User Interface Issues in Bimanual Dual Object Control

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Abstract

While many facets of two handed tasks are encompassed in human-computer interaction, there are still several forms of interaction which remain underdeveloped in the virtual world. Specifically, controlling two objects simultaneously has not been examined as closely as it could be. Bimanual dual object control (BDOC) tasks, in which users manipulate one object with each hand, are ubiquitous in everyday life. The potential to open up new and unique interfaces for a variety of applications, such as tele-robotics, remote surgery and advanced visualization, is too significant to ignore. Applications exploiting this form of user interaction could easily be crafted, though it remains to be seen whether or not BDOC interaction is viable.

Through experimentation, the viability of BDOC applications and the mechanisms by which such applications can be optimized for the user experience were determined. During a simple navigation task, parallelization of object movement was shown to improve overall completion time by 40%, but at the cost of movement accuracy and individual completion time. Out of five factors tested in an obstacle dodging task, only differentiating the shape of the subject controlled objects led to improved dodging performance. Several of the factors expected to improve performance in the dodging task actually resulted in decreased performance. Auditory cues originally intended as a warning of incoming obstacles only served to distract subjects. Differentiating the color of the two controlled objects had a negative effect on one of them, but not the other. Changing the time between obstacle appearances had little effect, regardless of the length of time. Finally, placing the subject controlled objects too close together or too far apart had the expected effect of decreasing dodging performance.

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Chapter 1 – Introduction

As two-handed creatures, human beings regularly use two hands to perform a wide array of different activities. Many of these activities require the coordinated effort of both hands. For example, on the surface, writing seems to be an activity which only uses a single hand. A person writing on a piece of paper may only consciously use the hand holding the pen to write. However, the other hand could be used to steady the paper while writing or to move it into a more desired orientation. Clearly, even tasks which appear to only use a single hand may actually use two.

1.1 Problem Explanation

Unfortunately, while these "bimanual" tasks are regularly done without much thought, they are not easy to transfer into a virtual space. There are several issues which need to be addressed during the virtualization of a bimanual task. A primary concern is exactly what kind of bimanual interaction is necessary for the task: symmetric, in which both hands perform a similar function or asymmetric, in which each hand performs a different function. The distinction between these methods of interaction is important in determining the structure of the user interface. It is also a factor in deciding the type and number of input devices used.

There are many ways in which applications incorporate bimanual user interfaces. A typical word processor, for instance, allows a user to type on a keyboard with both hands in a bimanual symmetric task. Alternately, an Internet browser may use both the mouse and keyboard, for navigation and input respectively, in a bimanual asymmetric task. Interfaces which do accommodate two-handed interaction have traditionally been limited in their scope by restricting two-handed input to interaction with a single object or scene. This is typically manifested in the form of orientation through the non-dominant hand and interaction with the dominant hand, though the tasks of each hand could be the same [1].

While there are many instances of bimanual tasks present in the virtual domain, there are still forms of two handed interaction which have been relatively unexplored. In particular, the simultaneous bimanual control of two separate objects, one by each hand, is not well understood. Although this style of interaction is not unheard of in the physical world, applications of this interaction technique in the virtual world are few and far between. Interfaces which incorporate bimanual dual object control interaction techniques could be the stepping stone towards opening up unique and novel applications, ranging anywhere from remote surgery to video game design.

1.2 Research Goals

Simply adding support for a new control scheme to an existing interface does not necessarily mean that the resulting system will be usable [2]. Therefore, it is first necessary to determine whether or not the use of an interface designed to support simultaneous bimanual control of separate objects is actually a viable method in which subjects can perform such an activity. Treatments involving accuracy and reaction time will be used to evaluate subjects' performance in bimanual dual object control tasks.

Controlling two objects requires a significant amount of consideration regarding many elements of the user interface, such as how the objects are displayed. It is essential to see if subject performance in bimanual dual object control tasks can be improved by varying those elements. Similarly, it is important to determine which elements of the interface have a more significant impact than others. Particular interest will be focused on the attentional difficulties present when two objects must be maintained by a subject concurrently and how these difficulties can be alleviated.

Finally, using the results of the previously mentioned research, an outline will be presented for the design of user interfaces which accommodate bimanual dual object control tasks. Best practices for the creation of new user interfaces and individual elements to focus on will also be established. Additionally, pitfalls which can degrade task performance will be noted.

Chapter 2 – Literature Review

While there has been little formal research directly about dual object control techniques, there has been considerable exploration of individual correlated facets. In particular, attentional distribution, visual searching and the relationship between symmetric and asymmetric bimanual tasks are directly applicable. Each of these topics, along with several others, will be examined here in the context of bimanual dual object control applications.

2.1 Traditional Task Classifications

In order to understand the challenges associated with the control of two objects at the same time, it is useful to examine the various methods by which human-computer interaction takes place. Traditionally, interaction tasks have been classified by how the hands are used in those tasks. In general, the spectrum of interaction methods can be broken into three types: unimanual, bimanual symmetric and bimanual asymmetric tasks. Each of these types has distinct characteristics and advantages.

2.1.1 Unimanual Tasks

Unimanual tasks utilize input from only a single hand. A second hand is not involved in the task at all. This leads to some common miscategorizations when it is not clear that a second hand is actually involved in an activity. In particular, when a second hand is used to provide a frame of reference, an orientation or position of an object provided by one hand to facilitate the input provided by the other hand, it may not be readily apparent that the task is actually bimanual.

Simpler in nature, unimanual interaction can be easier to use than other forms of interaction, but it is also considerably limited in capability [3]. By restricting input to only a single hand, unimanual applications can provide a simplified input mechanism, requiring a user to use only a single device [4]. However, a shallow analogy could be made that anything one hand can do, two hands can do doubly so.

Using a simplified input mechanism such as this comes at the cost of requiring more time to complete some tasks. The time required to complete a complex task is increased due to the need to switch input modes [5]. In a seemingly simple alignment task requiring both movement and orientation, a user may be required to repeatedly switch input modes from positional to rotational in order to complete the alignment. This can lead to suboptimal performance when compared to bimanual techniques, since a single hand is performing under several different roles at any given time [4].

There are many activities which can be done using a single hand. Using a mouse in a "point and click" environment, one where a keyboard is not required for input, would be one such activity. A remote control used to operate a television set is another example where unimanual input is used. In both the mouse and remote control cases, the input device is specifically designed to be used by a single hand. Although this can improve interaction performance for unimanual tasks, such tasks can also be performed on devices meant for bimanual input.

2.1.2 Bimanual Symmetric Tasks

Limiting interaction to a single hand, as is the case with the aforementioned unimanual tasks, also limits the extent of the overall interaction complexity. To accommodate some of the more complex interactions, two hands can be used at the same time to work on a task. Two handed tasks are broken into two categorizes. The first, referred to as bimanual symmetric, encompasses tasks in which each hand performs a similar function.

In order to perform in a bimanual manner, both hands need to be able to provide input simultaneously through the same device or a pair of devices. For symmetric input, these devices could be the same or similar. This can be accomplished by using two separate, but similar devices, such as a pair of computer mice [4]. Other devices, a video game controller or the aforementioned keyboard for instance, can allow both hands to interact with a single device in a symmetric fashion. In each situation, actions are independent, but remain coordinated towards a common goal.

There are many real world situations where two hands act in a similar, symmetric way during an activity. Juggling is an obvious example of an activity which requires the coordinated effort of two hands, though it could also be performed solely with a single hand. Another common example of bimanual symmetric physical activities includes playing certain musical instruments, such as the piano or drums. While text entry (i.e. typing on a keyboard) is also a bimanual symmetric task, true computer based symmetric tasks are generally less common. One reason for this is that symmetric tasks logically benefit from having equivalent input devices [3]. Aside from keyboard driven tasks, very few computer applications naturally support symmetric interaction.

2.1.3 Bimanual Asymmetric Tasks

The other set of bimanual interaction techniques are asymmetric tasks. Similar to symmetric tasks, asymmetric tasks also use both hands for input. However, in this case both hands do not need to provide the same kind of input. Instead, each hand can be completely independent in how they move and provide input to an application. Even though each hand performs a different function in bimanual asymmetric tasks, actions are still coordinated towards a common goal, much like symmetric tasks [6]. By allowing each hand to operate not only independently, but in different modes, asymmetric input can accommodate more diverse applications than symmetric input.

Peeling an apple is an example of a common activity where one hand provides a frame of reference for the actions of the other. One hand holds and turns the apple while the second hand peels the skin off. It would be very difficult to peel an apple by using only a single hand due to the lack of a frame of reference and grounding. While some musical instruments fall into the bimanual symmetric category, others require asymmetric interaction. A guitar requires the musician to manipulate the position of the strings with one hand in order to allow the second hand to produce a desired musical note by plucking or strumming the manipulated strings.

2.2 Task Processing

Approaching the design of user interfaces oriented around controlling two objects entails examining how the underlying task is performed. Tasks can be completed in a variety of ways. The method in which a task is completed can be dependent upon any number of factors, including the preference of the user completing the task, the design of the task itself, or even operating constraints existing within the task or the environment in which the task is being completed.

Serial processing is the method by which tasks are broken up into individual steps and completed independently [7]. These steps, or subtasks, may have dependencies on the order in which they are performed, such as sequential processing restraints, but this is not a necessarily the case for all tasks. Users are able to complete the current subtask independently of any other, allowing them to focus on only that portion of the overall task. Consider the sequence of steps that a normal person may follow to begin a car trip. It would be logical to assume that one would need to unlock the car, open the door, sit in the driver's seat, close the door and put on a seatbelt before even turning the vehicle on. Each of these actions is independent or semi-independent of each other, yet there is a sequential constraint which prevents some of them from being performed either in conjunction with, or before others. The driver could not put the seatbelt on before he or she sits down in the driver's seat. Likewise, the driver could not open the car door before it is unlocked. Processing tasks or subtasks in a serial manner may be required in order to accommodate certain conditions, such as the sequential constraint on entering a car, or a more complex aircraft landing maneuver [8].

Conversely, when parallel processing is used to finish a task, a user may perform two or more individual portions of the task simultaneously. Continuing with the car example, a driver who shifts gears while simultaneously turning a steering wheel, possibly in preparation to handle an upcoming curve, would be an appropriate example of a parallel task. Each of these segments, shifting gears and turning the steering wheel, could be done individually. However, performing these actions in a serial fashion might not be as efficient, or as in this case, as safe as performing them in parallel [8].

The distinction between operating in a serial mode versus operating in a parallel mode becomes important during the design of an interface supporting the manipulation of multiple objects simultaneously. Serial and parallel tasks each have their own advantages, but it would be naïve to treat them in isolation from each other. Often, it is the case that a task can be performed in either a serial or parallel fashion, and it is left up to the individual performing the task to choose the desired processing mechanism. In other cases, a task may routinely flow back and forth. As subtasks are completed, the available pool of additional subtasks may become exhausted, preventing the user from performing more than one subtask at a time. Likewise, constraints could be introduced into the task environment, requiring that remaining subtasks be performed in a specific order [7].

Hand dominance is an issue which can easily be taken for granted and ignored since most people are right handed. Hence, right handed people tend to design for other right handed individuals, sometimes unintentionally. Right handed bias is prevalent in the designs of things such as scissors and ergonomic mice, though applications exhibit this form of bias as well. This effect can even be seen in the design of a simple keyboard through what MacKenzie and Guiard refer to as the "power keys" [1]. These keys, which include the navigational arrows, insert and delete, among others, are predominantly positioned on the right side of the keyboard.

In the case of asymmetric tasks, hand dominance can lead to situations where the user prefers to use one hand for a specific type of task, while the other hand is used for a different type of task. A common occurrence is for a person to use one hand to position and steady an object, while the other hand is used to interact with that object [9]. In other words, one hand is providing a frame of reference for the other hand to operate within. A frame of reference, while not strictly required, can improve the performance of some tasks [10].

However, the possibility of a frame of reference being provided by one hand for another cannot easily be transferred into symmetric tasks. Necessarily, both hands in a bimanual symmetric task are performing the same or similar functions. In essence, each hand may be expected to provide a frame of reference for itself. Much like unimanual tasks, bimanual symmetric tasks revolving around the independent manipulation of multiple objects may require each hand to constantly switch modes in order to orient as well as interact with an object.

2.3 Attention

The attentional burden of tracking, controlling and interacting with two objects is a considerable concern. While focusing on a particular object, events related to a second object may be missed or misinterpreted by a user. The potential need to track, select and switch between multiple targets raises several attentional issues.

2.3.1 Attentional Blink

A primary concern regarding attention is the attentional blink phenomenon. When two stimuli are received within a small window of time, often the second stimulus is missed. Though the time frame for such missed opportunities is small, attentional blink can occur for stimuli spaced roughly less than a half second apart, it is still a large enough window to cause complications in real-time systems [11-14]. Especially in situations where visual stimuli are rapidly displayed to a user with small intervals in-between, the potential to miss a large number of events is a major concern to interface designers. In some instances, it may be completely unacceptable to miss a single event. A missed collision warning by an air traffic controller, for example, could result in catastrophe [8].

There is a slight anomaly with the attentional blink phenomenon. It appears that the minimum time penalty between events can potentially be decreased through practice.

Green and Bavelier noted during a study on "gamers," people who spend a significant amount of time playing video games, that various aspects of visual attention were improved through practice [15]. Of note, they found that the effect of attentional blink was less for video game players, allowing subsequent targets to be acquired after a shorter period of time [15].

Additionally, while attentional blink is a concern for visual stimuli, the same cannot necessarily be said about auditory stimuli. In experiments, it has been shown that auditory stimuli do not suffer from attentional blink due to the longer amount of time spent processing such events [14]. However, while mixing stimuli, a visual stimulus followed immediately by an auditory stimulus or vice versa, did show a lag effect, the effect could be contributed to the cost of switching sensory modes instead of an attentional blink from cross-modal stimuli events [14].

A similar effect to attentional blink can be seen in the form of simultaneous stimuli suppression [16]. During experiments looking into perceived similarity, subjects were presented with multiple objects and asked if they are similar in various aspects, such as shape, size or color. King noted that when two halves of a circle were presented simultaneously, performance on color differentiation experiments was lower than when the same halves were presented with a small delay between them [17]. Simultaneously displayed colors were also perceived to be more alike, indicating that objects presented at the same time may be difficult for a user to discriminate.

2.3.2 Attentional Distribution

A user performing a task in a complex or crowded environment must choose which stimuli to focus on. In the case where that user must concentrate on multiple sources of stimulation, the user's attention must necessarily be distributed among those sources [18]. Experimentation by Palmer, et al., indicated that attention could in fact be distributed over several distinct locations, but not without consideration for the number of locations [19]. It is more likely that stimuli could be missed with a higher number of areas where attention is distributed. Similarly, performance on multiple concurrent tasks can be degraded as attention is distributed among them or as specific attention is given to a prioritized task [20].

An experiment by Yokoi, et al., centered on the spatial distribution of a subject's visual attention while playing a series of three different video games [21]. Typically in a video game, attention is focused towards the center of the screen. Here, the visual angle for each subject was restricted while playing the series of games. The key result from these experiments is that the area of focus, the amount of the screen which must be available for viewing, required for maximal performance was different depending upon the game being played [21]. However, increasing the available visual angle past 30 degrees did not result in further improved performance over more restricted displays, implying that there is a limit to the area in which attention can be distributed.

2.3.3 Multisensory Integration

As mentioned previously, the effect of attentional blink was not present when switching between visual and auditory stimuli. Though there is a cognitive penalty in switching modes to focus on the different form of stimuli, the prospect of using multiple methods of sensory stimulation for an event may alleviate some of these difficulties as well as those associated with attentional blink [22]. In the meta-analysis by Burke, et al., the combination of visual and either auditory or tactile sensory feedback consistently enhanced the reaction time and performance of users on a wide range of tasks [23].

Providing feedback through multiple senses introduces its own problems. One sensory form of stimulus can affect the perception of another, leading to cases where a stimulus is perceived to originate from the source of a different stimulus [24]. For example, an auditory cue may be perceived as emanating from an object's location as it is positioned visually on a display device, even though the sound may have actually originated from a different location. The positional discrepancy created here could cause problems in tasks where the difference is highly important to the task efficacy. On the other hand, a user's attention can also have a correlation on the effectiveness of multisensory integration. In several experiments, subjects demonstrated improved integration performance when the stimuli were attended [24-26].

2.4 Visual Search

In virtual environments, vision serves as the primary conduit of information regarding the status and relationship of various elements within that environment. Also known as a target acquisition task, the primary goal of a visual search task is for the user to find or track a specified object or event. Visual search tasks have a variety of uses ranging anywhere from obstacle avoidance to recognizing a change in an object's current state. The ease and efficacy with which a visual search task is performed relies on several factors, including the choice of tactics involved in the underlying search and the composition of the environment being searched.

The difference between low-level vision and high-level vision processing has a significant affect on visual searching. High-level vision relies on the ability to focus on a specific task, notice pertinent details and interpret relationships between objects. The use of high-level vision leads to top-down processing: a conscious effort by a user to achieve a particular goal, such as finding an object which meets a certain criteria in a visual scene. Searching in this manner is voluntary guided by the user and requires an understanding of how to accomplish the task at hand [27].

The visual scene must be searched and analyzed to achieve the goal of a searching task. During top-down processing, this can lead to a subtle side effect where visual details of unrelated objects are missed. Cater, et al., found this effect of "inattentional blindness" to be present when subjects were asked to perform a searching task, counting pencils, in an animated scene [27]. Participants who only watched the animation and were not asked to perform the searching task were better able to recognize and recall details about the scene, including the color of certain objects unrelated to the searching task and the overall level of detail of the scene. Although this could be useful during sequences where unimportant or irrelevant objects could be rendered with less precision, situations where multiple tasks must be performed within the scene could lead to degraded performance as the scene may need to be researched for each different task [27].

While top-down processing requires a cognitive effort to focus on a task and analyze how the visual scene relates to it, bottom-up processing uses reactionary low-level vision responses. Low-level vision elicits involuntary responses to salient visual stimuli, conspicuous visual effects such as color or movement, leading to the eye being drawn towards that stimulus [28]. Intentionally using salient stimuli could be valuable in efforts to draw a user's attention toward a particular object or warning as deemed necessary for an application [29]. During dual object control tasks, this technique could be used to alert a user of an important event happening or about to happen to one object, such as an impact, when the user is focusing on the manipulation the other object.

The reactionary nature of low-level vision can lead to an undesired effect when the visual search task requires examination of a crowded or chaotic scene. In this case, non-target objects, which are usually meant to be unattended, can gain the focus of the user and become distractors. Duncan and Humphreys theorized that visual search difficulty is directly related to the perceived similarity of targets and distractors [30]. When the similarity between targets and distractors increases, search performance decreases. The task performance penalty of distractors can be reduced if they are visually or audibly distinct from target objects or objects of greater importance in a task. Specifically, varying the color between targets and distractors can lead to improved target acquisition performance, even if the colors of the targets differ from one another [11].

Lavie and Cox propose a unique view on search efficiency and distractors. They state that improving the efficiency of target selection does not necessarily result in a positive benefit. Through experimentation, increasing the efficiency of a letter searching task resulted in reduced efficiency in ignoring distractors [31]. This seemingly paradoxical result is explained due to the excess amount of processing ability present when target acquisition was more efficient [31]. As the difficulty of finding the visual target increased, there was less processing overflow to the distractors.

Motion blindness is also a side effect of a visual searching task which has similar consequences as attentional blink. Like attentional blink, motion blindness causes information, object motion, to be missed. However, in the case of motion blindness, the loss of information is due to the inhibition of perceived distractors. As a user's focus is directed towards looking for a particular event or target, irrelevant distractors are ignored. Similarly, the motion of the distractors is also inhibited. The overall effect of motion blindness, the time between inhibiting a distractor and recognizing its motion, has also been found to be related to perceptual load of the user [12]. Consequently, as more potential distractors are introduced and the perceptual load increases, the effect of motion blindness increases. The presence of an inhibited distractor is required for motion blindness to have any effect. If an object in motion is currently being tracked and not inhibited, then the effect of motion blindness disappears [12].

2.5 Task Training

There are many different approaches to learning and practicing a task. Initially, a decision must be made regarding whether the whole task will be learned and practiced or only a part of the task will be practiced at any given time. The method which is used to practice a task can have a drastic impact on that task's performance.

2.5.1 Part Task Training

As detailed by Wightman and Lintern, there are three methods of separating whole tasks into their partial task counterparts [32]. Fractionation is the most straightforward method of part task training and involves tasks which can be decomposed into at least two operationally independent subtasks. Each of these subtasks is then practiced independently of each other. In the case of bimanual tasks, decomposition could occur between hands. One hand could perform the actions of one subtask while the second hand independently performs the actions of a second subtask, as is commonly done while practicing the piano. However, completing or practicing the whole task may require preserving dependencies between the subtasks, something which cannot typically be done during part task training [32, 33].

Fractionation could be thought of as separating operationally parallel task constructs, such as shifting gears while holding in a vehicle's clutch. An alternative way of breaking down a task into parts is to look at it as a series of smaller tasks. Segmentation separates such operationally serial tasks into segments which would normally be performed in succession. During practice, more difficult or critical segments could receive more focus. A pilot, for instance, is likely to need to practice take-off and landing procedures in a simulator more often than maintaining a cruising altitude [8, 34]. Segmentation would allow the pilot to practice just the portion of the overall flying task which is most important.

Merely breaking a task into different components, as the fractionation and segmentation methods do, might not be useful or possible in some circumstances. In these cases, complicated tasks could possibly benefit from a simplification process. Tasks can be simplified by reducing the number of elements in the working environment, removing certain performance requirements, or in other ways which make the task easier or faster to practice. This process has the benefit of being able to tailor the task to a user's ability by adjusting the difficulty of the practiced task as necessary, allowing the practice to be more transferable to performing the actual whole task [8, 35].

