object features would increase average task time. When object shape was more similar to the target object, movement time did increase. Prior research has supported this hypothesis in two dimensional visual displays (Baeuer, 1998; Duncan, 1989), and this confirms consistency of principles on feature similarity in 3D virtual environments. However, when color was highly similar between the target object and distractors compared to a distinct color, no difference was seen. In this study, it was expected that the highly similar color would be of a sufficient degree to affect performance, but that was not the case. Prior research has indicated that color is the most powerful distinguishing characteristic for the human visual system (Wickens, 1992), and the subjects in this study proved adept at identifying the color difference.

It was expected that mixed distractors would have a greater average task time than either preattentive case. When there was a conjunction target, sharing features with the distractors, it was expected to take much longer for a person to visually identify the target, resulting in a far greater task time. The significant difference between the two preattentive cases contradict expectation. Previous literature (Aks, 1996; Baeuer, 1996; Liu, 2003) has indicated that preattentive targets, whether unique by color or shape, should have similar times, less than 250ms, for visual identification. In this case, distractors with a different color but the same shape resulted in a lower average task time compared to the case of distractors with the same color but a different shape from the target object.

The results imply that in regards to distractor features and degree of similarity, people may be more dependent on object shape and geometric features as opposed to color in a virtual environment. While subject performance degraded with increasing similarity of distractor object geometry, performance did not significantly change with increased color similarity indicating a higher sensitivity to color. These results provide strong evidence that differences color may be a preferred method to provide distinction between objects in a three dimensional virtual environment as opposed to geometric features. The results strongly support the use of haptic feedback to improve task time regardless of visual distraction. The lack of significant interaction effect between visual distraction and haptic feedback is consistent with the implications of multiple resource theory. Furthermore, these results show strong support for the use of haptic feedback not only for the significant effect, but also due to the lack of interaction effect between visual distraction and haptic feedback. This implies that haptic feedback has the potential to reduce task time in pointing-type tasks with minimal effect of visual interface.

5.2 Average Root Mean Square Error

Haptic feedback was shown to have a significant effect on the average root mean square error in accordance with Hypothesis 3, which stated that haptic feedback would significantly reduce average root mean square error of motion. There was a significant reduction in the average root mean square error when comparing constant haptic assistive feedback to the no feedback condition. There was no significant difference between the haptic pulse and no feedback conditions in their effect on this measure. These results mirror those for average task time. The constant haptic assistive feedback provided a directional aid to user motion, helping to guide the cursor in a more direct path to the target. This has implications for human motor control, where haptic feedback, even at a moderate force, can significantly change user range of motion while moving through a virtual environment to an objective location. The haptic pulse did not provide any significant benefit compared to no feedback in reducing the average root mean square error. This result makes sense, as the pulse was designed to provide an initial prompt for users, not to direct or modify their motion towards the target. An initial pulse has no direct influence on the continued motion of a user, and as such no effect was seen on the root mean square error.

It was hypothesized that manipulations of visual layout would have no influence on average root mean square error of motion path. Once a target is visually identified, the motion taken to reach the target is fundamentally the same. Results support Hypothesis 4, that manipulating distractor feature would not result in any significant difference of average root mean square error. Considering the results on average task time, this implies that the visual layout presented to a person does not significantly influence variability of their motion. This supports the idea that in tasks such as this, the sub-tasks of visually scanning and physically moving to a target object are largely discrete and distinct. In other words, because there is no significant effect of visual layout on the motion path assessment, the results depict a case of two distinct phases of visual scanning then motion to the target. Subjects' need to adjust their motion while moving the cursor towards the target was only nominal in terms of visual requirements, and there are no indications in this study that the visual layout influenced that portion of the task. The appearance of this distinction was likely influenced by the instructions, identifying subjects should visually scan for the target object, then move to it as quickly and accurately as possible. Results may have been different if subjects were only told to complete the task as quickly as possible. This does highlight one limitation of this study, that only a controlled case with specific instructions was examined. Other scenarios may have very different results in terms of how subjects would approach the task in terms of unique or personal strategies.