An additional complication during part task practice is determining the order in which the parts are practiced. One method, blocking, involves always practicing the parts in a specified order. Blocking reinforces an entire task structure and can sometimes lead to better performance on a specific structured task [7]. Alternatively, random practice may use portions of a task which are out of order or have several task items mixed. Instead of reinforcing the mechanics of a particular series of tasks, as blocked practice does, random practice reinforces the core elements which make up a task and can lead to better understanding of the task elements [36].

2.5.2 Bimanual Part Task Examples

The mechanics of bimanual offbeat rhythmic tapping tasks have been studied extensively [37-39]. Offbeat tapping, where one hand taps at a different beat spacing than the other, is an extremely difficult task to perform due to the tendency of one hand to mimic the beat spacing of the other [37]. When practicing, a person might decide to practice maintaining the offbeat rhythm with both hands at the same time or could choose to practice each hand individually.

While not strictly a bimanual only task, the act of driving is also an example of a task which could be decomposed into individually practicable subtasks. At its base, driving is made up of two parts: steering and acceleration control. The steering mechanic entails the driver turning the steering wheel to manipulate the path of the vehicle. If the vehicle is a manual transmission, acceleration control may require operation of a gear shift and clutch, turning the acceleration subtask itself into one which could be further decomposed to separate the gear shifting complexities of driving. All parts of this task, steering, acceleration and gear shifting, must be carefully coordinated during an actual driving experience, even though they may be practiced in isolation.

Playing the piano is also a task which can also be decomposed into fractionated left and right handed parts. The parts for each hand could be practiced individually and then reintegrated for a full performance. In this manner, it is common for a pianist to practice a difficult portion of a musical score independently of the rest of the piece. Practicing in a segmented manner such as this could afford the pianist much needed improvement in a particular area, while reducing the time spent practicing unnecessary segments.

2.5.3 Whole Task vs. Part Task Training

It is generally held that whole task training, practicing an entire task as it may normally be performed, is preferred and results in better performance [7, 33, 38, 39]. Particular tasks may require intricate relationships between subtasks to be maintained at all times. Practicing subtasks individually, part task training, may be inconsequential if the maintenance of the relationships between the subtasks is not also practiced [40]. Although it is possible to practice either steering or acceleration control individually, for example, the dependent nature of the two actions necessitates that both of them be performed concurrently during a real driving task. The costs of dividing a task into parts and the subsequent reintegration of those parts may outweigh any benefits gained from the part task training [33].

However, there are still certain situations which may benefit from part task training. Performance is not always the only factor involved in determining the best practice method. In cases where the cost of simulation time is extraordinarily high, it might be more desirable to focus a trainee's practice on only a specific part of the whole task to maximize the cost-benefit ratio [41, 42]. In other cases, the complexity or randomness of the task itself may dictate that only generic or predetermined conditions can be practiced. An air traffic control task may benefit more from the controller's individual practice of specific scenarios, even if several of those scenarios arise concurrently [8].

2.6 Bimanual Dual Object Control

Much study has been done into efficient endpoint manipulation for two dimensional and three dimensional objects such as lines, curves and boxes. The applications for such tasks can range anywhere from drawing and modeling to simple object grouping and manipulation. Studies have shown that bimanual input, in both symmetric and asymmetric forms, can improve performance times in these kinds of tasks [43, 44].

Though endpoints could be considered two separate objects which must be manipulated for a common goal, this is as close as most research has come to examining the issues related to bimanual dual object control. Wilson and Agrawala's research into using a dual joystick configuration in a virtual typing task has shown that such an input scheme has the potential to improve user performance [45]. However, the improvements over single joystick text entry seen in this particular case cannot be disambiguated from the effect that the shorter travel distances for the dual cursors has on performance. A complimentary study was performed using an alternate form of symmetric joystick typing input. In this second study, one joystick selected a 3 x 3 "zone" of letters, while the other joystick selected the actual letter to be typed [46]. Though the interaction could be classified as bimanual symmetric input, in essence, one joystick provided a frame of reference for the other. While no formal comparison has been made between the two studies, the topic deserves future consideration.

Hinckley, et al., describes a neurosurgical visualization task which demonstrates an actual bimanual dual object control application. The use of one input device, a doll's head "prop" signifying the patient's brain, provided a frame of reference for the other, a plastic plate used to orient a virtual cutting plane [47]. Though the authors only considered the fact that one input device, the doll's head, provided a frame of reference for the other, the actual usage of these two devices clearly shows a bimanual dual object control situation. The orientation of either the brain or the cutting plane was directly controlled by the orientation of the appropriate input device, both of which were tracked in 3D space. In this case, the input devices used and the application itself were highly specialized. Further research by Rhijn and Mulder suggest that devices closely related to the input task, such as rotational orientation controlled by a spinning knob, leads to best subject performance [48]. The question remains as to whether or not this can transfer into an application using generalized input devices, such as a pair of mice of a dual joystick controller.

Some potential concerns are raised over the possibility of decreased performance during bimanual dual object control tasks. During a series of "dual task" experiments containing both a bimanual coordination task and a reactionary task, both tasks were shown to suffer when performed simultaneously compared to when they were performed individually [20]. An interference effect was found to occur between the coordination and reaction tasks, though it was also shown that performance of the coordination task improved when subjects were instructed to focus their attention on the task. While the bimanual portion of this task was coordinated, the possibility of interference between objects during a bimanual dual object control task is likely. It remains to be seen whether or not attentional focus on one object can temporarily override the interference effect.

Chapter 3 – Problem Approach

As Beaudouin-Lafon states, it is necessary to design for the mechanism of interaction, not just the interface [49]. Certain activities lend themselves well to a specific type of interaction. It would make little sense to force a user to use two hands in a task which is best performed in a unimanual fashion. Likewise, a task which is best done with two hands should not be restricted to only one.

It has been suggested that users are willing and able to perform in a bimanual fashion even when they are not asked to do so [50, 51]. Unfortunately, little formal research has been performed in the specific domain of bimanual dual object control tasks. Therefore, it is beneficial to determine whether or not a dual object control application benefits from the introduction of a compatible input structure. Once this question of viability has been answered, then the question of how to best design a user interface to facilitate this type of control can also be addressed.

3.1 Object-Input Model

The organization of tasks into bimanual and unimanual forms has been beneficial for improving how people use computer applications. By understanding the strengths and weaknesses of one and two handed interaction techniques, appropriate design accommodations can be made to better represent certain interactions. It is clear that the distinction between bimanual symmetric and bimanual asymmetric interaction presents a problem when trying to classify situations where a user is controlling two objects simultaneously. At any given time, a user could be performing in either a symmetric or asymmetric mode, possibly even switching back and forth. Such activities could not reasonably be categorized as merely symmetric or asymmetric. Strictly focusing on the differences between using one hand and two in this manner does not completely account for all of the facets of virtual object interaction.

For bimanual dual object control tasks, it becomes necessary to view input from a different classification perspective and shift focus to the objects, while also maintaining the importance of the hands. Here, a new *Object-Input* model of interaction classification is introduced. This new model is not intended to supplant the current unimanual/bimanual method of interaction classification. Instead, the Object-Input model is meant to provide an alternate perspective in which interfaces can be viewed and designed. The traditional view of the handedness of an application is augmented with a new emphasis on the number of objects being interacted with.

3.1.1 "Object-Input" Definition

As previously mentioned, the Object-Input model focuses on both the objects in the environment which can be interacted with and the actual input to those objects. "Input" refers to any possible method of interaction with an object, including, but not limited to: changing orientation or position information and directly providing input to the object through other means such as pressing a button on the object or cycling through a color palette.

The difference between single and dual input classifications denotes whether a task uses one or two hands respectively. This is not to be confused with applications which allow a user to provide multiple forms of input simultaneously. An application which accommodates multi-digital input could potentially allow a single hand to interact with multiple objects or provide multiple distinct inputs to one object concurrently [52].

Regardless of the limit or extent of each hand's interactive capability with an object, the focus of the Object-Input model is on the relationship between the number of hands and the number of objects in an application environment. Because of this new shift in focus, the previous problem with disambiguating tasks which encompass both symmetric and asymmetric components can be avoided.

There are four primary classifications in the Object-Input model. These classifications are organized by both the number of objects which can be interacted with, single or multiple, and the handedness of the application, single or dual. Additionally, specializations of the multiple object classifications are possible to accommodate specific situations involving x number of objects, where x is greater than one. In all instances, the objects being interacted with can be the same, similar or completely different. A summarization of the classifications in the Object-Input model is shown in Table 3-1.

Table 3-1: Object-Input classifications.

Classification	Objects	Inputs
Single Object, Single Input (SOSI)	One	One
Single Object, Dual Input (SODI)	One	Two
Multiple Objects, Single Input (MOSI)	Multiple	One
Multiple Objects, Dual Input (MODI)	Multiple	Two
Dual Objects, Dual Input (DODI)	Two	Two

3.1.2 Single Object, Single Input (SOSI)

The most reduced of the object interaction methods utilizes only a single object and a single hand for input. Many unimanual tasks follow this model of interaction by limiting the number of objects which can be dealt with at any given time. On the surface, it would be logical to try to fit all unimanual tasks exclusively to this model of interaction. However, it is important to realize that not all unimanual tasks are also *single object, single input* (SOSI) tasks. On the contrary, there are many cases where a user needs to control more than one object, but only has the ability to use one hand to do so. For example, a person playing virtual chess must move many pieces over the course of a game, but may be restricted to just using a mouse to make those moves. This would instead be a case of a *multiple objects, single input* (MOSI) model which is discussed below.

SOSI tasks typically encompass simplistic and limited interactions. Drinking from a glass would be one example. Only a single hand is necessary in order to interact with the glass. Similarly, turning a doorknob to open a door also requires only a single hand. In both of these examples, both hands could be used for extra stability of strength, changing them into single object, dual inputs tasks. Though these are simple examples, more complicated SOSI tasks are possible, such as controlling the movement of an avatar through a virtual environment with a one handed joystick.

3.1.3 Single Object, Dual Inputs (SODI)

A common occurrence is for a person to be able to use both hands to manipulate an object. Peeling an apple, writing a letter and 3D modeling have all been mentioned previously as examples of physical bimanual applications. In each of these examples, one hand provides a frame of reference for another as would be the case for many bimanual asymmetric tasks. Larger objects, such as a box or a pole, may require both hands to guide their orientation and movement, which would similarly equate to a bimanual symmetric task [53]. Under the Object-Input model of classification, each of these bimanual tasks are considered *single object, dual inputs* (SODI) tasks, as they utilize two hands and interact with a single object.

Opening a bottle of water demonstrates a SODI task. One hand must orient and ground the bottle while the second removes the cap. As an extreme counter example, take the case of a baseball player holding a bat. The exact method in which a bat is held depends on the left or right-handedness of the batter. However, a baseball bat is typically held and swung using both hands, which adds stability and control over the arc of the swing. Even though in the first case a frame of reference for the bottle was provided by one hand and in the second Guiard's kinematic chain theory was demonstrated using both hands to manipulate the bat, each of these tasks fall under the SODI classification [53].

3.1.4 Multiple Objects, Single Input (MOSI)

Interacting with multiple objects has many similarities with single object interaction when only one hand is involved. With the introduction of additional objects, users now need to deal with switching between those objects in addition to other interaction concerns, such as changing the mode of input from positioning to scaling. When limited to the input of a single hand, objects can only be interacted with in either a serial fashion, one at a time, or in groups. This new concern over how to deal with *multiple objects, single input* (MOSI) situations can cause complications as the user needs to process extra information regarding the additional objects, as well as determining the order of interactions for all objects and how to switch between them.

Playing chess or checkers, among other board games, is an example of this type of interaction. Players generally only need to move one piece at a time even though there are many candidate pieces which could be moved. In the case of capturing a chess piece, a player could also be expected to manipulate more than one piece at a time, as the captured piece could be removed from the board at the same moment as the capturing piece is moved.

3.1.5 Multiple Objects, Dual Inputs (MODI)

The final main category of Object-Input interaction includes tasks which use several objects and utilize both hands for input. Tasks which use more than two objects may require some form of object delegation as a user needs to determine which objects are currently being interacted with and what form of interaction needs to take place for each of those objects. Merely changing one of the currently controlled objects can be a challenge depending upon the attentional demands of the task or each object. Once again, interaction can take place between objects individually, or they could be grouped together. In this fashion, each hand could control an arbitrary number of objects. Additionally, situations in *multiple objects, dual inputs* (MODI) applications could be present where one hand is providing a frame of reference for a group of objects being interacted with by the other hand.

An experienced juggler could be capable of keeping many different objects in the air at the same time while also changing the flight patterns of those objects. At any given time, each hand may only be interacting with one object individually, but the juggler needs to be aware of the current positions and trajectories of all of the objects. In the same fashion, a complex control panel, such as one which might be found in a fighter jet, can present the same concerns for the user. The deceptively simple act of shuffling a deck of cards and dealing a poker hand is also a case of MODI interaction. Though shuffling and dealing are normally performed without much thought, this act requires the coordinated effort of both hands to keep track of, and manipulate dozens of cards in a small time span.

3.1.6 Dual Objects, Dual Inputs (DODI)

A specialization of the MODI classification, *dual objects, dual inputs* (DODI) applications deal specifically with the control of two objects. Handling two separate objects at the same time, in parallel, creates an entirely different set of complications than is created when handling multiple objects in series. Depending on the objects and the task at hand, the user's focus could constantly shift from serial to parallel functions. Though the simplest specialization of MODI tasks, DODI tasks can still provide a demanding situation for any user as interaction is not limited to just moving an object. A user could simultaneously move one object while changing the scale of the second. Of equal note, DODI tasks are not necessarily limited to just symmetric or asymmetric interactions. Instead, DODI tasks could require constant switching between interaction modes.

A prime example of a DODI task would be that of remote or tele-operation tasks. In a tele-operation task, users typically use both hands to control two separate effectors in a virtual environment or as physical apparatuses in a different location. These effectors could be robotic arms, surgical instruments or other similarly constructed equipment. Quite often, the corresponding effectors operate in a coordinated effort, such as may be required in a medical procedure.

3.2 Bimanual Dual Object Control Concerns

With the introduction and description of the Object-Input interaction models completed, focus can shift to a subset of DODI applications dealing with the problems involved in controlling two objects simultaneously, one with each hand. Of particular interest is how an interface system can be structured in order to enhance the user's ability to maintain effective control over each of the two objects simultaneously. As with any application, the design of an interface supporting these *bimanual dual object control* (BDOC) tasks is dictated by the purpose of the application. Depending on the application, there are many concerns which may need to be considered:

- Will the objects be able to interact with each other?
- Will there be hazards or obstructions in the environment?
- Is the user under a time constraint?
- Do the objects represent real objects?
- Are both objects operating in the same domain?

The problem comes down to the potential for a user to lose track of one or both objects during the course of performing a BDOC task. This could occur due to any number of reasons. The two objects may be similar enough in shape and size to each other, or to a background object, that the user could confuse one of the controlled objects for a different one. Objects which blend into the background or objects which are difficult to see and follow could be lost by the user, a critical problem in some applications. Another potential problem is that a user could lose track of the state of one object when the other object is the center of focus, subjecting it to possible environmental or entropy hazards.

Several aspects of visual attention could possibly be leveraged to improve bimanual dual object control applications. One of the most important is to ensure that the objects being controlled by the user are easily differentiated from each other and from the environment. Previous research has shown that objects which are similar to each other or to distractors can be problematic [11, 28, 31]. Similarities between objects can range anywhere from shape to size and even color [11, 28, 29]. Ensuring that primary objects (e.g. the objects a user is directly controlling) are distinctive could help prevent confusion between objects as well as making important objects stand out more than others.

Aforementioned problems with attentional blink and motion blindness raise concerns about the temporal spacing of event notifications. If the user is notified of events as they occur, there is a chance for the notifications to be too close to each other. A possible application of this temporal effect is to separate, by time, any effects meant to gain the user's attention. By spacing out such effects, the chance of an attentional blink occurring can be minimized. Unfortunately, the potential also exists for intentionally delayed notifications to be irrelevant by the time they are delivered to the user.

Aside from temporal spacing of attention gathering effects, carefully planning the physical spacing of the objects may also enhance tracking capability. Objects which are allowed to overlap could cause them to commingle and lose their identities [54]. This concept of object crossover could make it more difficult to tell the objects apart. A user controlling two virtual objects might choose to control the rightmost object with the right hand and the leftmost object with the left hand. Controlling two objects in this manner makes it easier to associate hand movements with the virtual object movements. If the movement of the objects causes them to cross, such that the right hand is now controlling the leftmost object and the left hand is now controlling the rightmost object, it could become difficult to properly control either object. Keeping objects from crossing each other may prevent this situation, but the design of an application's environment may stop this solution from being feasible.

Spacing objects too far apart may have a detrimental effect as well, since users must divide their attention between the two objects. From any given point, there is a limited horizontal and vertical field of vision where movement or state changes can be detected [21]. Events occurring outside of the useful field of vision may be ignored or lost. One possible way of stopping this from happening may be to keep objects within a limited frame of movement, relevant to each other's positions.

All of these factors, both individually and when combined together, potentially affect the level of performance during BDOC tasks. The attentional strain of tracking and controlling two objects could result in lower collective performance. Overshooting a target, difficulty avoiding obstacles or increased overhead incurred from switching between objects during serial task processing are just a small sample of detrimental effects.

3.3 Addressing Bimanual Dual Object Control Concerns

The problems listed above are caused by an object losing the attention of a user for various reasons. In order to minimize this risk, it is logical to optimize the ability of an object to gain and maintain the attention of a user as necessary. There are three fields of attention to consider when dealing with computer applications: visual, auditory and haptic. Potential solutions for dual object control tasks in which focus on each of these sensory areas are discussed below.

3.3.1 Visual

Even when multiple senses are being used for interaction, visual references can become the dominant method of feedback to a user [10]. Unfortunately, the heavy reliance on visual feedback leaves the user open to various problems, including: attentional blink, motion blindness, limited area of focus and distractor confusion, among others. In order to minimize the effects of these problems, several visual aspects need to be considered.

Object characteristics have a direct effect on visual searching tasks. The effect of distractors on task completion can be reduced by differentiating them from target objects. Varying the shape, the size or the color of objects could make them easier to discern from one another [11, 30]. In cases where objects are animated or in motion, a difference in movement could also be beneficial.

Adequately separating objects and events is also a key to maximizing the visual domain. Maintaining and enforcing an optimal range for spatially separating objects will help reduce the potential for object confusion. Objects being allowed to be too close together prevent users from discriminating between them. On the other hand, a user may not be able to preserve tracking when objects are allowed to be too far apart and no longer stay in the user's field of vision. Similarly, temporal separation of events and notices is necessary for them to be noticeable by an intended user. Attentional blink and motion blindness can occur when visual events are too close together. However, events which are forced to be delayed to ensure their perceptibility may lose their context in the now current environment.

3.3.2 Auditory

In the realm of a bimanual dual object control task, it is possible to associate certain sounds to certain objects. A user focused on one controlled object may be prone to miss visual cues from the other object. This might not be the case if a sound were used to alert the user to an event. While images of Pavlov's dog may be conjured, the underlying act of associating a sound with an object for enhanced attention gathering capability is a legitimate one. Regardless of where the user is currently looking, a sound cue does not need a relative focal position and can help to direct the user's attention towards a properly associated object. In the same manner as visual effects, if the associated sounds are too similar to each other, then a user may end up confusing the two [55]. Variations in frequency and pitch could be used to help single out each sound.

Spatial separation of auditory feedback works in a similar fashion as visual feedback does. If sounds are placed too close together in a virtual environment, then they can be confused with each other. The physical distance between sounds does not appear to be an issue as it is with the limited field of vision and visual cues. However, placement of sounds can have a detrimental effect if they are perceived to be originating from a different source when multimodal stimulation occurs [24].

It is also helpful that the attentional blink phenomenon, which visual cues are prone to, does not appear to apply to auditory responses due to how sound is processed [14]. Though the conspicuousness of a sound may not be affected by its temporal proximity, there is still the possibility of aliasing effects if sounds are played simultaneously. Since it may be difficult or even impossible to disambiguate sounds heard at the same time, temporal spacing of auditory cues is still necessary.

3.3.3 Haptic

Haptic feedback can be used in the same ways as visual and auditory by providing a method of alerting a user to an event. Vibration, for instance, can be given in multiple variations by changing the intensity, the frequency or even the pattern of vibration. Like sound, the use of haptic feedback does not require a pre-existing focus of attention, instead requiring that direct contact be made between a user and a haptic device [56, 57]. Variable methods of feedback could be used to distinguish events related to a particular object. One pattern or frequency of vibration could be used for events related to one of the controlled objects, while a distinct second pattern could be used for the events of a second controlled object.

A BDOC task could also potentially utilize haptic feedback in a different way. If the capability exists for the user to receive individualized haptic feedback for each hand, such as through the use of two separate devices or a specialized device with multiple locations which can give feedback, then haptic feedback can also be provided on per-device basis. Whenever the attention of the user should be directed towards one of the objects being controlled, the device associated with that object (i.e. the device being used by the user to control the object) could provide a haptic response. In this way, haptic feedback for that device would be correlated to the object controlled by that device.

Timing concerns related to haptic responses have little to do with distinguishing between different stimuli. As the body receives a constant tactile stimulation, the stimulus becomes less potent over time. In order to maximize the usefulness of haptic feedback, this numbing effect must be reduced or eliminated through the use of pulsing techniques.

3.4 Additional Considerations

A question remains as to whether or not Fitts' Law applies to bimanual dual object control tasks [58]. It has been suggested that Fitts' Law is violated during bimanual tasks when movements have differing degrees of difficulty, though the reason for this violation may be due to the attentional distribution present in such tasks [59]. Similarly, differences in the movement speed of two controlled objects may also have an effect on the applicability of Fitts' Law [60]. While performance in aiming tasks is important to consider in the design of bimanual dual object control interfaces, other considerations must also be taken into account.

Input device construction has a noteworthy impact on interface design. Equally important is the proper pairing of an input device to the current activity [61]. Though the use of different types of devices may affect the performance of dual object control tasks, to minimize potential input confusion, identical devices should be used.

Through the use of multi-digital control, a single hand could potentially control multiple objects [52]. Aside from simple grouping, each finger could have the capability to manipulate an object, or multiple objects, individually. The inherent complexity in such a system would unnecessarily confound the examination of general dual object control issues.

It is likely that switching input modes to accommodate various forms of interaction will incur some performance overhead similar to that incurred by switching between bimanual symmetric and asymmetric interaction modes. In a complex dual object control task, it is possible that this switching could occur continuously and have a significant effect on the overall task performance. However, initial experimental emphasis should remain on BDOC tasks limited to symmetric interaction, such as the simultaneous movement of two objects.

Chapter 4 – Experimental Design

Several issues have been raised relating to the viability of implementing bimanual dual object control (BDOC) applications. Separately, the possibility of optimizing BDOC interactions also warrants investigation. The experiments described in this chapter are intended to explore the questions left unanswered by previous work.

There are two basic tasks that will serve as the foundation of the experiments described in the following sections: path navigation and obstacle dodging. While each task will vary slightly depending upon the particular experiment being executed, the underlying structure of each task remains similar. The primary focus of the path navigation tasks was to record the subjects' completion time. Obstacle-dodging tasks were oriented towards tracking the percentage of obstacles successfully dodged as well as the total collision time for obstacles that were not successfully dodged.

4.1 Path Navigation Task

In the path navigation task, subjects were asked to move two objects through a pair of separate paths. Each object needed to be moved independently from a clearly defined start point to an end goal. The paths themselves were constructed such that each object was contained in its own area. The two paths each encompassed half of the visible screen. Three variations of the paths were randomly presented to the subjects: the two separate paths were identical; the two separate paths were mirror images of each other; and the two separate paths had no logical correlation with each other.

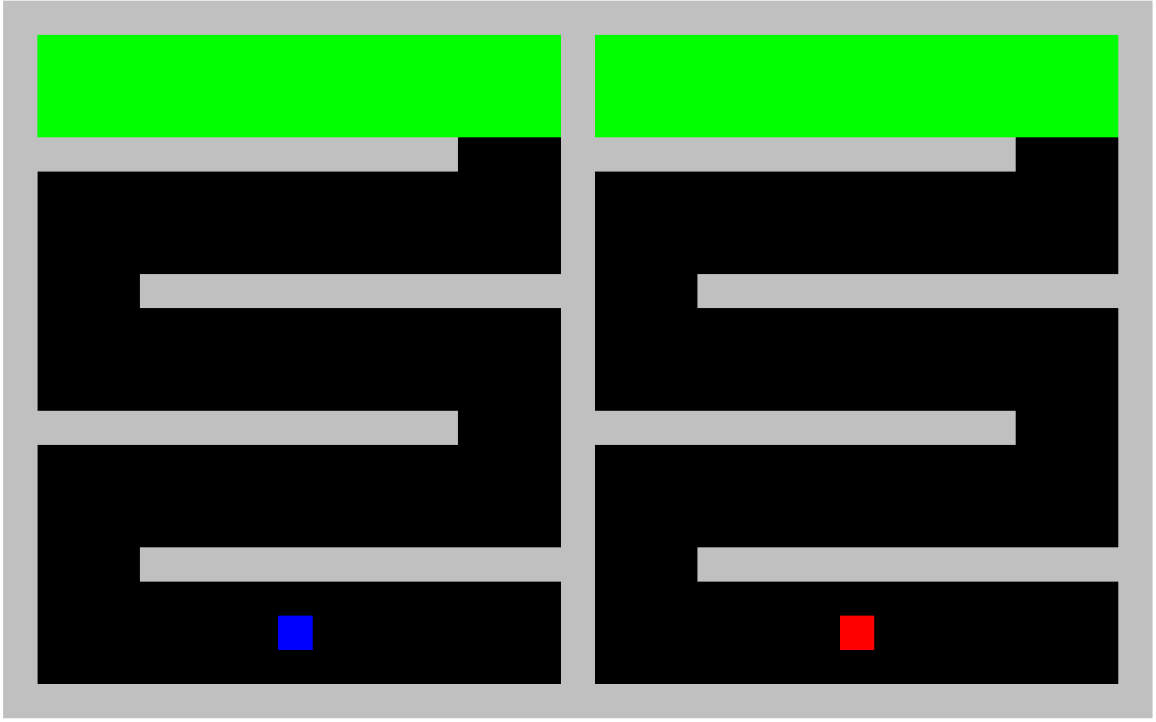
In addition to simply navigating the paths, subjects were instructed to complete the navigation task in the shortest amount of time. The number of object collisions with walls or obstacles during the task was recorded in addition to the completion time. However, subjects were informed that the number of collisions should not be a factor during task completion. When both subject-controlled objects had entered the goal area, the current experimental run was considered complete.

4.1.1 Design Method

The path navigation task was constructed as a within subjects, repeated measures experiment. A single independent variable for this experiment, movement type, was controlled on two levels: serial movement and parallel movement. Subjects were presented with two sets of 24 paths to navigate, 48 paths in total. For the first set of paths, subjects were instructed to navigate exclusively in either serial mode, moving only one object at a time, or parallel mode, moving both objects simultaneously. After completing the first set of paths, the movement mode was switched for the second set of paths. The movement mode order, serial followed by parallel or parallel followed by serial, was counterbalanced across subjects.

A total of 24 different paths were constructed. Each path consisted of a pair of separate areas in which the two subject-controlled objects could move independently of each other. The pair of areas constituting a single path conformed to three different types, identical, mirrored and uncorrelated, with each type having eight distinct instances. Each set of 24 paths presented to subjects was randomized and each subject performed the path navigation experiment using two differently randomized sets, one each for the serial and parallel treatments. An example path layout showing a mirrored path pair can be seen in Figure 4-1.

Figure 4-1: Example path navigation layout.



Subjects were able to move the two objects independently, with each object constantly mapped to one of the two analog joysticks present on the input device used. All object movement was performed at a constant speed, regardless of the amount of exertion used on a joystick. Movement was constrained to prevent objects from passing through path walls and boundaries.

At the beginning of the experiment, subjects were presented with a series of informational computer screens briefly describing the goal of the research and the expectations of their participation. Subjects were asked to move two objects from the bottom of the screen to the green goal area at the top of the screen, while tailoring their performance in order to minimize their individual path completion time. Prior to the first timed path, subjects were given an explanation of the controls and an untimed practice screen. Each path was initiated with the two controlled objects in the same location, near the bottom of the screen, individually centered in their respective path areas. In between navigation paths, subjects were shown a status screen containing the completion time of the previous path. Additionally, subjects were provided the path number on the status screen in order to track their overall progress through the experiment.

Visually, paths were shown as neutral gray boxes representing walls contrasted against a pure black background. Subject-controlled objects were represented by two differently colored squares, blue for the left-hand object and red for the right-hand object. The size of the square was constant throughout the experiment. The thickness of the path walls varied depending on path iteration, but was never thinner than the size of the squares. The distance between walls for vertical movement was kept a constant size for all paths of three times the width of the squares. The distance between walls for horizontal movement varied between two and three times the size of the squares.

4.1.2 Hypotheses

Initially, it is necessary to determine whether or not parallel movement of two objects is a viable mechanism of interaction. The experiment will measure the differences between serial and parallel movement of two objects upon the completion time and accuracy of a path navigation task. The hypotheses for this experiment are as follows:

- Parallel movement will result in subjects completing the path navigation task in less time than using serial movement.
- While cumulative completion time is expected to decrease for parallel movement tasks, movement accuracy, as determined by the number of wall collisions and total time of collision during path navigation, is expected to be worse when operating in a parallel mode.

- Reduced accuracy during parallel movement will also result in the length of individual object completion paths being longer.
- Individual object completion times during parallel movement are expected to be worse when compared to the individual object completion times during serial movement.

4.1.3 Participants

A total of ten volunteers participated in the path navigation experiment. The number of male and female participants was evenly distributed. All participants were right handed and ages ranged between 18 and 24. The self-described video game playing level of the participants ranged from "plays very infrequently" to "plays very often," with the majority of participants playing video games at least weekly. Recruitment was done through flyers posted on the campus of The George Washington University. All participants were paid $10 in compensation for their time. Total participation time was approximately 20 minutes per participant.

4.1.4 Testing Apparatus

An Asus G1S laptop with an Intel Core 2 Duo T7500 processor, 3 GB of RAM, a 15.4" LCD widescreen monitor and running Microsoft Windows XP Service Pack 2 was used for testing. The screen resolution was fixed to 1680x1050 running at 60Hz. A standard Xbox 360 controller connected through USB was used for subject input. An Aiptek Action HD camcorder mounted on a generic tripod was used for videotaping.

4.1.5 Data Collection

During testing, all subject controller input was automatically recorded for later diagnostic playback. Information regarding subject performance was recorded for the following factors: path completion time for the left and right objects individually, total path completion time for the left and right objects combined, path collisions for the left and right objects individually, collision time for the left and right objects individually and path completion length for the left and right objects individually. Subjects were also videotaped in order to capture facial reactions.

4.1.6 Data Analysis

In order to compare completion times, an analysis of the difference of means between serial movement and parallel movement treatments was performed. Using information regarding the minimum possible completion time, the percentage above the minimum for actual completion times will be calculated and compared. Similarly, the percentage above the minimum possible completion length will also be calculated for the actual completion lengths.

4.2 Obstacle-Dodging Task

For the second experiment, subjects were asked to track two visually identical objects and dodge obstacles that moved through the screen. The two objects randomly swapped positions, forcing subjects to mentally keep track of which object was controlled by which hand. Obstacles appeared on the screen in different positions, one at a time, and moved in a straight horizontal or vertical path from one side of the screen to the other. For the top and bottom sides of the screen, there were five possible locations for each side that an obstacle could appear. The left and right sides of the screen had three possible starting locations each. In all cases, the location and size of the obstacle required the subject to move either the left object, right object or both objects from their home locations in order to successfully dodge the obstacle.

Obstacles could potentially be dodged in any of four directions: up, down, left or right. Dodging was initiated by the subject pressing and holding the button indicating the desired dodging direction for an object. This resulted in the corresponding object moving a proportional distance away from the object's stationary position in the direction indicated by the subject. The object returned to the stationary position when the subject stopped providing input.

Unlike the path navigation tasks, the obstacle-dodging tasks were untimed. Instead, subjects were instructed to respond to obstacles as quickly and accurately as possible. Subjects were allowed to correct their initial dodging direction if they felt it was incorrect or erroneous (e.g. an appropriate dodging direction was provided, but for the wrong object). Information regarding the response time and dodging direction(s) were recorded. Each run of an obstacle-dodging task was considered complete when a predetermined number of obstacles were presented to the subjects.

4.2.1 Design Method

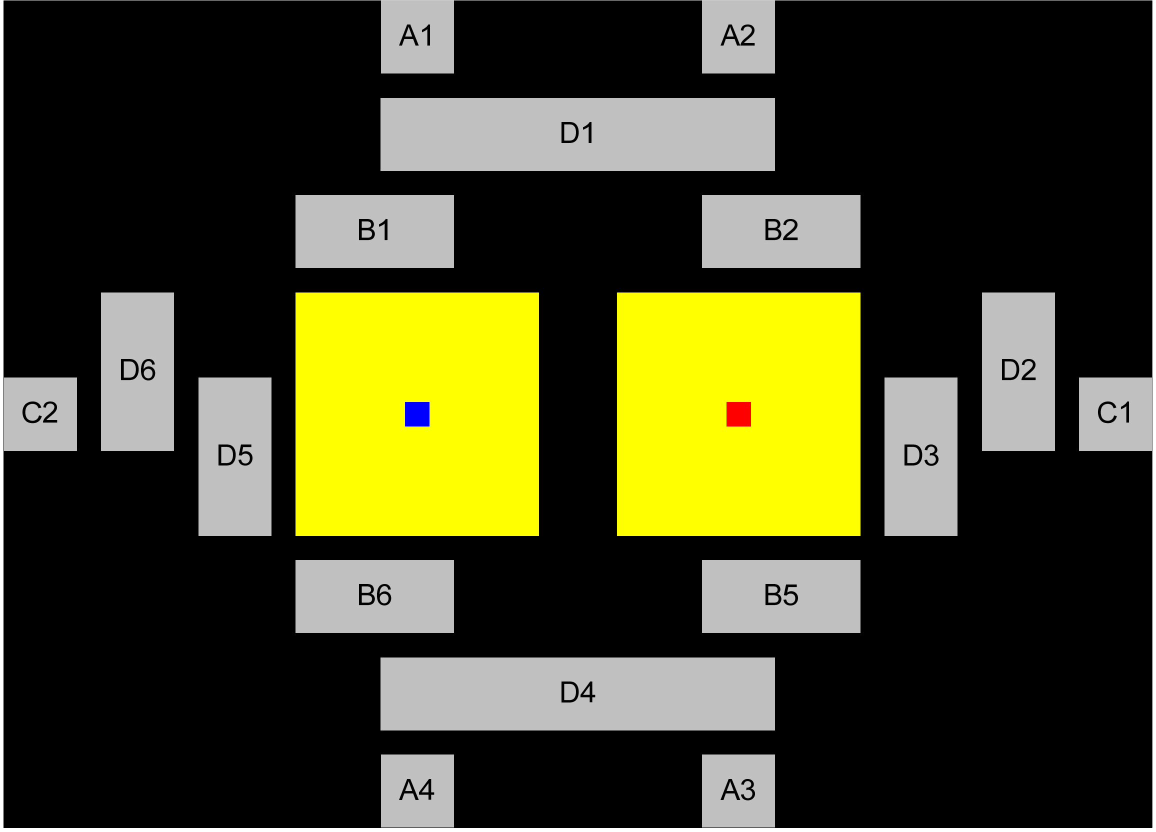
The obstacle-dodging task was designed as a within subjects, repeated measures experiment. Unlike the path navigation experiment, five factors are controlled here: color and shape differentiation for the subject-controlled objects, temporal separation of obstacle appearance, spatial separation of the subject-controlled objects and auditory cues marking the appearance of an obstacle. Of these five factors, two of them had three treatment levels each and the remaining had two levels each. In order to minimize confusion, the auditory cue factor remained constant throughout the experiment for any given subject, with subjects being randomly and evenly assigned to each of the three treatment levels. For the remaining four factors, a total of 24 separate runs were used, providing a full factorial design. A complete replication was also incorporated into the design, for a total of 48 separate runs to be completed by each subject.

The treatments for both color and shape differentiations are two level, with each either being present or absent. The temporal separation factor also had two levels for either a long or short delay between the disappearance of one obstacle and the appearance of the next. Delay time was randomly generated for normal delays between 1000 and 2500 milliseconds and for short delays between 100 and 500 milliseconds. Object spatial separation was controlled on three levels, with objects being spaced normally, close together and far apart. The final factor, auditory cue, also had three levels: no cue, a unified cue when an obstacle was about to appear, and a different cue for each controlled object which was in the collision path of the new obstacle.

Each of the 48 runs consisted of exactly 15 obstacles. There were 16 possible locations for an obstacle to appear: five each for the top and bottom sides of the screen and three each for the left and right sides of the screen. The starting location of the obstacles, as well as the amount of time before the appearance of an obstacle after the previous one had moved off of the screen, was randomly determined. The obstacles were positioned and sized such that the subject would be required to move one or both objects in a particular direction away from their home position in order to successfully dodge the obstacle. Several obstacles required a specific movement to dodge, while others simply required a movement on the X or Y axis to dodge the obstacle.

Figure 4-2 depicts the full complement of possible obstacle sizes and starting locations, with the subject-controlled objects' shown as blue and red squares and their respective movement range shown as yellow squares. While Figure 4-2 shows the obstacles at different distances from the subject-controlled objects, the obstacles initially appeared on the screen edges and moved directly across the screen to the opposite edge. For example, obstacle D1 would appear at the top center of the screen and move straight down until it disappeared off the bottom center of the screen. Obstacle C1 would correspondingly move from the right center to the left center of the screen.

Figure 4-2: Obstacle size and location reference.



Each obstacle prefixed with an "A" intersected with one-third of the movement range of a single object and required the subject to move the object in either direction perpendicular to the obstacle path. Obstacles prefixed with "B" similarly affected a single object, but intersected a full two-thirds of the object's movement range and required movement in a specific direction. "C" obstacles required that both objects be moved in either perpendicular direction, but only crossed a third of each object's movement range. Finally, "D" obstacles required that both objects be moved in a specific direction to dodge by crossing two-thirds of each objects' movement range. The depth of each obstacle was three times the size of the subject-controlled objects.

Subjects were able to move the two objects independently, with each object constantly mapped to one of the two analog joysticks present on the input device used. Movement was constrained to one axis at a time, X or Y, depending on which one had the highest input value. The distance the objects moved from their home position to a maximum positive or negative X or Y position was proportional to the amount of exertion on the joystick of the input device. Objects were returned to their home positions when input from the subject ceased. The home position of the two objects was sometimes swapped after an obstacle left the screen in order to introduce an intentional crossover effect. The swapping occurred randomly to prevent subjects from noticing and adjusting to a set pattern.

At the beginning of the experiment, subjects were presented with a series of informational computer screens briefly describing the goal of the research and the expectations of their participation. Subjects were asked to move two objects in the center of the screen in order to dodge obstacles that appeared on the edges of the screen and traveled in a straight line to the other side. Prior to the first obstacle set, subjects were given an explanation of the controls and an untimed practice screen. Each set was initiated with the two controlled objects in the same location, depending on the spatial treatment used for the set. In between obstacle sets, subjects were shown a status screen containing the dodging rate of the previous set. Additionally, subjects were provided the set number on the status screen in order to track their overall progress through the experiment.

Visually, obstacles not currently being collided with were shown as neutral gray boxes contrasted against a pure black background. When a subject-controlled object came into contact with an obstacle, the color of the obstacle was changed to yellow until the subject-controlled object was no longer in contact with it. Subject-controlled objects were represented differently depending on treatment. For treatments without color differentiation, both squares were displayed in the same neutral gray color as the obstacles. Treatments with color differentiation denoted the left-hand controlled object in blue and the right-hand controlled object in red. The size of the subject-controlled objects was constant throughout the experiment. The shape of the controlled objects varied depending on treatment, with the left hand controlled object always being represented by a square. The right hand controlled object was represented by a square when shape differentiation was absent and by a diamond when differentiation was present.

4.2.2 Hypotheses

The obstacle-dodging experiment will measure the effect of five different factors and whether or not the effect is desirable. Due to the number of factors, there are several hypotheses that need to be addressed. They are as follows:

- Differentiating objects by color during a bimanual dual object control task will reduce obstacle collisions and collision time.
- Differentiating objects by shape during a bimanual dual object control task will reduce obstacle collisions and collision time.
- Separating objects by too great or too short a distance during a bimanual dual object control task will increase obstacle collisions and collision time.
- Separating the appearance of obstacles by a shorter minimum amount of time during a bimanual dual object control task will increase obstacle collisions and collision time.
- Providing an auditory cue when an obstacle is about to appear will reduce obstacle collisions and collision time.
- Providing an individualized auditory cue for each object when a new obstacle appears will reduce obstacle collisions and collision time.
- Over time, average obstacle impacts will be reduced due to a practice effect.

4.2.3 Participants

A total of 21 volunteers participated in the obstacle-dodging experiment. The distribution of participants was 13 male and 8 female. Only two participants were left handed. Ages ranged between 18 and 24 for sixteen of the participants, between 25 and 34 for four of the participants and between 35 and 44 for the remaining participant. The self-described video game playing level of the participants ranged from "plays very infrequently" to "plays very often," with the majority of participants playing video games at least weekly. Recruitment was done through flyers posted on the campus of The

George Washington University. All participants were paid $10 in compensation for their time. Total participation time was approximately one hour per participant.

4.2.4 Testing Apparatus

The same hardware setup that was used in the path navigation experiment is used here. Additionally, a pair of externally powered stereo speakers set at a constant volume was used for auditory cue playback. No other changes were made between the path navigation and obstacle-dodging experiments.

4.2.5 Data Collection

During testing, all subject controller input was automatically recorded for later diagnostic playback. Information regarding subject performance was recorded for the following factors: obstacle collisions for the left and right objects individually, collision time for the left and right objects individually and the number of obstacles collided with per set. Subjects were also videotaped in order to capture facial reactions.

4.2.6 Data Analysis

An analysis of variance (ANOVA) was used to determine the significance of each independent factor. The effect of each significant factor was evaluated for desirability. Two and three factor interaction effects was calculated for significance and interactions found to be significant was evaluated for effect desirability. For the practice effect, a simple analysis of mean performance over time was used.

Chapter 5 – Path Navigation Task

Subject participation resulted in 10 different test sets, with each set containing a collection of 48 individual tests. A total of 480 tests were collected and a simple analysis of the difference of means between serial movement and parallel movement treatments was performed. Due to the sample size, statistical significance was not examined. Effects are broken down into four different categories of dependent variables: completion time, both for each individual object path and the pair as a whole, individual path collisions, total time of collision and completion length.