5.3 Subjective Responses

The subjective results provide interesting insight towards subject perception of difficulty and their own performance. Hypothesis 5, which stated subjects would rate the task as significantly less difficult in trials with haptic feedback, was supported for constant haptic assistive feedback. Subjective ratings for difficulty with the constant feedback were consistent with actual performance results, where a more difficult rating of the task indicated greater task time and greater average root mean square error. What is of interest is that the Tukey groupings showed constant haptic force and no feedback as distinct, yet the haptic pulse was not perceived as significantly different than either of the other conditions. Where both performance measures, average task time and average root mean square error, indicate a significant difference between the constant feedback compared to the pulse, here there is no significant difference. This indicates that subjects did perceive an effect of the haptic pulse on the difficulty of the task, though in terms of actual performance the pulse was not sufficient in duration or appropriate in style to generate an improvement.

Self-assessment of performance was consistent with actual performance results. Hypothesis 6, which stated that subjects would self-assess their performance as significantly better in trials with haptic feedback, was supported in the case of constant haptic assistive feedback. Similarly, there was no perception of improved performance for the haptic pulse. It is interesting that the perceived difficulty was not significantly different between constant haptic assistive feedback and haptic pulse feedback, however the ratings for performance are significantly different. Part of the issue may again be rooted in the nature of the haptic pulse.

The 250ms duration was likely insufficient to aid in the motion component of the task due to visual scanning taking longer than this time. In that event, the haptic pulse may by its nature have provided some reduction in difficulty by repositioning the cursor closer to the target, though it was not perceived as influencing performance as the physical sensation ended for the majority of movement.

Hypothesis 7, which stated that subjects would rate the task as more difficult in trials where distractors were more similar to the target, was supported for the geometric features of distractors. The groupings show that only the trials with similar but different shape and same color distractors and trials with highly similar mixed distractors had significantly greater perceived difficulty. These subjective ratings mirror the performance results. Furthermore, Hypothesis 8, which stated that subjects would self-assess their performance as significantly worse in trials where distractors were more similar to the target, had identical results to the difficulty ratings. These subjective ratings are consistent with actual performance results.

In many previous studies (Aks, 1996; Bergman, 1995; Healey, 1996), it was shown that manipulation of only one distractor object feature, such as shape or color, would result in a similar response time if all other factors are held constant. This returns to the idea that people are more sensitive to differences in color in a 3D virtual environment as opposed to changes in shape, with color being one of the most powerful discriminating visual characteristics (Wickens, 1992). The only cases with significantly worse average task time were those where distractors of the same color but dodecahedron, or a highly similar level of different shape, were present. Ultimately color serves as the most compelling feature to use in virtual environments to enhance user ability to distinguish different objects of interest.

In general, when subjects identified a trial as more difficult, their self-rating of performance was lower. Likewise, in trials they rated as easier, their self-rating of performance was higher. The relationship in subjective ratings is very similar to average task time and average root mean square error across the independent variables as well.

6. CONCLUSION

This study investigated the effects of haptic feedback, distractor similarity, and visual layout on performance in a visual scanning and pointing task in a 3D virtual environment. Performance was assessed based on average task time and average root mean square error, and subjective ratings of difficulty and self-assessment of performance were examined. Results showed that constant haptic feedback improved performance, reducing average task time and average root mean square error, supported by subjects rating the task as less difficult and rating their performance as better with constant haptic feedback. Furthermore, haptic feedback improved subject performance regardless of visual layout, indicating strong support for use of haptic assistive feedback regardless of visual distractions. Visual layout independently was found to influence performance. In particular, the cases of distractors with a highly similar shape but the same color as the target object and mixed distractors, of both highly similar shape and same color as well as same shape with a highly similar color, had the greatest negative impact on performance.

With respect to virtual environment design, it is important to utilize color as a distinguishing feature of objects when possible instead of shape. Even if intended users may be colorblind, there are sufficient resources to identify acceptable, easily distinguished colors for people of any vision level. By utilizing color as a primary feature of difference, system users should be more adept at quickly and easily identifying targets when compared to using shape or geometry as a feature of difference. Providing additional sensory feedback through the haptic modality may also provide users significant improvements in their performance in objective tasks. Especially in complex environments, this additional feedback may greatly improve user performance and in turn, their experience.