5.1 Completion Time

The individual completion time for each subject-controlled object, as well as the total combined completion time for both objects, was recorded for each path. During serial movement treatments, individual time for the first object was calculated from the moment the path was displayed until the object had completely entered the goal zone. The time for the second object began the moment the first object had completed its path and continued until the second object had completely entered the goal zone. For parallel movement treatments, individual time was calculated from the moment the path was displayed until an object had completely entered its goal zone. Total time was calculated from the moment the path was displayed until both objects had completely entered their respective goal zones.

Statistics are displayed in Table 5-1 for the total completion time in milliseconds. Average time of completion for a pair of paths was 5.9 seconds during parallel movement tests. Serial tests had an average completion time of 9.9 seconds for a path pair. Because each path had a different optimal completion time, times were normalized by comparing the percentage difference between the optimal completion time and the actual completion time. A normalized completion time of 1.0, for example, would indicate that the actual completion time was twice the minimum possible completion time. Table 5-2 shows the average percentage above minimum for each individual object path as well as the total time of completion. Both serial and parallel movement times are shown in the table. Average left and right object performance for parallel tests is very similar, with each actual completion time being approximately 41% above minimum. Serial performance was also similar, with the left object averaging 24% above minimum and the right object averaging 23% above minimum. Total completion time resulted in an average 43% and 23% above minimum for parallel and serial tests respectively. It should be noted that the negative minimum time displayed for the right object during serial movement indicates that there was at least one occurrence where a subject did not completely finish one path before beginning the other.

Table 5-1: Total completion time data.

Mode	N	Mean	Median	StDev	SE Mean	Minimum	Maximum
Parallel	240	5892.1	5707	1370.3	88.5	3216	11000
Serial	240	9907	9714	1930	125	5994	15418

Table 5-2: Percentage above minimum time data.

Type	Mode	N	Mean	Median	StDev	SE Mean	Minimum	Maximum
Left	Parallel	240	0.4155	0.3714	0.2228	0.0144	0.0979	2.067
	Serial	240	0.24381	0.22318	0.11448	0.00739	0.04168	0.77265
Right	Parallel	240	0.4118	0.3801	0.216	0.0139	0.1236	2.0951
	Serial	240	0.22602	0.20793	0.12613	0.00814	-0.01423	0.61846
Total	Parallel	240	0.4287	0.3875	0.2215	0.0143	0.1236	2.0951
	Serial	240	0.23488	0.22398	0.10426	0.00673	0.0263	0.69555

5.2 Path Collisions

Object collisions with a path wall was measured from the time that the object first came in contact with a wall until it left contact with that wall. Continuous collisions were counted as a single event. An object could collide with one or more walls multiple times during a single path.

Information regarding the number of collisions for the path navigation experiment is shown in Table 5-3. Discrete collisions per parallel test averaged 6.4 for the left object and 6.2 for the right object. Collisions for serial tests averaged 5.8 for the left object and 6.0 for the right object.

Table 5-3: Path collision data.

Type	Mode	N	Mean	Median	StDev	SE Mean	Minimum	Maximum
Left	Parallel	240	6.396	6	2.312	0.149	1	15
	Serial	240	5.75	6	2.328	0.15	0	11
Right	Parallel	240	6.163	6	2.109	0.136	2	11
	Serial	240	5.946	6	2.247	0.145	0	13

5.3 Collision Time

Collision time for the path navigation task was computed as the number of frames where a subject-controlled object was in direct contact with a path wall. Each frame was equivalent to 2 ms of wall clock time, or 500 frames per second. Continuity of the individual collisions had no effect on the total time of collision.

Results related to the total collision time are shown in milliseconds in Table 5-4. Average collision time for the left object was approximately 1658 ms for parallel movement. The right object had an average time of 1928 ms during parallel tests. Serial tests saw an average collision time of 854 ms for the left object and 1306 ms for the right object.

Table 5-4: Path collision time data.

Type	Mode	N	Mean	Median	StDev	SE Mean	Minimum	Maximum
Left	Parallel	240	1657.8	1398	1026.6	66.2	16	5624
	Serial	240	854.4	744	551.8	35.6	0	2970
Right	Parallel	240	1928.2	1911	1097.6	70.8	180	6886
	Serial	240	1306.4	1180	876.2	56.6	0	4718

5.4 Completion Length

The length of a completed path was tracked as the number of pixels traversed by an individual object from its starting point until it was completely within its respective goal area. Actual completion time had no effect on the length of the completion path. Similar to path completion times, different paths had different optimal completion lengths. As such, individual completion lengths were also normalized as percentages above the minimal possible length.

Table 5-5 shows the percentage differences for completion lengths in the path navigation task. The average percentage difference for parallel movement was 50% for the left object and 47% for the right object. Serial movement resulted in an average difference of 44% and 45% for the left and right objects respectively.

Table 5-5: Path completion length data.

Type	Mode	N	Mean	Median	StDev	SE Mean	Minimum	Maximum
Left	Parallel	240	0.49605	0.47101	0.14501	0.00936	0.23954	1.05853
	Serial	240	0.44472	0.42678	0.11041	0.00713	0.22655	0.76532
Right	Parallel	240	0.47082	0.45031	0.12375	0.00799	0.18038	0.85144
	Serial	240	0.44673	0.42432	0.12557	0.00811	0.20841	0.83737

5.5 Analysis

On cursory glance, it is clear to see that the average completion time for the path navigation tests were lower when subjects moved both objects in parallel. While not quite half of the completion time for serial movement tests, parallel movement resulted in a 40% reduction in completion time averaged across all test sets. This is a substantial difference between the two and shows that there is merit in further examination of parallelizing tasks.

Individual collisions for serial and parallel tests were comparable, with serial movement having a slightly lower collision rate for both the left and right objects. Total time of collision, however, showed a large difference between the two movement modes. Parallel movement resulted in a 50-100% increase, depending on the object, in collision time compared to serial movement. A potential explanation for this large increase is due to the decreased focus on any one object when a subject's attention was split. Completion length showed a similar tendency as collision time and collision rate, with slightly worse performance for parallel movement.

For the path navigation task, parallel object movement showed a distinct advantage for absolute completion time. Even so, this improvement for paired completion time comes at the cost of individual completion time and accuracy. While the performance loss for individual collisions and completion length are minor, the increase in individual path completion time was much larger. Though subjects were not specifically instructed to complete both portions of a path in tandem, a possible explanation for this is the tendency of some subjects to stop the movement of one object in order to allow the other object to perceivably catch-up and complete the path at the same time. While two-thirds of the path pairs had identical minimum completion times, leading to closely spaced subject completion times for each part, the remaining third with disparate minimal completion times also exhibited similar closely spaced performance.

Chapter 6 – Obstacle-Dodging Task

The obstacle-dodging task examined several factors. Subject participation resulted in a total of 21 different test sets, with each set containing a collection of 48 individual tests. A total of 1008 tests were analyzed using a general linear model. The five main factors were examined, along with two and three factor interactions. Effects are broken down into two different categories of dependent variables: the number of discrete collisions, both per test and per object for each test, and the total time of collision for each object individually.

6.1 Obstacle Collisions

Collisions in the obstacle-dodging experiment were tracked and calculated in two separate ways: independent occurrences of a collision with a subject-controlled object and whether or not a particular obstacle collided with either object. A single collision encompassed the entire time that an obstacle came in contact with an object until it left contact with that object. One obstacle could collide with the same object multiple times, if the subjects' movement was especially erroneous. A general linear model was used to analyze single factors, as well as two and three factor interactions. Of the five original factors, temporal separation was found to be insignificant for left object collisions, right object collisions and total obstacle collisions.

As shown in Table 6-1, each of the remaining factors, except for auditory cues, was very significant in regards to the number of collisions with the left object. Respectively, color differentiation, shape differentiation and spatial separation had values of $F_{(1, 968)} = 13.04$, $F_{(1, 968)} = 14.02$ and $F_{(2, 968)} = 53.20$ for $p < 0.001$. All of the two factor interactions involving shape differentiation were very significant, with $F_{(1, 968)} = 13.69$ for interactions with color differentiation, $F_{(1, 968)} = 10.90$ for interactions with temporal separation, $F_{(2, 968)} = 6.82$ for interactions with spatial separation and $F_{(2, 968)} = 4.61$ for interactions with auditory cue variations, each for $p < 0.001$. An additional two factor and a three factor interaction were also found to be significant.

Table 6-1: Left object obstacle collision data.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Color	1	26.358	26.358	26.358	13.04	0
Color*Shape	1	27.668	27.668	27.668	13.69	0
Color*Shape*Spatial	2	3.77	3.77	1.885	0.93	0.394
Color*Shape*Temporal	1	0.168	0.168	0.168	0.08	0.773
Color*Spatial	2	17.389	17.389	8.694	4.3	0.014
Color*Temporal	1	0.287	0.287	0.287	0.14	0.707
Cue	2	11.341	11.341	5.671	2.81	0.061
Cue*Color	2	5.365	5.365	2.683	1.33	0.266
Cue*Color*Shape	2	15.722	15.722	7.861	3.89	0.021
Cue*Color*Spatial	4	4.236	4.236	1.059	0.52	0.718
Cue*Color*Temporal	2	2.437	2.437	1.218	0.6	0.548
Cue*Shape	2	18.627	18.627	9.313	4.61	0.01
Cue*Spatial	4	15.581	15.581	3.895	1.93	0.104
Cue*Temporal	2	0.984	0.984	0.492	0.24	0.784
Shape	1	28.334	28.334	28.334	14.02	0
Shape*Spatial	2	27.579	27.579	13.79	6.82	0.001
Shape*Temporal	1	22.025	22.025	22.025	10.9	0.001
Shape*Temporal*Spatial	2	1.175	1.175	0.587	0.29	0.748
Spatial	2	215.056	215.056	107.528	53.2	0
Temporal	1	0.834	0.834	0.834	0.41	0.521
Temporal*Spatial	2	10.484	10.484	5.242	2.59	0.075
Error	968	1956.532	1956.532	2.021		

Collision analysis for the right object is tabulated in Table 6-2. Shape differentiation, $F_{(1, 968)} = 20.60$ for $p < 0.001$, and spatial separation, $F_{(2, 968)} = 52.05$ for $p < 0.001$, were the only single factors to have significant effects. Similar to the effects on the number of left object collisions, the only very significant two factor interactions are those which involve shape differentiation. Interactions between shape differentiation and color differentiation, $F_{(1, 968)} = 20.60$ for $p < 0.001$, temporal separation, $F_{(1, 968)} = 19.01$ for p

< 0.001, and spatial separation, $F_{(2, 968)} = 8.60$ for $p < 0.001$, were also very significant here, though interactions between shape differentiation and auditory cue variation were not found to be significant for the right object. Several other two factor interactions were found to be significant, but no three factor interactions were significant.

Table 6-2: Right object obstacle collision data.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Color	1	3.223	3.223	3.223	1.62	0.203
Color*Shape	1	40.882	40.882	40.882	20.6	0
Color*Shape*Spatial	2	6.704	6.704	3.352	1.69	0.185
Color*Shape*Temporal	1	0.223	0.223	0.223	0.11	0.737
Color*Spatial	2	21.256	21.256	10.628	5.36	0.005
Color*Temporal	1	16.509	16.509	16.509	8.32	0.004
Cue	2	6.151	6.151	3.075	1.55	0.213
Cue*Color	2	9.214	9.214	4.607	2.32	0.099
Cue*Color*Shape	2	2.437	2.437	1.218	0.61	0.541
Cue*Color*Spatial	4	4.548	4.548	1.137	0.57	0.682
Cue*Color*Temporal	2	0.071	0.071	0.036	0.02	0.982
Cue*Shape	2	5.746	5.746	2.873	1.45	0.236
Cue*Spatial	4	31.159	31.159	7.79	3.93	0.004
Cue*Temporal	2	1.365	1.365	0.683	0.34	0.709
Shape	1	40.882	40.882	40.882	20.6	0
Shape*Spatial	2	34.145	34.145	17.072	8.6	0
Shape*Temporal	1	37.723	37.723	37.723	19.01	0
Shape*Temporal*Spatial	2	0.042	0.042	0.021	0.01	0.99
Spatial	2	206.585	206.585	103.293	52.05	0
Temporal	1	2.191	2.191	2.191	1.1	0.294
Temporal*Spatial	2	11.871	11.871	5.936	2.99	0.051
Error	968	1921.048	1921.048	1.985		

Results for the number of unique individual obstacles collided with per set are shown in Table 6-3. Similar to right object collisions, color differentiation was not significant. As with both objects, however, shape differentiation and spatial separation factors were each individually very significant, with corresponding results of $F_{(1, 968)} = 16.89$ and $F_{(2, 968)} = 52.46$ for $p < 0.001$. Auditory cues were also very significant for the number of individual collided obstacles, with $F_{(2, 968)} = 6.98$ for $p < 0.001$. While several two factor interactions were significant, no three factor interactions were significant for the unique obstacle collisions. Once more, interactions of shape differentiation with color differentiation, temporal separation or spatial separation were very significant, with $F_{(1, 968)} = 16.29$, $F_{(1, 968)} = 11.65$ and $F_{(2, 968)} = 6.77$ for $p < 0.001$ in that order. Interactions between auditory cues and spatial separation were also very significant $F_{(4, 968)} = 4.81$ for $p < 0.001$.

Table 6-3: Unique obstacle collision data.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Color	1	1.587	1.587	1.587	0.54	0.463
Color*Shape	1	48.016	48.016	48.016	16.29	0
Color*Shape*Spatial	2	2.776	2.776	1.388	0.47	0.625
Color*Shape*Temporal	1	0.321	0.321	0.321	0.11	0.741
Color*Spatial	2	5.931	5.931	2.965	1.01	0.366
Color*Temporal	1	2.099	2.099	2.099	0.71	0.399
Cue	2	41.167	41.167	20.583	6.98	0.001
Cue*Color	2	10.698	10.698	5.349	1.82	0.163
Cue*Color*Shape	2	3.008	3.008	1.504	0.51	0.6
Cue*Color*Spatial	4	9.766	9.766	2.441	0.83	0.507
Cue*Color*Temporal	2	1.913	1.913	0.956	0.32	0.723
Cue*Shape	2	20.008	20.008	10.004	3.39	0.034
Cue*Spatial	4	56.667	56.667	14.167	4.81	0.001
Cue*Temporal	2	0.532	0.532	0.266	0.09	0.914
Shape	1	49.778	49.778	49.778	16.89	0
Shape*Spatial	2	39.895	39.895	19.947	6.77	0.001
Shape*Temporal	1	34.321	34.321	34.321	11.65	0.001
Shape*Temporal*Spatial	2	0.149	0.149	0.074	0.03	0.975
Spatial	2	309.185	309.185	154.592	52.46	0
Temporal	1	0.099	0.099	0.099	0.03	0.854
Temporal*Spatial	2	20.478	20.478	10.239	3.47	0.031
Error	968	2852.607	2852.607	2.947		

6.2 Collision Time

The total time of collision was calculated as the number of recorded frames where an obstacle was in collision with a subject-controlled object. As with the path navigation task, each frame was equivalent to 2 ms of wall clock time, or 500 frames per second. Again, temporal separation was not a significant determining factor for overall time of collision for either the left or right object. However, auditory cue variation was found to be significant.

Table 6-4 displays the analysis for the total time of collision with the left object. Color differentiation was found to be significant with $F_{(1, 968)} = 7.74$ for $p < 0.01$. Auditory cue variation, shape differentiation and spatial separation factors were very significant for left object collisions, with $F_{(2, 968)} = 8.56$, $F_{(1, 968)} = 17.03$ and $F_{(2, 968)} = 38.25$ for $p < 0.001$ respectively. Several two factor and one three factor interactions were significant, including very significant effects for interactions of color and shape differentiation, $F_{(1, 968)} = 18.14$ for $p < 0.001$, and interactions of shape differentiation and temporal separation, $F_{(1, 968)} = 14.33$ for $p < 0.001$.

Table 6-4: Left object obstacle collision time data.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Color	1	155655	155655	155655	7.74	0.005
Color*Shape	1	364648	364648	364648	18.14	0
Color*Shape*Spatial	2	102438	102438	51219	2.55	0.079
Color*Shape*Temporal	1	12943	12943	12943	0.64	0.423
Color*Spatial	2	87260	87260	43630	2.17	0.115
Color*Temporal	1	26190	26190	26190	1.3	0.254
Cue	2	344004	344004	172002	8.56	0
Cue*Color	2	103285	103285	51643	2.57	0.077
Cue*Color*Shape	2	251631	251631	125816	6.26	0.002
Cue*Color*Spatial	4	100336	100336	25084	1.25	0.289
Cue*Color*Temporal	2	6654	6654	3327	0.17	0.847
Cue*Shape	2	171499	171499	85749	4.27	0.014
Cue*Spatial	4	238379	238379	59595	2.96	0.019
Cue*Temporal	2	19509	19509	9755	0.49	0.616
Shape	1	342255	342255	342255	17.03	0
Shape*Spatial	2	194574	194574	97287	4.84	0.008
Shape*Temporal	1	287990	287990	287990	14.33	0
Shape*Temporal*Spatial	2	1462	1462	731	0.04	0.964
Spatial	2	1537987	1537987	768993	38.25	0
Temporal	1	10108	10108	10108	0.5	0.478
Temporal*Spatial	2	78265	78265	39133	1.95	0.143
Error	968	19459190	19459190	20102		

The analysis for the right object time of collision is displayed in Table 6-5. Unlike the left object collision time, color differentiation was found to not be significant for the right object. Auditory cue variation was found to be significant with F $_{(2, 968)}$ = 3.82 for $p < 0.05$. Both shape differentiation, F $_{(1, 968)}$ = 23.30 for $p < 0.001$, and spatial separation, F $_{(2, 968)}$ = 53.78 for $p < 0.001$, factors remain very significant for right object collisions. Again, several multi-factor interactions were significant. Two factor interactions of color differentiation, temporal separation and spatial separation with shape differentiation each were found to be very significant, where F $_{(1, 968)}$ = 29.04, F $_{(1, 968)}$ = 26.42 and F $_{(2, 968)}$ = 12.65 for $p < 0.001$. Additionally, interactions between auditory cue variation and spatial separation were very significant F $_{(4, 968)}$ = 4.90 for $p < 0.001$.

Table 6-5: Right object obstacle collision time data.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Color	1	6706	6706	6706	0.35	0.554
Color*Shape	1	554977	554977	554977	29.04	0
Color*Shape*Spatial	2	185626	185626	92813	4.86	0.008
Color*Shape*Temporal	1	225	225	225	0.01	0.914
Color*Spatial	2	98455	98455	49227	2.58	0.077
Color*Temporal	1	113496	113496	113496	5.94	0.015
Cue	2	145975	145975	72987	3.82	0.022
Cue*Color	2	97359	97359	48680	2.55	0.079
Cue*Color*Shape	2	106252	106252	53126	2.78	0.063
Cue*Color*Spatial	4	109758	109758	27440	1.44	0.22
Cue*Color*Temporal	2	15439	15439	7720	0.4	0.668
Cue*Shape	2	52513	52513	26256	1.37	0.254
Cue*Spatial	4	374636	374636	93659	4.9	0.001
Cue*Temporal	2	1827	1827	913	0.05	0.953
Shape	1	445368	445368	445368	23.3	0
Shape*Spatial	2	483512	483512	241756	12.65	0
Shape*Temporal	1	504914	504914	504914	26.42	0
Shape*Temporal*Spatial	2	9706	9706	4853	0.25	0.776
Spatial	2	2055857	2055857	1027928	53.78	0
Temporal	1	11712	11712	11712	0.61	0.434
Temporal*Spatial	2	76837	76837	38419	2.01	0.135
Error	968	18501975	18501975	19114		

6.3 Practice

Average performance over time is plotted separately for the individual number of collisions and the total time of collision. Figure 6-1 displays number of individual collisions for the left and right object along with the total number of unique obstacles that were hit per test. The total time of collision is shown for the left and right objects in Figure 6-2.

Figure 6-1: Average collisions over time.

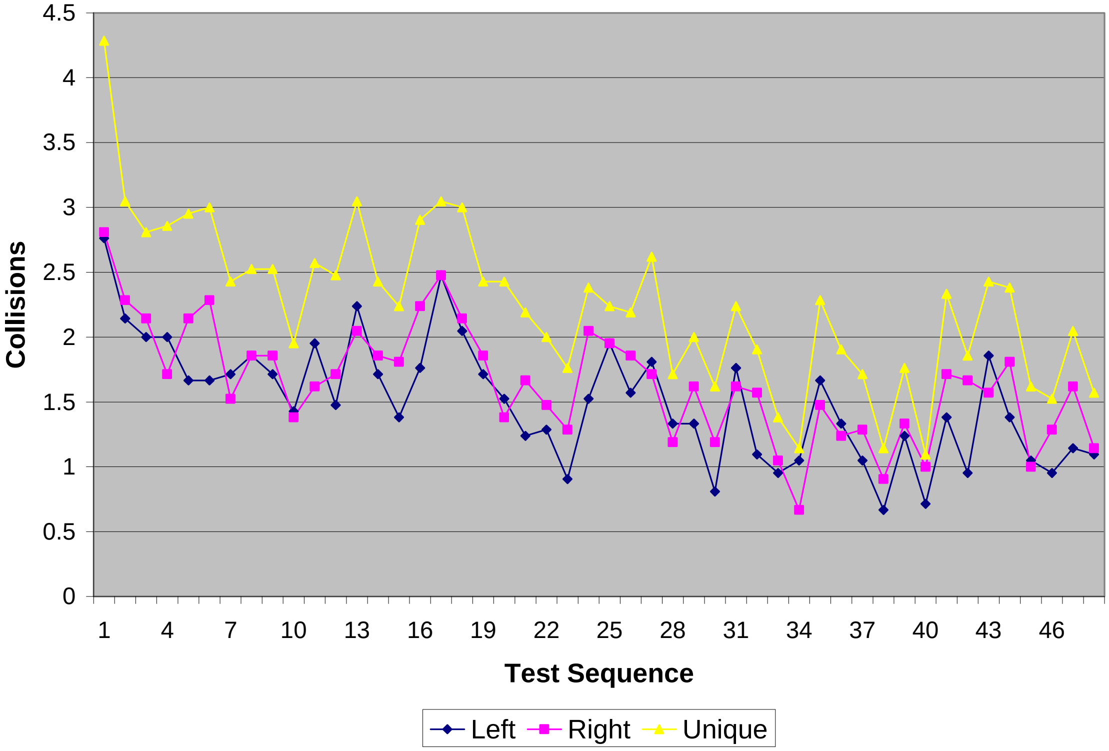
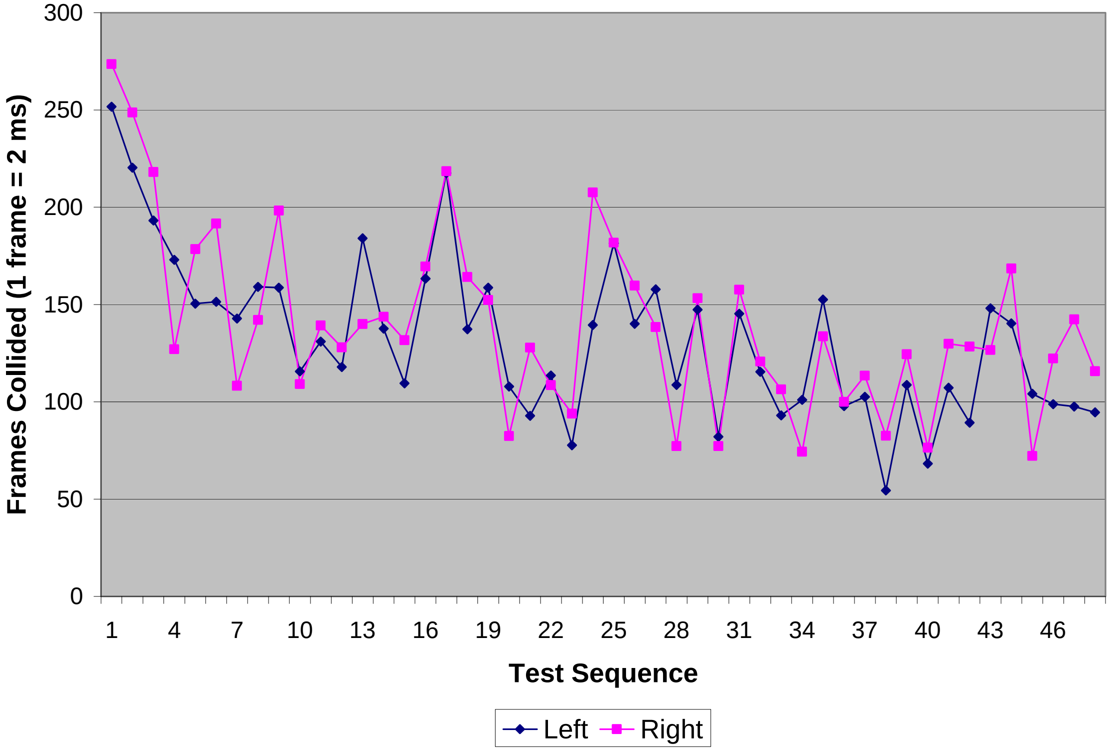


Figure 6-2: Average time of collision over time.



6.4 Analysis

Initially, some inconsistencies become apparent when comparing the significance of various factors on the performance of the left hand controlled object versus the right hand controlled object. While many factors had a significant effect on both objects for either independent collisions or time of collision, there are also several that were shown to be significant only for one object or the other. For comparison, Table 6-6 shows the overall collection of main and interaction effects that were found to be significant, ordered by the number of dependent variables affected. An "X" indicates that the effect or interaction was significant for a dependent variable. A "-" indicates that the effect or interaction was not significant.

Table 6-6: Significant main and interaction effects.

Source	Count	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit
Color*Shape*Spatial	1	-	X	-	-	-
Temporal*Spatial	1	-	-	-	-	X
Color	2	X	-	X	-	-
Color*Spatial	2	-	-	X	X	-
Color*Temporal	2	-	X	-	X	-
Cue*Color*Shape	2	X	-	X	-	-
Cue	3	X	X	-	-	X
Cue*Shape	3	X	-	X	-	X
Cue*Spatial	4	X	X	-	X	X
Color*Shape	5	X	X	X	X	X
Shape	5	X	X	X	X	X
Shape*Spatial	5	X	X	X	X	X
Shape*Temporal	5	X	X	X	X	X
Spatial	5	X	X	X	X	X

Of the five single factors, only shape differentiation and spatial separation were significant for each of the dependent variables. Additionally, several two factor interactions were significant for all five of the affected variables. It should be especially noted that all three of these two factor interactions involve shape differentiation, a relationship that will be further explored in the next chapter. A single two factor interaction, auditory cue variation and spatial separation, was significant for all but one of the dependents, while auditory cue variation, both by itself and as an interaction effect with shape differentiation, affected three of the dependent variables. The remaining main and interaction effects were only significant for one or two dependent variables.

Though significance and magnitude help to determine the importance of each factor and interaction, it is also necessary to evaluate whether or not the effect on subject performance was desirable. Figures 6-3 through 6-7 show the main effect plots for each of the dependent variables. A descending plot indicates improved performance when varying the factor and an ascending plot indicates worsening performance due to varying the factor. For each plot, 0 shows the performance when a two-level factor is absent and 1 shows the performance when the factor is present. In the case of auditory cues, 0 indicates no cues, 1 indicates a shared cue and 2 indicates separate cues. For spatial separation, 0 indicates a normal spacing, 1 indicates close spacing and 2 indicates far spacing.

Figure 6-3: Left object collision time main effects.

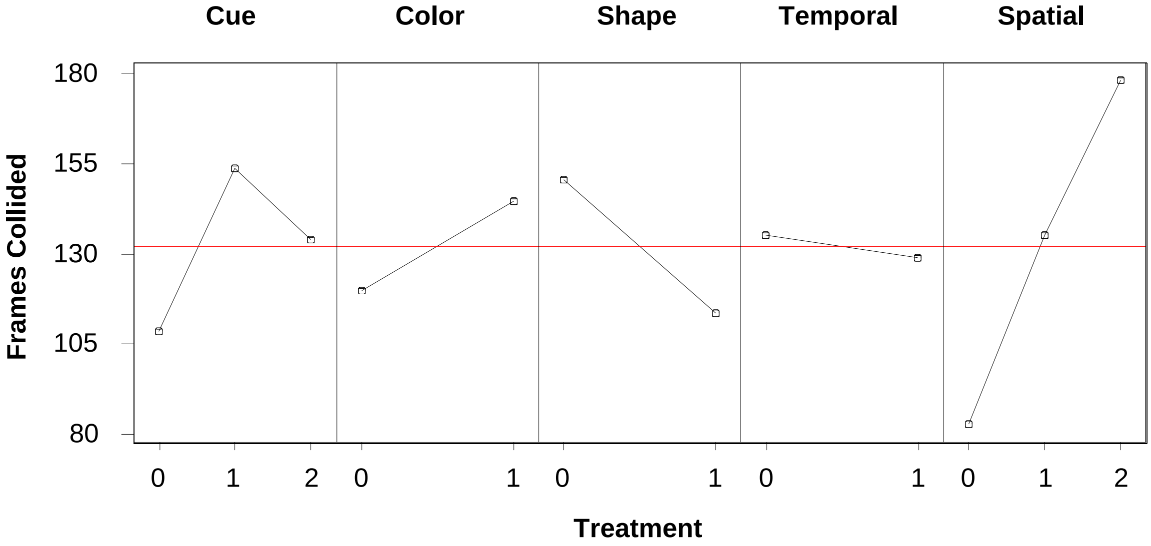


Figure 6-4: Right object collision time main effects.

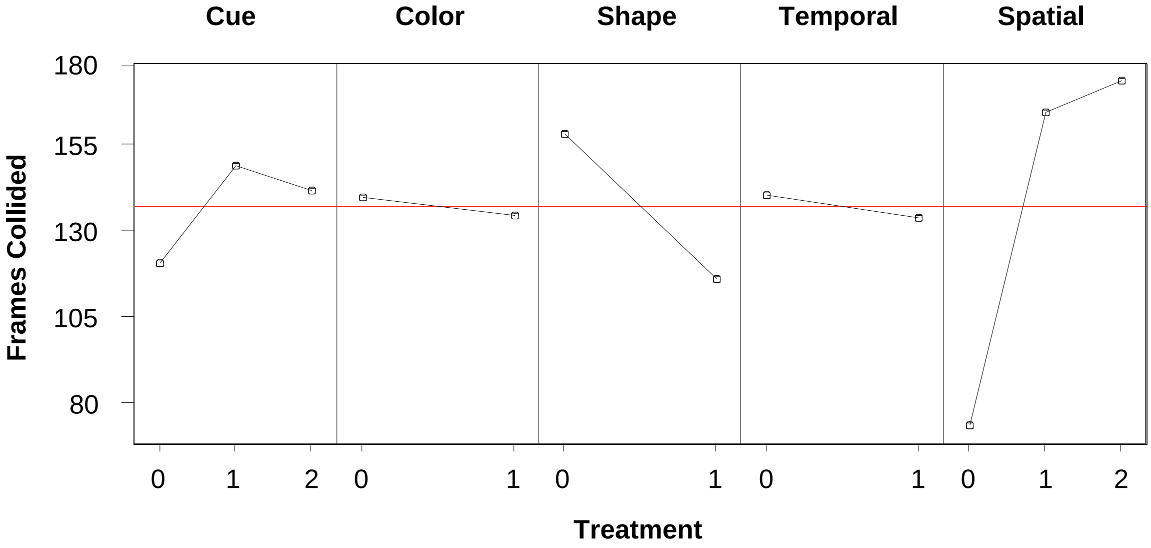


Figure 6-5: Left object collision main effects.

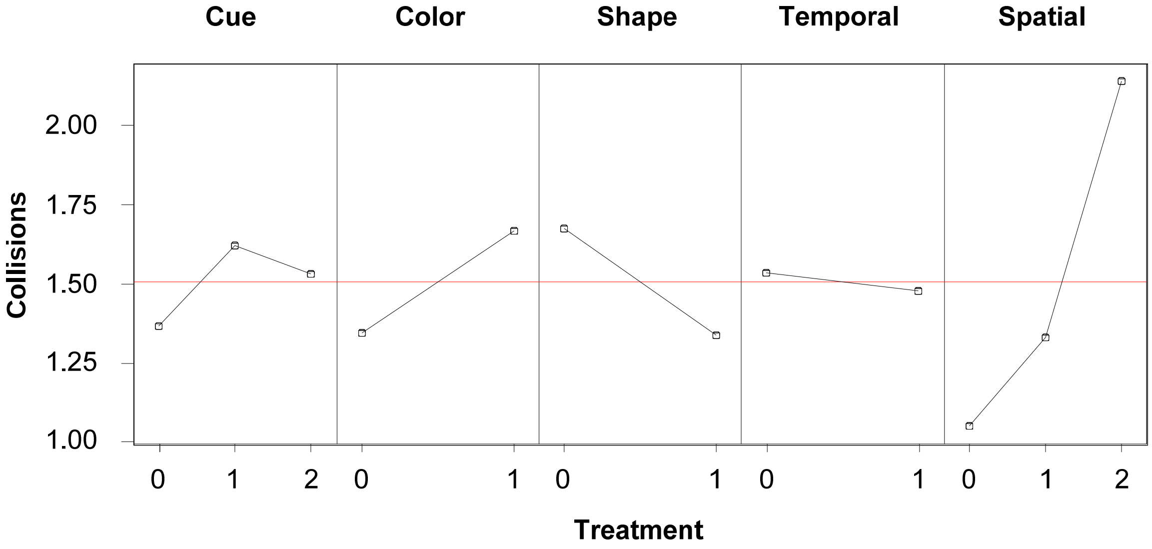


Figure 6-6: Right object collision main effects.

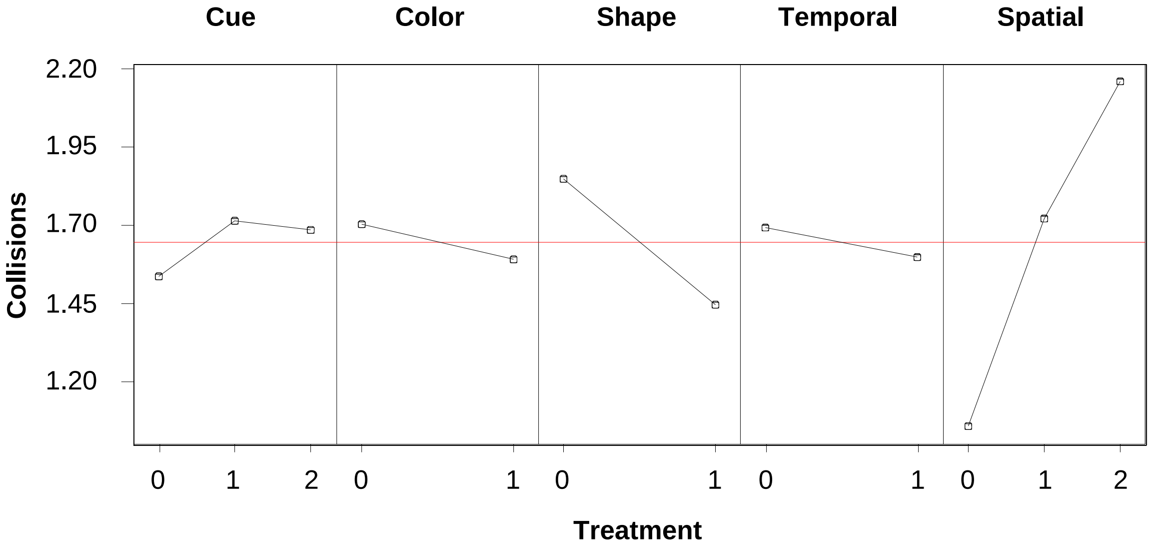
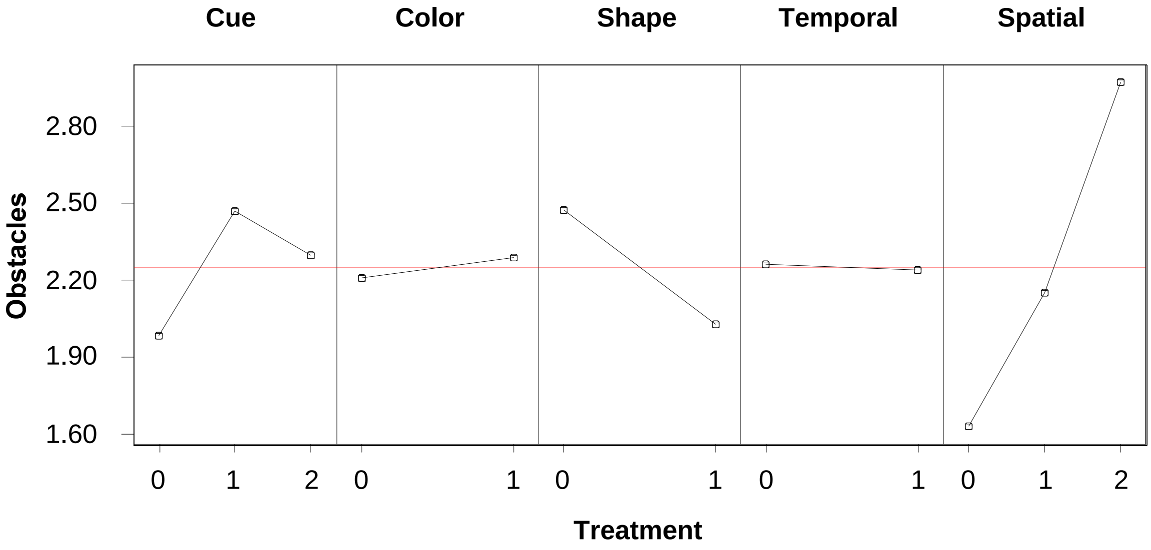


Figure 6-7: Unique obstacle collisions main effects.



Plots detailing interactions between the five dependent factors are shown in Figures 6-8 through 6-12. As before, a descending plot indicates improved performance when varying the factor and an ascending plot indicates worsening performance due to varying the factor. The interaction plots are row-major, meaning that the main effect is per row and the interaction is per column. For example, the top row shows the interaction effect of auditory cues with the other four factors. Each variation of auditory cue is shown with a separate line. As with the main effect plots 0 is used for no cues, 1 for a shared cue and 2 for separate cues. The interaction effects of the other four factors with auditory cues are shown in each column from left to right, with 0 indicating that the two-level factor was not present and 1 indicating that it was. Spatial separation is again denoted with a 0 for normal spacing, 1 for close spacing and 2 for far spacing. The remaining interactions can be examined similarly.

Figure 6-8: Left object collision time interaction effects.

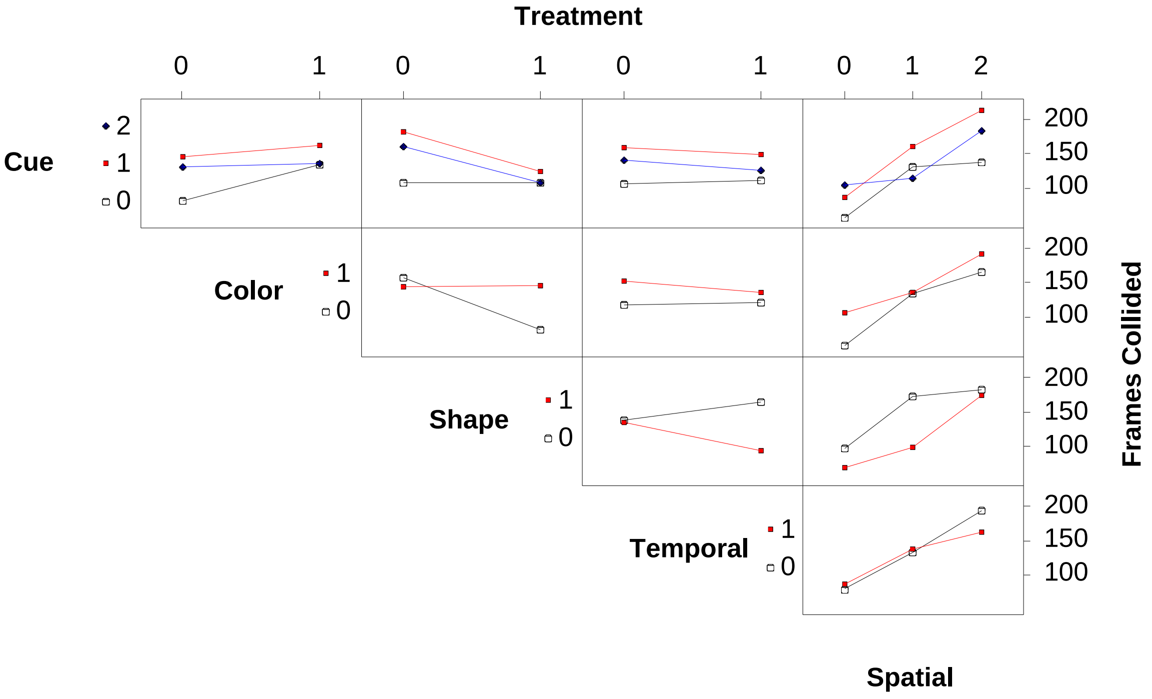


Figure 6-9: Right object collision time interaction effects.

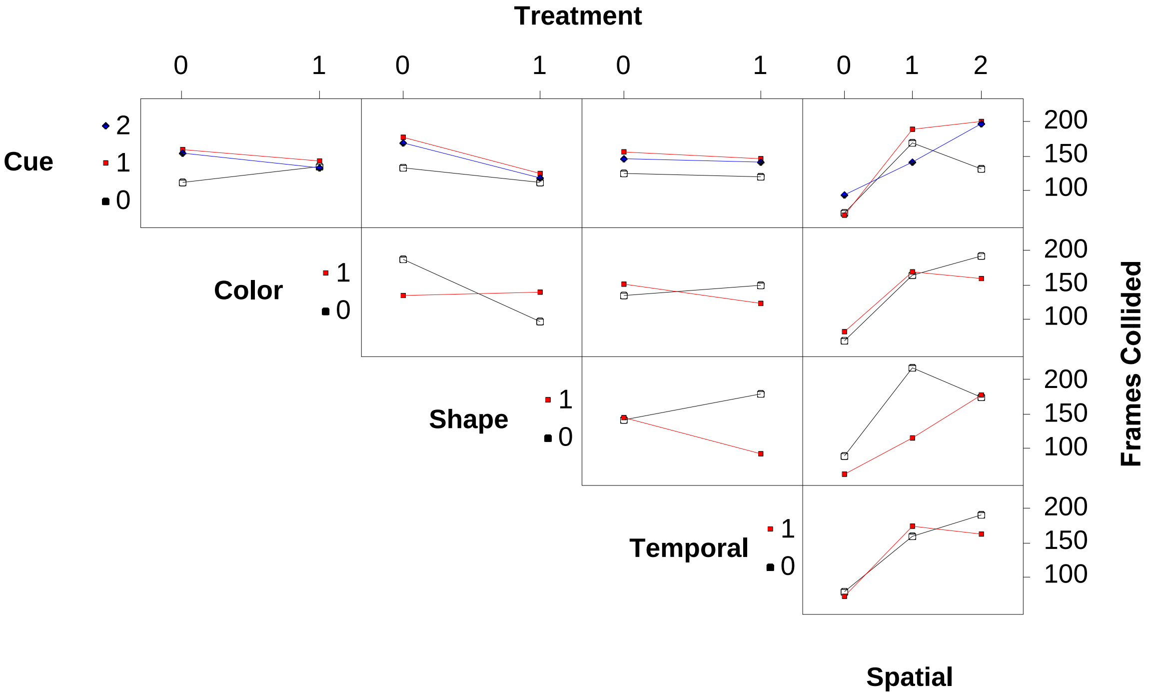


Figure 6-10: Left object collision interaction effects.