7. LIMITATIONS OF CURRENT STUDY AND RECOMMENDATIONS FOR FUTURE WORK

Other forms of sensory feedback have great potential value in virtual environments, and should be explored. This current study only examined two forms of haptic feedback, but many other forms of sensory feedback may have value in different applications of virtual environments, such as use of vibration feedback for proximity warnings or redundant auditory signals to complement haptic feedback. The levels of similarity used in this study were simplistic, and more degrees of similarity may result in results with more clarity about the effect of similarity on user performance. Furthermore, other features beyond the basic elements of color and shape should be examined, including environment lighting, object orientation, and so on. The number of objects present was held constant in this study, though the number of objects present is also a factor that should be examined. Use of eye tracking may add significant additions to this work, providing a better examination of the visual scanning portion of the task. Even within the basic elements of color and shape, further diversifying the distractors may lead to different results. For example, in trials with distractors of a different color but the same shape as the target, more than one distractor color might be utilized. The scale and perceived size of the virtual environment should also be studied to provide more precise understanding of the exact effect of visual window on user performance. A further extension should be to see how users with disability, such as blind users, or other special populations might benefit from additional sensory feedback.

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APPENDICES

Appendix A: Demographic Survey

1. Age: _______
2. Gender: _______
3. Vision Correction, if any: ________________
4. The estimated number of hours you spend on a computer each week:_____________
5. The estimated number of hours you spend playing video games each week:________
6. Please describe your experience with virtual environments (e.g., video games, 3D modeling, animation) if any:____

   ____
7. Please describe your experience with haptics (e.g., vibration feedback on game controllers) if any:____

   ____
8. Please briefly describe any disabilities you have (note: write N/A if not applicable or you prefer not to answer):____

____

Appendix B: Informed Consent

North Carolina State University
INFORMED CONSENT FORM for RESEARCH
This consent form is valid from March 7, 2013 through March 7, 2014

Title of Study: Human Performance in a Virtual Environment with Visually Intensive Interfaces and Haptic Feedback

Principal Investigator Brendan Corbett   Faculty Sponsor (if applicable) Dr. CS Nam

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What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

What is the purpose of this study?
The purpose of this study is to examine performance in a pointing task under different visually intensive interfaces, as well as to examine the effect of haptic feedback.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to utilize a Novint Falcon haptic device to interact with a virtual environment. The haptic device acts similarly to a mouse, enabling you to interact with a computer system in three dimensions and with haptic, or physical feedback. You will first complete a demographic survey, then a field dependency tests. There will be three training sessions to familiarize you with the system. There will be 21 main trials, each taking no longer than 2 minutes to complete. In each trial, you will be tasked with visually scanning to identify the target object, then moving your cursor to the object and clicking. Between each trial you will be provided up to a 2 minute break, and will be asked to complete a brief questionnaire about difficulty of the task and perceived performance. The study will take place in Daniels Hall room 475, taking no more than 1 hour to complete.

Risks
The potential risks include minor wrist / arm fatigue from use of the device, minor eye strain from viewing the computer screen, and minor nausea or headache from viewing the virtual environment. To minimize any potential, you will be provided with a short break between each trial. If you feel discomfort, a longer break will be taken to allow symptoms to dissipate. These risks are minor in nature and if they do occur, they should completely clear within an hour of completing the study.

Benefits
There are no direct benefits from participation.

Compensation
For participating in this study you will receive credit towards completion of ISE452 or ISE544. You are able to earn these credits through signing up for other studies should you choose to do so.

Freedom to Withdraw

You have the right to refuse to participate in this study. Furthermore, you may withdraw your agreement to participate at any time with no penalty of any kind. Should you choose to withdraw, you will still be provided with one (1) Experimetrix credit per half-hour of participation, rounded up.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely in a locked room on secure computers in Daniels Hall. No reference will be made in oral or written reports which could link you to the study. You will NOT be asked to write your name on any study materials so that no one can match your identity to the answers that you provide.

What if you have questions about this study?

If you have questions at any time about the study or the procedures, you may contact the researcher, Brendan Corbett, at 458 Daniels Hall, 111 Lampe Drive, Raleigh NC, 27607, via email at bcorbet@ncsu.edu, or by phone at (540) 903-6547.

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

Consent To Participate

"I have read and understand the above information. If requested, I will receive a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

I would like a copy of the informed consent:

_____ Please email me an electronic copy at my email address: ____________________________

_____ Please provide me with a hard copy

Subject's signature_______________________________________ Date _________________

Investigator's signature__________________________________ Date _________________