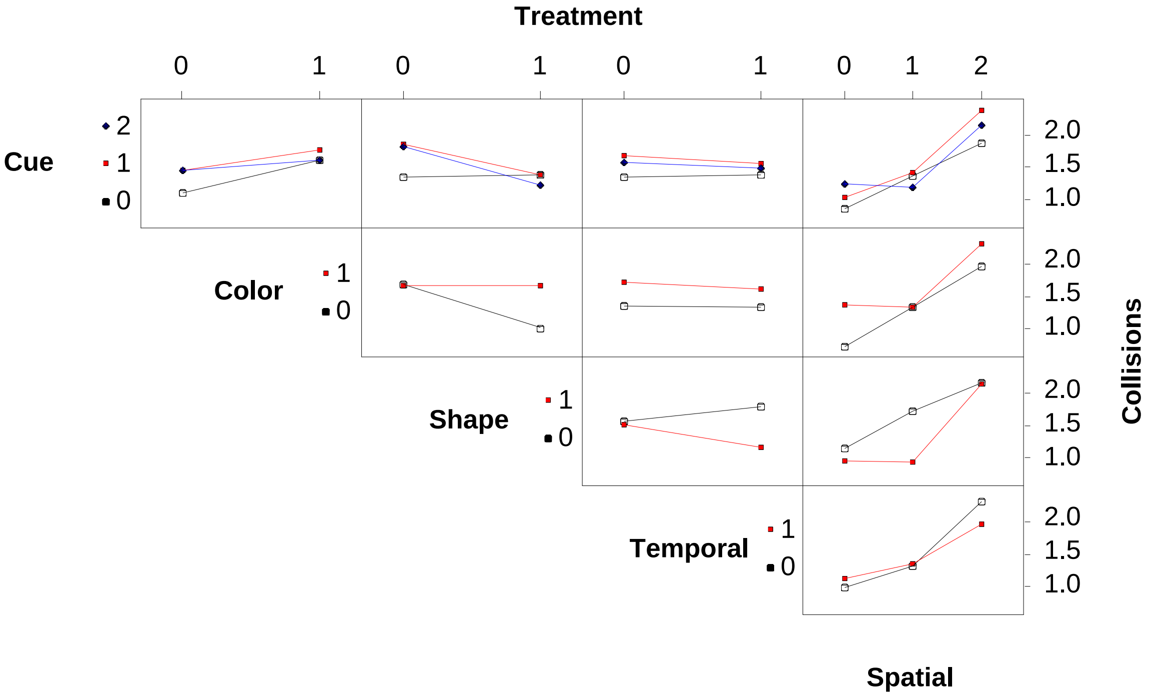


Figure 6-11: Right object collision interaction effects.

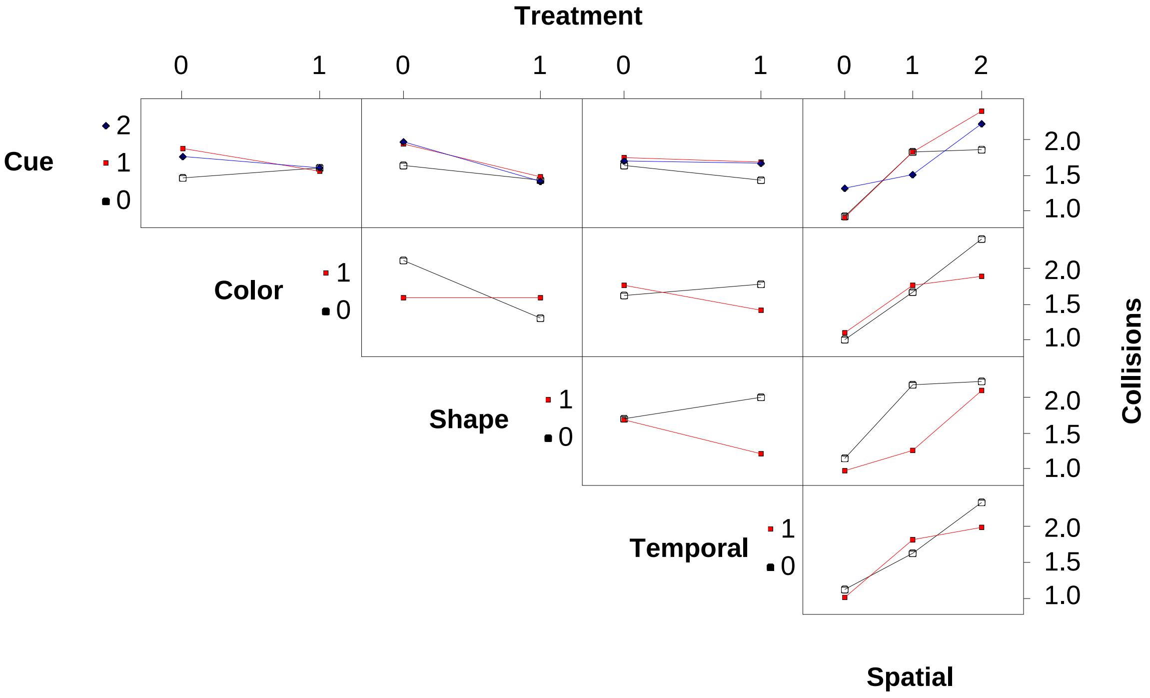
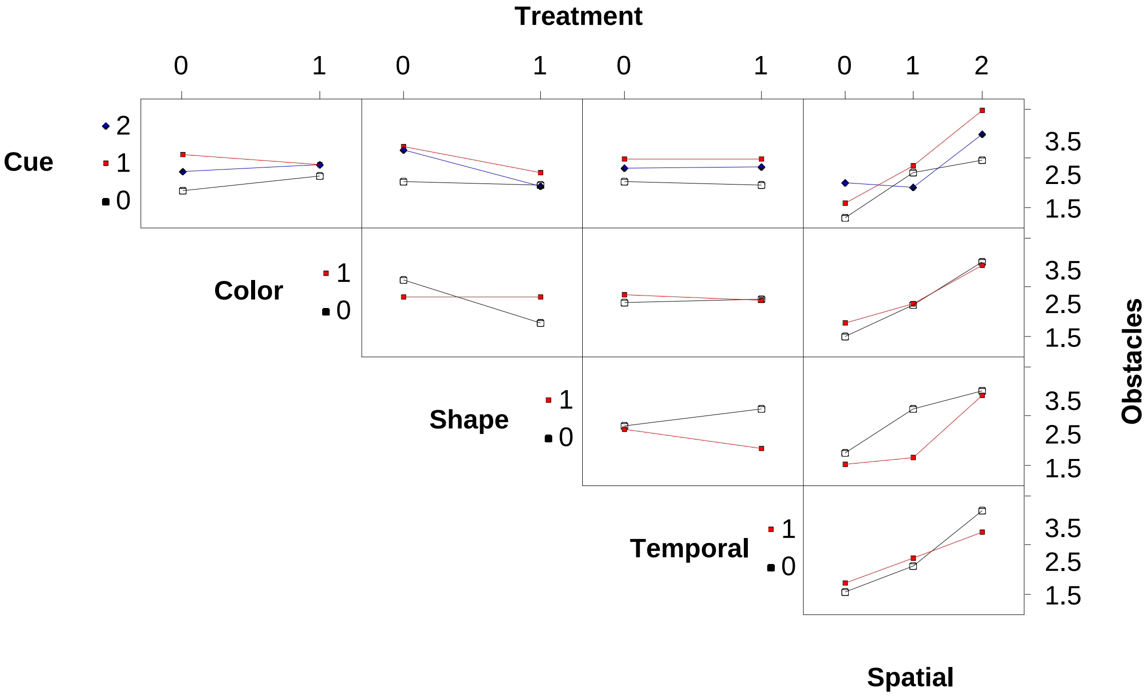


Figure 6-12: Unique obstacle collisions interaction effects.



6.4.1 Auditory Cue Variation

Independently, auditory cue variation was significant for discrete collision totals, but not for total collision time. As evidenced by the main effect plots in Figures 6-3 through 6-7, auditory cues decreased performance when they were present. Individualized auditory cues performed slightly better than a shared auditory cue for obstacle appearance. However, this still resulted in worse performance overall than when no auditory cues were present.

It should be noted that after the obstacle-dodging experiment was concluded, subjects were informally polled regarding what they liked and disliked about the experience. Many of the participants stated after the experiment that the auditory cues only served as a distraction rather than a benefit. The data supports this conclusion as the best performance was achieved without warning cues of any type.

6.4.2 Color Differentiation

Though it was expected that color differentiation would be a very beneficial factor to incorporate into the obstacle-dodging task, the opposite holds true. Color differentiation by itself was shown to only be significant for the performance of the left object, for both individual collisions and the total time of collision. In each case, worse performance was achieved: average collisions and average time of collision were elevated when the subject-controlled objects had different colors.

The effect of introducing color initially appears to contradict previous work. It is important to realize that even though the majority of participants in the study were right handed, the majority were also people with regular video game playing experience. A common occurrence for game players is to use their left hand for avatar control, leading to a tendency to associate primary movement control with the left hand. The fact that color had no significant effect on the performance of the object controlled by the subjects' right hand, while it did result in a significant performance reduction for the left hand object, could indicate that subjects were focused primarily on the left hand controlled object. Color differentiated tests may have allowed subjects to more easily notice and respond to obstacles affecting the right hand object, even though this may have been treated cognitively as a distractor relative to the left hand object. Though not significant, the average performance for the right hand controlled object saw a slight improvement during color differentiated tests, providing further suggestion of such a domain focused hand dominance effect.

6.4.3 Shape Differentiation

Shape differentiation was one of only two factors found to be consistently significant across all dependent variables. Additionally, all of the two factor interactions and a few three factor interactions involving shape differentiation were also significant for several variables. In all cases, differentiating the shape of the two objects resulted in a clear improvement in subject performance. Even in cases where the introduction of another factor was detrimental to performance, such as adding auditory cues to obstacle appearances, the further differentiation of shape still served to mitigate some of the performance loss.

Several subjects had commented that they felt less stress during tests where the shapes were different. Also, many of the same respondents believed that their performance was considerably better during such tests. While those subjects did have the benefit of seeing their relative dodging performance during the breaks between tests, it does appear that shape differentiation was the most beneficial factor.

6.4.4 Spatial Separation

Spatial separation was the only other factor to be consistently significant on its own, with several multifactor interactions also being significant. Unlike shape differentiation, spatial separation contributed to a negative performance change. In some cases, the number of collisions and total collision time was doubled when the two subject-controlled objects were moved far apart. A similar effect was seen when the two objects were moved close together, though the degradation was not as severe as when the objects were far apart in most cases.

The degradation of performance when the objects were close together is more easily explained, as their movement range allowed them to cross paths and be obscured by each other. The introduction of crossover only served to enhance the problem. This is not the case for the normal or far apart conditions, since the objects range of motion did not overlap in those instances. The severity of the performance penalty for cases where the two objects were far apart could be the result of a combination of elements. First, the distance of the separation makes it difficult to keep both objects within a comfortable field of focus. If the subject happened to be focusing on one object instead of the other, it would take longer to notice and respond to the appearance of an obstacle in peripheral vision. However, a necessary consequence of moving the objects apart is that they end up closer to the edges of the screen and allow for lower maximum reaction time to respond correctly to obstacle appearances from those edges.

6.4.5 Temporal Separation

Looking at the five factors explored by this research, temporal separation was the only one that did not have a significant effect on any dependent variable. However, there were several two-factor interactions in which temporal separation appear to have a significant effect. In each of the three significant interactions, reducing the time between obstacles improved performance slightly. Although the only interaction with temporal separation to be significant for all five of the dependent variables was that with shape differentiation, the performance improvement was consistent across all variables and significant interactions.

During such tests where obstacles were presented in rapid succession, subjects were visually observed to appear more focused on those tests. Subjects were less likely to make extraneous object movements between obstacles and less likely to demonstrate restlessness in their body movements. It is possible that even though temporal separation was not significant by itself, subjects may have been responding more instinctively rather than thinking about or potentially over-thinking their object movements.

6.4.6 Practice

Unfortunately, due to the differences in the location of obstacles and the number of object crossovers introduced in each test, it is difficult to make a concrete conclusion regarding the effect of practice on subject performance for the obstacle-dodging experiment. An initial performance improvement can be clearly seen between the first and second test averages as subjects become accustomed to the testing equipment and procedures. After the initial improvement, performance over time becomes less clear. However, a minor trend over time towards improved performance can be seen in both the number of individual collisions in Figure 6-1 and the total time of collision in Figure 6-2.

Chapter 7 – Summary

Bimanual dual object control tasks encompass a large range of interaction. A simple path navigation task was selected and tested to examine the effect of parallel movement on completion time and accuracy. Similarly, several factors were tested for their effect on performance during an obstacle-dodging task.

7.1 Classification

Simply put: all tasks are not created equal. Even with current classification schemes, a large variety of bimanual tasks cannot be properly classified. Tasks that switch between symmetric and asymmetric interaction modes currently have no clear method of categorization. The introduction of the Object-Input model alleviates this discrepancy between pure symmetric and asymmetric classifications.

In the Object-Input model, the emphasis of classification is shifted from the mode of interaction, symmetric or asymmetric, to the objects being interacted with. The intent is not to supplant the traditional unimanual, bimanual symmetric and bimanual asymmetric designations for tasks. Rather, the Object-Input model is meant to offer an additional tool to use for interaction design. Though only bimanual dual object control tasks were examined in depth, the entire classification model provides a different perspective with which interaction can be viewed.

7.2 Speed vs. Accuracy

Overall completion time for a path pair was considerably shorter during parallel tests, despite the fact that reduced completion time came at the cost of accuracy. Though subjects were not specifically instructed to avoid the walls during the path navigation experiment, the difference in performance between serial and parallel tests still shows a trend for worse performance during parallel tests. In the case of individual collisions and completion length, the difference is minimal. However, the total time of collision was considerably greater when a subject's focus was split between moving both objects simultaneously.

The path navigation experiment demonstrated a clear distinction between completion times for serial and parallel movement. In applications where time is of the essence, parallelization of movement tasks could be advantageous when obstacle collisions or the exact movement path is of lesser consequence. On the other hand, when obstacle avoidance or movement accuracy is absolutely critical over the speed of completion, then it may remain best to restrict movement to one object at a time.

7.3 Object Differentiation

7.3.1 Auditory Cue Variation

The presence of auditory cues had a consistently negative impact on subject performance. While individual cues for each object during the obstacle-dodging task did not degrade performance as much as a single cue for both objects, the effect was still undesirable. On a conscious level, subjects were aware and commented repeatedly that the cues were not helpful in any way. Because of this, auditory feedback appears to act as more of a hindrance and should be avoided during BDOC tasks.

7.3.2 Color Differentiation

Surprisingly, color differentiation did not have the expected benefit. Instead, the effect that emerged was significantly detrimental to the dodging accuracy of the left hand controlled object. Though the minimal increase in dodging accuracy for the right object was not significant, this could be an indication of the previously mentioned domain focused hand dominance effect. This slight improvement could be the result of a cognitive shift in focus from the dominant hand to the non-dominant hand and deserves further exploration on its own.

7.3.3 Shape Differentiation

Shape differentiation surfaced as the most beneficial in the obstacle-dodging task. Universally, shape differentiation helped to improve subject performance, both for number of collisions as well as collision time. Though the greatest benefit was seen when shape differentiation was included by itself, the negative effects of other factors were partially reduced when included in conjunction with shape. While this may introduce a visual discontinuity when representing two identical objects virtually, the performance benefit is more than worthwhile.

7.3.4 Spatial Separation

As expected, situations where the controlled objects were too close or too far apart resulted in lower performance. The performance loss when objects were close together is clearly explained. The movement range for such objects allowed them to not only come into contact with each other, but to actually switch places. The explanation for the loss of performance during tests in which the objects were spaced far apart is less clear. While the greater distance between the objects could have made them difficult for subjects to focus on simultaneously, the shorter distance between the objects and the edges of the screen could have had a negative effect on subject response time. The inconclusive cause of this negative effect deserves further exploration for clarification. Regardless, the distance between objects should be carefully controlled.

7.3.5 Temporal Separation

The only factor which did not have a significant effect by itself was temporal separation. A couple of interaction effects did prove to be significant. A smaller delay between the disappearance of one obstacle and the appearance of the next actually led to slightly improved performance. The minimum delay did not quite approach the range of attentional blink concerns, but may have prevented subjects from over-thinking their actions.

7.4 Future Work

A minor trend towards improved performance over time was found during the obstacle-dodging task. Due to the composition of the experiments, the effect of practice on BDOC tasks could not be completely analyzed. Further experimentation regarding long term use of BDOC applications would be able to provide a clearer picture on the real effect of practice on performance.

The use of haptic feedback was previously mentioned as a way to help reduce visual overload. A suitable device providing individualized haptic feedback could not be procured for the research performed here. While most of the visual feedback indicators expected to help BDOC tasks did not perform completely as predicted, exploration into other sensory realms could provide additional performance benefits.

A simple off the shelf video game controller was used as an input device during experimentation, which afforded each hand the same method of hardware interaction. Though the method of interaction and capabilities for both objects was identical during experimentation, BDOC tasks may not enforce that both objects need to have the exact same capabilities. Controlling multiple objects with a unique set of capabilities for each of them is a very likely task. It would make sense to use the most appropriate hardware to interact with each object, even if that means using different devices within the same interface. Applications requiring the simultaneous control of a land vehicle and a sea vehicle, for instance, could use identical or very different hardware as necessary. The effects, both positive and negative, of using different input devices need to be evaluated in part to determine if the appropriateness of using different input devices outweighs the consistency of identical interaction when using identical devices.

The domain focused hand dominance effect which emerged during the obstacle dodging task can greatly impact the way that interfaces are viewed and designed. While the effect could only be inferred during color differentiation tests, no further exploration was performed due to the statistical insignificance of the effect on the right hand controlled object. Regardless of significance and hand preference, the decreased performance seen for the left hand controlled object, in conjunction with the slightly increased performance for the right hand controlled object, is indicative of the domain focused hand dominance effect and deserves further consideration. Due to the relatively small size of the testing pool, a more exhaustive research study could help to determine if this effect really does exist, as well as providing further validation of the testing data presented here.

Only two simple BDOC tasks were tested here: path navigation and obstacle dodging. Though each task would be classified as a *dual object, dual input* (DODI) task under the Object-Input model, neither task required the subject to switch between symmetric and asymmetric interaction modes. Clearly, BDOC and DODI tasks encompass a much larger application domain, including applications with considerably more complex interactions. The benefits and detriments shown for simple tasks may or may not translate into similar performance for complex or variable tasks. It would be prudent to continue investigating the nuances of BDOC tasks in a much larger area of interaction influence.

7.5 Conclusion

Human-computer interaction has evolved tremendously over the years. New methods of interaction have been incorporated in applications and interface design, while existing means have continued to improve. Though under represented, there is clearly potential in the virtualization of bimanual dual object control tasks. Many applications, such as remote robotics or surgery, stand to benefit from the introduction and improvement of interaction schemes for BDOC tasks.

The experiments conducted here initially resolve the question of viability regarding using bimanual dual object control systems compared against single object systems. Clearly, one of the benefits that parallelizing tasks can expose is the potential to drastically improve time performance. However, that improved performance in one area can come at the cost of another, such as the number of obstacle collisions.

Additionally, the techniques for implementing such interaction schemes were explored, with the most effective and least effective ones determined. While it may seem more intuitive to display similar objects with the same shape, but different colors, experimentation indicated that the opposite is true. Shape differentiation emerged as the clear performance leader in the obstacle-dodging task. Color and object spacing had large effects on performance, but both resulting in worse performance. Auditory cues had a negative effect all around, while obstacle timing had little effect at all.

Many questions have been put forward by this research, but many more yet remain. A single factor was deemed as being beneficial, while many others have been acknowledged as detrimental for a simple obstacle-dodging task. These factors are by no means the only ones worth exploring. With further study, additional improvements or pitfalls for BDOC tasks can be identified and incorporated in application development as appropriate.

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Appendix A – Path Navigation Experiment Data

A.1 Collision and Completion Length Results

The collision and completion length results for the path navigation experiment are contained in tables A-1 through A-10. Each table corresponds to the results obtained from an individual participant. The columns are labeled as follows:

- Test: Test sequence number.
- ID: Path used during the test.
- ColRawL: Collision time for the left object in frames (1 frame = 2 ms).
- ColRawR: Collision time for the right object in frames (1 frame = 2 ms).
- ColRealL: Individual collisions for the left object.
- ColRealR: Individual collisions for the right object.
- LengthL: Completion length for the left object.
- LengthR: Completion length for the right object.

Table A-1: Collision and length data from path set 1.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	20	556	624	7	4	2679	2478
2	19	343	526	4	5	2742	3124
3	3	248	573	5	3	2466	2476
4	15	545	658	10	7	3312	3190
5	12	113	448	3	3	2439	2440
6	13	40	145	2	2	1825	1730
7	14	60	828	4	4	2634	2657
8	8	504	689	5	6	2637	2748
9	21	490	948	6	9	2701	3578
10	5	23	143	2	3	1842	1858
11	9	200	11	4	2	3094	3090
12	17	223	1492	5	9	3026	3810
13	16	406	778	3	6	2717	2630
14	11	325	12	5	2	2382	2426
15	2	422	583	9	3	3632	3676
16	18	388	556	10	4	3566	2992
17	22	344	510	6	9	2464	3224
18	7	400	346	8	7	3266	3205
19	10	435	422	11	7	3452	3721
20	23	361	715	7	6	3306	2992
21	4	358	299	5	5	2379	2452
22	6	172	44	8	3	2647	2639
23	1	318	131	5	4	2968	3093
24	24	436	255	7	4	2358	1754
25	1	369	1328	9	4	3249	3491
26	2	691	1277	7	7	3817	3726
27	11	557	488	5	6	2518	2483
28	4	157	548	4	3	2357	2348
29	19	983	1234	6	7	2700	3199
30	20	389	1408	5	5	2731	2776
31	7	902	848	10	8	3200	3044
32	10	1251	1777	11	6	3716	3815
33	21	914	918	7	9	2801	3233
34	16	714	445	6	3	2642	2721
35	3	590	1010	5	5	2364	2687
36	6	266	1020	4	4	2551	2582
37	8	732	1144	4	4	2622	2478
38	22	807	659	6	11	2322	3156
39	13	431	173	4	3	1750	1844
40	14	876	1200	5	5	2616	2640
41	9	1273	1511	5	5	3051	3056
42	18	1585	1502	9	5	3666	3158
43	5	354	418	3	3	1718	1636
44	12	925	1344	6	5	2416	2440
45	17	876	1992	6	5	3027	3682
46	24	1083	1008	5	4	2367	1667
47	23	963	1799	10	7	3281	3156
48	15	777	859	8	8	3282	3462

Table A-2: Collision and length data from path set 2.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	1	641	201	8	3	3597	3059
2	18	659	322	6	6	4059	3204
3	19	804	657	8	8	2815	3478
4	6	484	434	6	6	3008	2608
5	9	362	295	5	5	3213	3190
6	13	294	184	4	3	1915	1924
7	12	304	92	6	5	2783	2725
8	7	560	502	6	10	3275	3258
9	15	531	254	9	7	3267	3289
10	2	1166	1960	11	6	3996	3788
11	17	627	2108	4	5	3332	3758
12	14	82	574	3	5	2735	2761
13	4	518	472	5	4	2665	2461
14	16	557	935	7	7	2633	2772
15	21	1264	1303	6	8	2978	3338
16	3	404	592	8	5	2930	2374
17	5	117	292	1	2	1833	1692
18	8	462	1192	6	6	2747	2773
19	24	315	318	5	3	2739	1924
20	10	145	1011	6	8	3962	3953
21	22	266	1027	8	8	2998	3338
22	11	247	366	6	5	2820	2609
23	20	320	686	6	6	2666	2805
24	23	1209	1061	10	6	3441	3356
25	4	118	395	3	5	2549	2863
26	5	618	600	5	2	2116	1792
27	14	566	0	4	0	2759	2601
28	18	309	203	5	5	3634	3142
29	12	58	58	2	4	2633	2460
30	6	0	16	0	1	2568	2643
31	19	250	286	1	7	2783	3308
32	1	330	924	6	2	3280	3116
33	7	454	507	9	8	3296	3009
34	21	294	314	7	7	2849	3143
35	2	103	1601	3	4	3800	3826
36	24	251	433	2	5	2493	1708
37	3	127	642	4	4	2348	2392
38	23	328	49	8	2	3299	3110
39	22	135	458	4	6	2430	3101
40	10	705	1467	7	6	3880	4109
41	9	36	121	2	5	2996	3160
42	17	3	649	1	8	3017	3776
43	15	345	516	11	8	3306	3494
44	8	461	269	6	6	2865	2723
45	11	200	505	4	4	2416	2416
46	20	282	491	7	5	2883	2644
47	13	508	162	5	3	1984	1719
48	16	520	777	5	4	2797	2674

Table A-3: Collision and length data from path set 3.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	2	2326	3443	8	5	3942	3968
2	1	503	1023	6	8	3189	3253
3	4	621	619	6	5	2763	2507
4	9	1649	632	7	6	3327	3418
5	3	1276	1549	8	6	3262	2756
6	21	1264	2264	4	8	2686	3338
7	6	1686	1486	6	5	2814	2919
8	24	551	979	6	4	2563	1822
9	11	572	296	5	4	2546	2475
10	19	1585	474	4	7	2763	3402
11	5	690	458	2	3	1782	1740
12	8	1287	1321	5	4	2747	3155
13	23	1618	1018	9	5	3434	3422
14	18	1497	1122	10	7	3846	3206
15	17	1282	2094	8	7	3502	4038
16	13	260	608	2	3	1848	1823
17	12	983	531	4	6	2547	2638
18	16	1220	520	5	6	2706	2822
19	14	746	1232	6	4	2715	2638
20	10	1312	1410	7	8	3884	3841
21	15	1681	1153	9	7	3278	3323
22	22	1211	1616	6	6	2546	3338
23	20	1589	2317	7	4	3129	2923
24	7	1456	1661	10	7	3496	3338
25	3	114	234	1	5	2432	2481
26	16	1153	764	7	6	2898	2923
27	21	262	447	6	7	2797	3322
28	19	107	762	3	5	2507	3290
29	11	148	35	4	2	2306	2473
30	9	33	520	3	5	3118	3280
31	22	486	1239	4	10	2484	3477
32	6	186	740	6	7	2465	2835
33	23	523	1002	9	10	3219	3707
34	18	655	1811	6	6	3784	3432
35	14	359	881	7	8	2707	3078
36	8	420	1043	6	4	2797	2789
37	1	674	380	7	7	3463	3438
38	10	779	551	8	7	3800	3923
39	2	537	1405	7	10	3814	4138
40	7	392	338	11	8	3244	3461
41	17	678	631	8	7	3547	4122
42	4	285	467	6	6	2589	2684
43	20	266	374	5	7	2916	2909
44	12	336	350	4	4	2731	2642
45	24	255	606	4	4	2729	2027
46	15	658	470	11	11	3312	3323
47	5	492	104	4	4	2149	1833
48	13	293	157	4	3	2048	1858

Table A-4: Collision and length data from path set 4.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	24	171	283	4	6	2692	2077
2	6	231	214	3	6	2611	2452
3	18	171	207	6	3	3704	2925
4	13	158	297	3	4	1864	1814
5	12	9	172	2	5	2500	2484
6	21	706	458	8	9	2850	3206
7	4	101	433	2	6	2434	2425
8	9	134	260	6	4	2981	2892
9	2	152	1185	9	8	3794	3487
10	1	1027	1157	7	4	2958	2901
11	7	542	222	11	7	3070	3155
12	14	106	332	4	4	2508	2517
13	23	454	795	10	7	3202	2813
14	10	189	630	7	9	3485	3496
15	16	314	686	7	8	2779	2564
16	20	217	436	4	7	2597	2658
17	22	176	350	4	9	2316	3161
18	17	435	902	6	7	2887	3392
19	5	198	520	4	5	1832	1787
20	3	349	487	5	4	2400	2249
21	8	512	415	8	6	2730	2648
22	15	443	582	10	8	3136	3067
23	11	142	270	4	5	2350	2344
24	19	7	258	2	5	2475	2903
25	14	273	356	6	7	2520	2562
26	1	90	548	3	3	2975	2846
27	18	1009	1203	9	7	3879	3427
28	11	170	99	4	4	2410	2417
29	24	461	279	5	4	2595	1913
30	16	159	556	5	2	2792	2687
31	4	484	784	3	5	2800	2491
32	7	518	253	10	8	3329	3374
33	8	263	453	6	7	2763	2808
34	12	367	90	4	5	2419	2538
35	20	675	450	5	7	2666	2675
36	6	21	294	2	7	2717	2665
37	17	526	1041	3	8	3006	3548
38	9	578	1242	8	6	3098	3094
39	21	662	678	7	9	2683	3205
40	2	1035	1169	5	9	3604	3602
41	19	543	1300	4	6	2874	2973
42	10	503	2021	9	9	3658	3576
43	13	8	225	2	3	1766	1876
44	3	208	525	2	3	2391	2310
45	15	522	461	10	10	3296	3296
46	22	247	501	6	9	2946	3272
47	5	166	867	3	4	1798	1808
48	23	541	157	8	5	3215	3538

Table A-5: Collision and length data from path set 5.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	14	176	1038	3	5	2632	3013
2	21	1419	2377	6	8	2898	3756
3	9	1082	1147	7	8	3114	3252
4	3	894	900	5	4	2498	2426
5	16	644	1203	5	5	2897	2822
6	6	1517	960	4	7	2657	3021
7	10	2704	1654	6	7	3778	3886
8	18	1817	758	8	5	3741	3256
9	24	660	1285	4	5	2998	1822
10	19	1000	1067	5	7	2840	3072
11	23	673	1146	8	6	3272	3252
12	11	664	1284	5	6	2512	2757
13	4	250	477	4	4	2600	2447
14	17	1178	2024	5	7	3315	4270
15	8	808	1612	6	6	2934	2924
16	7	1252	912	6	9	3272	3288
17	22	835	1314	5	9	2482	3338
18	20	1268	1236	8	10	2650	3640
19	1	1532	1323	4	7	3079	3091
20	12	1285	901	4	5	2482	2538
21	13	418	697	3	4	1848	1924
22	2	2812	2186	6	7	3862	4386
23	5	253	316	5	4	1848	1822
24	15	1311	1322	10	10	3312	3337
25	2	417	2359	8	5	3716	3826
26	6	283	985	5	5	2767	2871
27	12	432	857	4	5	2673	2392
28	20	79	845	5	5	2641	2823
29	24	483	593	4	3	2509	1822
30	7	479	1037	6	11	3220	3422
31	17	281	1924	7	6	2968	3808
32	23	413	1350	7	5	3254	3055
33	15	290	1089	8	9	3170	3303
34	8	960	920	5	7	2874	2823
35	21	503	938	5	10	2721	3371
36	3	81	891	2	5	2377	2494
37	9	268	1541	7	5	3257	3124
38	1	344	1474	7	5	3018	3000
39	16	384	496	4	5	2768	2822
40	4	437	679	5	5	2722	2507
41	5	192	616	3	3	1912	1815
42	10	325	1652	8	5	3752	3799
43	13	175	786	4	3	1848	1878
44	22	611	811	4	10	2682	3338
45	14	184	949	7	6	2549	2624
46	11	940	607	7	3	2972	2491
47	19	259	675	4	6	2517	3013
48	18	201	1099	7	6	3816	3154

Table A-6: Collision and length data from path set 6.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	22	1571	1648	6	7	3012	3438
2	24	679	495	5	4	2563	1822
3	4	804	1683	8	4	2863	2456
4	9	1340	1976	11	6	4231	3252
5	12	740	248	5	6	2563	2538
6	18	1538	1466	7	6	3814	3224
7	20	1045	1378	11	3	3029	2698
8	7	765	1215	15	6	3733	3146
9	14	591	360	7	8	3009	3257
10	19	800	1302	7	7	3658	3420
11	2	1236	2068	9	5	4260	3826
12	10	1835	707	7	11	3867	4060
13	17	1473	2189	6	10	3227	4186
14	13	777	1581	5	4	1949	2374
15	15	1177	1055	9	10	3246	3429
16	16	1260	1454	7	7	3300	3022
17	1	1940	1846	8	10	3594	3835
18	23	2240	1153	10	8	3661	3652
19	21	815	1550	7	8	2714	3294
20	11	757	792	5	7	2612	2741
21	8	1052	1677	6	6	2897	2857
22	3	612	977	4	7	2497	2538
23	5	447	817	5	3	2132	1922
24	6	725	1277	8	6	3133	3007
25	6	565	1769	6	5	2770	2803
26	1	551	965	7	9	3415	3753
27	13	285	1092	4	4	1775	1934
28	11	294	765	5	6	2739	2537
29	24	635	718	6	4	2517	1822
30	10	482	2322	9	6	3691	3967
31	5	212	412	3	4	1953	1758
32	21	667	1102	4	8	2888	3306
33	9	736	438	7	8	3432	3538
34	16	720	970	6	5	2699	2822
35	22	45	933	3	7	2523	3262
36	2	1001	655	9	12	3914	4168
37	3	137	183	3	3	2394	2508
38	12	844	433	9	5	3197	2538
39	15	564	913	10	8	3437	3337
40	23	373	809	7	5	3087	3390
41	14	275	1044	8	8	2997	3004
42	17	665	1019	9	9	3427	3908
43	18	301	872	6	7	3809	3172
44	8	765	1703	6	6	2702	2956
45	20	375	1392	9	6	3051	2906
46	4	1145	1107	5	5	2617	2343
47	7	596	871	11	8	3335	3254
48	19	473	945	6	7	2701	3438

Table A-7: Collision and length data from path set 7.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	11	608	645	6	4	2564	2537
2	15	846	738	11	8	3312	3503
3	19	995	226	4	4	2792	3256
4	8	808	902	6	6	2868	3357
5	9	1258	194	6	6	2981	3308
6	24	1191	295	4	5	2371	1822
7	1	1485	344	5	6	2927	3124
8	16	830	785	7	7	2997	3108
9	21	295	871	6	8	3033	3325
10	6	701	317	5	7	2799	2808
11	3	858	324	3	5	2467	2604
12	13	510	254	4	7	1700	1924
13	7	673	737	10	9	3312	3412
14	14	683	20	5	3	2863	2650
15	10	458	1449	11	13	3784	4923
16	4	415	177	7	6	2408	2370
17	18	1102	136	8	4	3798	3140
18	5	205	476	6	4	1989	1822
19	2	1116	1565	8	7	3652	3790
20	17	934	876	7	6	2986	3826
21	22	901	555	6	10	2304	3354
22	23	723	587	9	5	3424	3388
23	20	735	845	6	6	2683	2814
24	12	551	534	5	6	2422	2424
25	13	252	311	2	3	1750	1794
26	23	1674	1021	8	8	3291	3188
27	10	2068	1156	6	9	3752	4030
28	7	1422	961	8	11	3412	3281
29	19	1275	782	6	5	2899	3206
30	15	822	402	10	8	3354	3224
31	24	530	271	6	6	2547	2021
32	1	2179	1326	9	7	3861	3105
33	16	1147	688	5	7	2797	2822
34	22	856	844	6	10	2696	3338
35	21	1012	1287	5	9	2797	3272
36	8	1529	1460	6	7	2897	2823
37	12	1200	643	6	4	2563	2538
38	18	1700	1087	8	6	3888	3568
39	6	521	707	11	7	2717	2976
40	4	759	1075	3	6	2501	2649
41	11	424	193	5	4	2740	2391
42	3	534	521	7	7	2612	2642
43	2	1244	1183	6	8	3810	4024
44	17	937	1900	8	9	3247	4070
45	5	784	620	4	2	1848	1727
46	20	1831	1385	7	5	2829	2875
47	14	1784	900	4	6	2708	3006
48	9	1227	305	6	5	3011	3026

Table A-8: Collision and length data from path set 8.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	6	1012	1320	7	6	3281	2771
2	8	1225	1043	6	6	2767	2924
3	22	871	499	6	10	2965	3277
4	17	459	1367	7	8	3073	3726
5	3	458	684	6	5	2865	2492
6	4	214	888	5	6	2585	2563
7	20	891	1361	7	4	3115	2823
8	19	845	770	8	5	2979	3188
9	21	896	990	8	10	2749	3315
10	24	446	276	6	3	2521	1774
11	16	654	929	7	5	2797	2790
12	10	509	546	6	6	3764	3792
13	12	237	283	6	7	2763	2538
14	14	660	1127	7	6	2700	2754
15	18	685	285	9	5	3753	3168
16	5	599	295	5	5	1837	1824
17	7	701	642	11	11	3253	3270
18	1	724	917	6	3	3049	3109
19	15	645	295	11	8	3411	3562
20	9	189	631	3	5	3134	3116
21	13	366	270	5	4	1887	1880
22	23	632	957	11	7	3347	3183
23	11	110	136	4	3	2771	2722
24	2	1580	317	8	8	3757	3993
25	19	629	716	5	5	2648	3158
26	18	989	271	7	7	3585	3171
27	15	331	541	9	9	3327	3289
28	10	184	1984	5	6	3768	3721
29	12	160	685	4	5	2599	2362
30	24	152	690	6	5	2611	1822
31	13	704	317	5	3	1839	1916
32	11	632	705	4	5	2431	2457
33	6	350	533	4	6	2599	2689
34	8	557	352	5	5	2769	2773
35	2	433	958	9	8	3676	3760
36	14	156	793	3	5	2460	2576
37	20	773	777	3	4	2782	2800
38	5	211	247	5	4	1939	1757
39	23	323	742	6	5	3367	3168
40	16	549	681	6	6	2843	2724
41	3	357	549	6	7	2416	2608
42	4	247	224	4	4	2386	2478
43	17	255	623	4	7	3001	3932
44	21	666	441	6	9	2517	3290
45	22	388	605	5	10	2393	3338
46	1	682	965	2	3	3089	3091
47	9	471	491	6	2	2863	3192
48	7	575	546	9	12	3237	3405

Table A-9: Collision and length data from path set 9.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	11	319	348	5	6	2847	3045
2	22	463	279	5	7	2788	3296
3	10	690	1039	9	9	4146	3991
4	3	235	409	4	6	2832	2962
5	5	279	285	4	7	2186	1923
6	9	364	435	6	8	3606	3560
7	14	151	164	4	7	2974	3104
8	7	377	351	7	9	3264	3272
9	19	200	253	3	7	2816	3824
10	4	371	483	6	7	2729	2793
11	23	329	490	8	7	3531	3752
12	12	115	215	4	7	2692	2896
13	15	340	239	6	7	3414	3438
14	13	81	17	4	1	1893	1943
15	6	185	211	5	5	3000	3265
16	24	217	233	5	5	2719	1822
17	8	384	568	4	5	2863	2807
18	16	374	364	6	7	2830	2726
19	1	428	286	8	9	3559	3721
20	2	682	398	10	8	4004	3776
21	20	100	241	3	7	2808	3074
22	17	348	731	5	9	3212	4008
23	21	365	187	5	8	2775	3406
24	18	189	96	6	5	3936	3274
25	4	325	310	6	7	2648	2857
26	7	697	1197	13	8	3476	3278
27	3	334	317	8	4	2834	2694
28	11	142	400	3	4	2700	2659
29	13	266	111	3	2	1868	1823
30	21	839	954	8	8	2819	3322
31	19	802	552	8	9	3299	3726
32	17	714	969	9	10	3745	4108
33	1	508	311	9	5	3647	3789
34	20	664	1184	9	4	3535	2757
35	2	656	1056	11	11	3942	4076
36	16	418	590	6	5	2931	2820
37	14	589	796	12	9	3179	3290
38	12	178	312	4	5	2739	2672
39	9	386	800	7	9	3497	3656
40	24	517	1027	5	5	2663	2206
41	23	696	758	11	8	3447	3390
42	18	258	1018	6	8	4125	3467
43	15	799	753	10	10	3347	3207
44	8	501	792	6	7	3013	2924
45	6	274	408	6	4	2959	2907
46	10	522	599	6	8	3891	4009
47	5	246	273	4	4	1723	1844
48	22	468	521	5	9	2582	3556

Table A-10: Collision and length data from path set 10.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	LengthL	LengthR
1	22	291	722	6	10	2783	3329
2	14	158	484	5	6	2784	2784
3	9	310	598	7	7	3369	3345
4	16	325	988	3	6	2483	2759
5	1	460	930	6	5	3292	2990
6	15	494	773	11	10	3282	3378
7	7	606	854	8	9	3312	3468
8	3	620	842	4	3	2790	2392
9	10	1204	861	10	10	3823	3558
10	11	451	721	5	6	2325	2336
11	24	496	926	6	2	2517	1723
12	23	426	1566	7	4	3424	3005
13	5	139	721	2	3	1742	1843
14	4	276	837	4	5	2400	2386
15	20	248	677	9	6	2427	3005
16	19	340	284	7	6	2536	3099
17	12	277	132	5	4	2676	2381
18	6	140	904	3	5	2547	2554
19	8	495	277	5	3	2865	2691
20	18	757	804	10	10	3706	2811
21	13	499	771	1	5	1734	1848
22	17	1070	2033	6	7	2868	3469
23	2	1245	1791	10	8	3509	3493
24	21	483	1026	5	10	2764	3171
25	24	342	989	5	3	2456	1775
26	2	1762	1578	8	9	4544	3770
27	6	767	1126	9	7	3184	3192
28	18	951	1084	8	5	3999	3172
29	14	1470	1724	12	5	3277	2738
30	1	392	948	6	5	3307	3245
31	17	575	1550	7	6	3574	3822
32	13	604	646	4	5	1914	1898
33	5	1104	784	4	3	1869	1822
34	9	313	1210	5	5	3163	3122
35	12	243	884	3	4	2563	2458
36	21	1001	1699	6	9	2747	3338
37	11	872	987	6	6	2535	2809
38	4	629	702	6	6	2663	2407
39	19	1992	1704	6	7	2763	3374
40	15	1046	1028	10	10	3312	3438
41	16	737	709	6	6	2797	3006
42	23	1584	1799	9	4	3682	3164
43	8	679	1435	5	5	2781	2791
44	3	457	766	3	5	3207	2408
45	20	684	1118	5	6	2732	2808
46	10	1520	2420	6	5	3816	3787
47	22	697	1352	8	10	3012	3375
48	7	1040	1106	7	10	3312	3272

A.2 Completion Time Results

The completion time results for the path navigation experiment are contained in tables A-11 through A-20. Each table corresponds to the results obtained from an individual participant. The columns are labeled as follows:

- Test: Test sequence number.
- ID: Path used during the test.
- Mode: Movement mode used during the test.
- TimeL: Completion time for the left object in milliseconds.
- TimeR: Completion time for the right object in milliseconds.
- Total: Total completion time in milliseconds.

Table A-11: Completion time data from path set 1.

Test	ID	Mode	TimeL	TimeR	Total
1	20	Serial	4420	4678	9098
2	19	Serial	4436	5496	9932
3	3	Serial	3856	4394	8250
4	15	Serial	4668	5496	10164
5	12	Serial	4266	4130	8396
6	13	Serial	3398	3248	6646
7	14	Serial	4418	4600	9018
8	8	Serial	4202	4692	8894
9	21	Serial	4146	5834	9980
10	5	Serial	3262	3400	6662
11	9	Serial	5282	5368	10650
12	17	Serial	4964	6634	11598
13	16	Serial	4362	4748	9110
14	11	Serial	3904	3994	7898
15	2	Serial	6214	6632	12846
16	18	Serial	6084	5112	11196
17	22	Serial	3864	4982	8846
18	7	Serial	4468	4816	9284
19	10	Serial	5848	6626	12474
20	23	Serial	4872	5112	9984
21	4	Serial	3870	4466	8336
22	6	Serial	4186	4698	8884
23	1	Serial	5504	5482	10986
24	24	Serial	3872	3166	7038
25	1	Parallel	5468	6222	6222
26	2	Parallel	6830	6724	6830
27	11	Parallel	4716	4434	4716
28	4	Parallel	4176	4212	4212
29	19	Parallel	4878	5696	5696
30	20	Parallel	4652	5416	5416
31	7	Parallel	5032	5230	5230
32	10	Parallel	6674	6866	6866
33	21	Parallel	4460	5332	5332
34	16	Parallel	4510	4650	4650
35	3	Parallel	4096	4964	4964
36	6	Parallel	4214	4258	4258
37	8	Parallel	4322	4546	4546
38	22	Parallel	3836	4960	4960
39	13	Parallel	3258	3398	3398
40	14	Parallel	4482	4414	4482
41	9	Parallel	5412	5342	5412
42	18	Parallel	6634	5416	6634
43	5	Parallel	3276	3324	3324
44	12	Parallel	4312	4424	4424
45	17	Parallel	5234	6598	6598
46	24	Parallel	4196	3308	4196
47	23	Parallel	5714	5612	5714
48	15	Parallel	5482	5800	5800

Table A-12: Completion time data from path set 2.

Test	ID	Mode	TimeL	TimeR	Total
1	1	Parallel	7916	7868	7916
2	18	Parallel	8132	6648	8132
3	19	Parallel	5530	7016	7016
4	6	Parallel	5250	5066	5250
5	9	Parallel	5798	5696	5798
6	13	Parallel	3682	3898	3898
7	12	Parallel	4544	4716	4716
8	7	Parallel	5732	5682	5732
9	15	Parallel	5046	5100	5100
10	2	Parallel	8668	7714	8668
11	17	Parallel	6432	7748	7748
12	14	Parallel	5298	5166	5298
13	4	Parallel	4582	4566	4582
14	16	Parallel	4742	4800	4800
15	21	Parallel	5848	6310	6310
16	3	Parallel	4496	4548	4548
17	5	Parallel	3718	3600	3718
18	8	Parallel	4866	5410	5410
19	24	Parallel	4928	3882	4928
20	10	Parallel	7516	7530	7530
21	22	Parallel	4430	5944	5944
22	11	Parallel	4350	4550	4550
23	20	Parallel	5066	5048	5066
24	23	Parallel	6496	6348	6496
25	4	Serial	4616	4302	8918
26	5	Serial	3632	3218	6850
27	14	Serial	4716	4400	9116
28	18	Serial	7132	5286	12418
29	12	Serial	4382	4334	8716
30	6	Serial	4728	4634	9362
31	19	Serial	4714	5254	9968
32	1	Serial	5466	5198	10664
33	7	Serial	4832	4752	9584
34	21	Serial	4416	4832	9248
35	2	Serial	7016	6602	13618
36	24	Serial	4350	2940	7290
37	3	Serial	4180	4252	8432
38	23	Serial	4916	5052	9968
39	22	Serial	4332	4870	9202
40	10	Serial	7266	8000	15266
41	9	Serial	5296	5118	10414
42	17	Serial	5198	6670	11868
43	15	Serial	4782	5402	10184
44	8	Serial	4632	4552	9184
45	11	Serial	4132	3946	8078
46	20	Serial	5098	4336	9434
47	13	Serial	3566	3194	6760
48	16	Serial	4816	4352	9168

Table A-13: Completion time data from path set 3.

Test	ID	Mode	TimeL	TimeR	Total
1	2	Parallel	9814	10248	10248
2	1	Parallel	6716	6650	6716
3	4	Parallel	5450	5250	5450
4	9	Parallel	7200	7200	7200
5	3	Parallel	6030	6330	6330
6	21	Parallel	5682	8084	8084
7	6	Parallel	7000	6796	7000
8	24	Parallel	4946	4700	4946
9	11	Parallel	4998	4878	4998
10	19	Parallel	5996	6450	6450
11	5	Parallel	3912	4112	4112
12	8	Parallel	6616	6648	6648
13	23	Parallel	6966	6846	6966
14	18	Parallel	7174	6402	7174
15	17	Parallel	7100	8500	8500
16	13	Parallel	3846	3778	3846
17	12	Parallel	5194	5466	5466
18	16	Parallel	5466	5666	5666
19	14	Parallel	5932	5344	5932
20	10	Parallel	7794	7566	7794
21	15	Parallel	6466	6516	6516
22	22	Parallel	5046	7050	7050
23	20	Parallel	6168	7050	7050
24	7	Parallel	6716	6950	6950
25	3	Serial	5040	4740	9780
26	16	Serial	5466	4968	10434
27	21	Serial	5448	5970	11418
28	19	Serial	4592	5408	10000
29	11	Serial	4244	4588	8832
30	9	Serial	5334	5684	11018
31	22	Serial	4292	5792	10084
32	6	Serial	4432	4568	9000
33	23	Serial	5132	5686	10818
34	18	Serial	6812	5706	12518
35	14	Serial	4696	4888	9584
36	8	Serial	4916	4952	9868
37	1	Serial	6244	5774	12018
38	10	Serial	6828	6956	13784
39	2	Serial	6930	7338	14268
40	7	Serial	4840	4876	9716
41	17	Serial	5850	6702	12552
42	4	Serial	4416	4168	8584
43	20	Serial	4814	4954	9768
44	12	Serial	4550	3984	8534
45	24	Serial	4548	3218	7766
46	15	Serial	5244	4690	9934
47	5	Serial	3664	3262	6926
48	13	Serial	3782	3364	7146

Table A-14: Completion time data from path set 4.

Test	ID	Mode	TimeL	TimeR	Total
1	24	Serial	4958	3508	8466
2	6	Serial	5400	3996	9396
3	18	Serial	6614	4654	11268
4	13	Serial	3226	2768	5994
5	12	Serial	4228	3728	7956
6	21	Serial	4672	4424	9096
7	4	Serial	4102	3810	7912
8	9	Serial	5014	4768	9782
9	2	Serial	6674	5896	12570
10	1	Serial	5076	4538	9614
11	7	Serial	4384	4200	8584
12	14	Serial	4044	3802	7846
13	23	Serial	4802	4378	9180
14	10	Serial	6260	5736	11996
15	16	Serial	4348	4008	8356
16	20	Serial	4264	3880	8144
17	22	Serial	3858	4296	8154
18	17	Serial	4958	5910	10868
19	5	Serial	3176	3096	6272
20	3	Serial	3996	3614	7610
21	8	Serial	4348	3996	8344
22	15	Serial	4402	4630	9032
23	11	Serial	3884	3576	7460
24	19	Serial	3950	4736	8686
25	14	Parallel	4402	4386	4402
26	1	Parallel	5148	5082	5148
27	18	Parallel	7348	6036	7348
28	11	Parallel	4044	3982	4044
29	24	Parallel	4604	3382	4604
30	16	Parallel	4516	4566	4566
31	4	Parallel	4526	4318	4526
32	7	Parallel	5032	4970	5032
33	8	Parallel	4598	4626	4626
34	12	Parallel	4252	4176	4252
35	20	Parallel	4298	4516	4516
36	6	Parallel	4682	4566	4682
37	17	Parallel	5162	6308	6308
38	9	Parallel	5416	5326	5416
39	21	Parallel	4670	5082	5082
40	2	Parallel	6460	6486	6486
41	19	Parallel	5132	5294	5294
42	10	Parallel	6544	6512	6544
43	13	Parallel	3330	3400	3400
44	3	Parallel	3998	4066	4066
45	15	Parallel	4982	4888	4982
46	22	Parallel	4498	4976	4976
47	5	Parallel	3326	3240	3326
48	23	Parallel	5082	5716	5716

Table A-15: Completion time data from path set 5.

Test	ID	Mode	TimeL	TimeR	Total
1	14	Parallel	10900	11000	11000
2	21	Parallel	6816	8718	8718
3	9	Parallel	6612	6600	6612
4	3	Parallel	5448	5548	5548
5	16	Parallel	5882	6216	6216
6	6	Parallel	6746	6812	6812
7	10	Parallel	7866	8112	8112
8	18	Parallel	7548	6250	7548
9	24	Parallel	5796	4630	5796
10	19	Parallel	6582	6746	6746
11	23	Parallel	5560	6882	6882
12	11	Parallel	5482	5446	5482
13	4	Parallel	5066	5196	5196
14	17	Parallel	6750	8616	8616
15	8	Parallel	5516	6284	6284
16	7	Parallel	6400	6400	6400
17	22	Parallel	4548	6782	6782
18	20	Parallel	5384	6966	6966
19	1	Parallel	5710	6362	6362
20	12	Parallel	5062	5096	5096
21	13	Parallel	3832	3728	3832
22	2	Parallel	9316	9430	9430
23	5	Parallel	3964	3962	3964
24	15	Parallel	6316	6366	6366
25	2	Serial	6932	7134	14066
26	6	Serial	4666	4398	9064
27	12	Serial	4402	4204	8606
28	20	Serial	4446	4804	9250
29	24	Serial	4982	3032	8014
30	7	Serial	5432	5434	10866
31	17	Serial	5364	6402	11766
32	23	Serial	5500	5040	10540
33	15	Serial	5082	5418	10500
34	8	Serial	4966	4750	9716
35	21	Serial	4694	5440	10134
36	3	Serial	4250	4070	8320
37	9	Serial	5366	5330	10696
38	1	Serial	5438	5008	10446
39	16	Serial	4666	4616	9282
40	4	Serial	5028	4528	9556
41	5	Serial	3410	2920	6330
42	10	Serial	6786	6878	13664
43	13	Serial	3458	3304	6762
44	22	Serial	5014	5154	10168
45	14	Serial	4280	4368	8648
46	11	Serial	5232	4280	9512
47	19	Serial	4648	5260	9908
48	18	Serial	6918	5478	12396

Table A-16: Completion time data from path set 6.

Test	ID	Mode	TimeL	TimeR	Total
1	22	Parallel	7366	7684	7684
2	24	Parallel	5316	4048	5316
3	4	Parallel	5450	5496	5496
4	9	Parallel	7778	7612	7778
5	12	Parallel	4626	4460	4626
6	18	Parallel	8066	6546	8066
7	20	Parallel	5450	5516	5516
8	7	Parallel	6148	6066	6148
9	14	Parallel	5596	5766	5766
10	19	Parallel	6166	6146	6166
11	2	Parallel	8312	8334	8334
12	10	Parallel	7696	7780	7780
13	17	Parallel	7328	8916	8916
14	13	Parallel	3934	4946	4946
15	15	Parallel	5932	6116	6116
16	16	Parallel	6466	6232	6466
17	1	Parallel	7516	7466	7516
18	23	Parallel	9116	8630	9116
19	21	Parallel	5344	7572	7572
20	11	Parallel	5366	5110	5366
21	8	Parallel	6098	6148	6148
22	3	Parallel	4848	4796	4848
23	5	Parallel	4300	4246	4300
24	6	Parallel	5584	5350	5584
25	6	Serial	5206	5578	10784
26	1	Serial	5898	7066	12964
27	13	Serial	3372	4028	7400
28	11	Serial	4768	5184	9952
29	24	Serial	4842	3388	8230
30	10	Serial	6984	7914	14898
31	5	Serial	3588	3408	6996
32	21	Serial	4916	5866	10782
33	9	Serial	6084	6134	12218
34	16	Serial	4602	5182	9784
35	22	Serial	4352	5600	9952
36	2	Serial	6952	7496	14448
37	3	Serial	4180	4364	8544
38	12	Serial	5436	4862	10298
39	15	Serial	5384	5766	11150
40	23	Serial	6900	6216	13116
41	14	Serial	5134	5562	10696
42	17	Serial	5984	8084	14068
43	18	Serial	6900	5818	12718
44	8	Serial	4402	5848	10250
45	20	Serial	4952	5464	10416
46	4	Serial	4404	4290	8694
47	7	Serial	4980	5766	10746
48	19	Serial	4458	6382	10840

Table A-17: Completion time data from path set 7.

Test	ID	Mode	TimeL	TimeR	Total
1	11	Serial	5166	5248	10414
2	15	Serial	5684	5818	11502
3	19	Serial	4812	5652	10464
4	8	Serial	5016	5434	10450
5	9	Serial	5288	5680	10968
6	24	Serial	4258	2876	7134
7	1	Serial	5540	5462	11002
8	16	Serial	5432	5084	10516
9	21	Serial	5382	5212	10594
10	6	Serial	4662	4704	9366
11	3	Serial	4382	4182	8564
12	13	Serial	3364	2896	6260
13	7	Serial	5216	4918	10134
14	14	Serial	4676	4586	9262
15	10	Serial	6916	8502	15418
16	4	Serial	4340	3866	8206
17	18	Serial	6782	5686	12468
18	5	Serial	3324	2920	6244
19	2	Serial	7684	6866	14550
20	17	Serial	5152	6616	11768
21	22	Serial	4240	4776	9016
22	23	Serial	5314	5686	11000
23	20	Serial	4600	4484	9084
24	12	Serial	4474	3834	8308
25	13	Parallel	3700	3712	3712
26	23	Parallel	7214	6584	7214
27	10	Parallel	7452	7664	7664
28	7	Parallel	7066	5964	7066
29	19	Parallel	6266	6332	6332
30	15	Parallel	5700	5600	5700
31	24	Parallel	4716	3406	4716
32	1	Parallel	8114	6598	8114
33	16	Parallel	5416	5366	5416
34	22	Parallel	5482	5596	5596
35	21	Parallel	5948	6282	6282
36	8	Parallel	6182	5300	6182
37	12	Parallel	5296	4562	5296
38	18	Parallel	8380	6846	8380
39	6	Parallel	5210	5282	5282
40	4	Parallel	5250	5166	5250
41	11	Parallel	4966	4582	4966
42	3	Parallel	4678	4494	4678
43	2	Parallel	7368	7350	7368
44	17	Parallel	5982	7910	7910
45	5	Parallel	4696	3626	4696
46	20	Parallel	6550	5634	6550
47	14	Parallel	5896	5896	5896
48	9	Parallel	5426	5446	5446

Table A-18: Completion time data from path set 8.

Test	ID	Mode	TimeL	TimeR	Total
1	6	Parallel	7034	7016	7034
2	8	Parallel	5982	6098	6098
3	22	Parallel	4900	5004	5004
4	17	Parallel	5880	7008	7008
5	3	Parallel	5286	4422	5286
6	4	Parallel	4916	5000	5000
7	20	Parallel	5828	5598	5828
8	19	Parallel	6434	6466	6466
9	21	Parallel	5282	5696	5696
10	24	Parallel	5066	3866	5066
11	16	Parallel	5282	5400	5400
12	10	Parallel	7182	7134	7182
13	12	Parallel	4548	4576	4576
14	14	Parallel	5066	5080	5080
15	18	Parallel	6962	5684	6962
16	5	Parallel	3676	3652	3676
17	7	Parallel	5094	5106	5106
18	1	Parallel	5780	5700	5780
19	15	Parallel	5530	5632	5632
20	9	Parallel	5578	5596	5596
21	13	Parallel	3476	3632	3632
22	23	Parallel	5594	6346	6346
23	11	Parallel	4460	4734	4734
24	2	Parallel	7562	7550	7562
25	19	Serial	4716	4996	9712
26	18	Serial	6756	5344	12100
27	15	Serial	4864	4464	9328
28	10	Serial	6866	6252	13118
29	12	Serial	4308	4164	8472
30	24	Serial	4270	3022	7292
31	13	Serial	3442	3188	6630
32	11	Serial	4278	3648	7926
33	6	Serial	4484	4564	9048
34	8	Serial	4566	4734	9300
35	2	Serial	6600	6402	13002
36	14	Serial	4248	4052	8300
37	20	Serial	4678	4324	9002
38	5	Serial	3316	3046	6362
39	23	Serial	4848	4902	9750
40	16	Serial	4448	4094	8542
41	3	Serial	4212	3916	8128
42	4	Serial	4330	4088	8418
43	17	Serial	5326	7108	12434
44	21	Serial	4482	4592	9074
45	22	Serial	4104	5046	9150
46	1	Serial	5494	4970	10464
47	9	Serial	4990	5260	10250
48	7	Serial	4576	4692	9268

Table A-19: Completion time data from path set 9.

Test	ID	Mode	TimeL	TimeR	Total
1	11	Serial	5348	5286	10634
2	22	Serial	3818	5948	9766
3	10	Serial	7390	7712	15102
4	3	Serial	4452	4598	9050
5	5	Serial	4026	3358	7384
6	9	Serial	5884	5600	11484
7	14	Serial	4916	4866	9782
8	7	Serial	4654	4996	9650
9	19	Serial	4350	6000	10350
10	4	Serial	4352	4466	8818
11	23	Serial	5050	5650	10700
12	12	Serial	4400	4484	8884
13	15	Serial	5116	4984	10100
14	13	Serial	3116	3616	6732
15	6	Serial	4648	4768	9416
16	24	Serial	3938	3256	7194
17	8	Serial	4366	4662	9028
18	16	Serial	4512	4416	8928
19	1	Serial	5380	5502	10882
20	2	Serial	6486	6566	13052
21	20	Serial	4750	4764	9514
22	17	Serial	5122	6680	11802
23	21	Serial	4496	4754	9250
24	18	Serial	6606	5328	11934
25	4	Parallel	4410	4548	4548
26	7	Parallel	5458	5682	5682
27	3	Parallel	4168	4284	4284
28	11	Parallel	4114	4250	4250
29	13	Parallel	3532	3582	3582
30	21	Parallel	4946	5326	5326
31	19	Parallel	5184	5734	5734
32	17	Parallel	5782	7350	7350
33	1	Parallel	5512	5850	5850
34	20	Parallel	5866	5432	5866
35	2	Parallel	6632	6782	6782
36	16	Parallel	4780	4966	4966
37	14	Parallel	5098	5482	5482
38	12	Parallel	4566	4616	4616
39	9	Parallel	5548	5616	5616
40	24	Parallel	4362	4182	4362
41	23	Parallel	5500	5766	5766
42	18	Parallel	7032	5916	7032
43	15	Parallel	5486	5332	5486
44	8	Parallel	5176	4932	5176
45	6	Parallel	4650	4548	4650
46	10	Parallel	6794	6800	6800
47	5	Parallel	3192	3216	3216
48	22	Parallel	4532	5684	5684

Table A-20: Completion time data from path set 10.

Test	ID	Mode	TimeL	TimeR	Total
1	22	Serial	5366	6152	11518
2	14	Serial	6300	5752	12052
3	9	Serial	7386	6000	13386
4	16	Serial	6566	5114	11680
5	1	Serial	6450	5580	12030
6	15	Serial	5596	5388	10984
7	7	Serial	5766	6534	12300
8	3	Serial	4650	4384	9034
9	10	Serial	6976	6626	13602
10	11	Serial	4558	4698	9256
11	24	Serial	4594	3754	8348
12	23	Serial	5566	5514	11080
13	5	Serial	3350	4196	7546
14	4	Serial	4398	4076	8474
15	20	Serial	4250	5350	9600
16	19	Serial	4450	5648	10098
17	12	Serial	4766	4594	9360
18	6	Serial	4368	5060	9428
19	8	Serial	5300	5384	10684
20	18	Serial	6842	6102	12944
21	13	Serial	3722	3708	7430
22	17	Serial	5282	6574	11856
23	2	Serial	6282	6482	12764
24	21	Serial	4734	5280	10014
25	24	Parallel	5246	3962	5246
26	2	Parallel	9728	8132	9728
27	6	Parallel	6300	6066	6300
28	18	Parallel	8514	6830	8514
29	14	Parallel	7180	7180	7180
30	1	Parallel	6278	6266	6278
31	17	Parallel	6780	7780	7780
32	13	Parallel	3574	3508	3574
33	5	Parallel	4046	3996	4046
34	9	Parallel	5778	5714	5778
35	12	Parallel	4578	4406	4578
36	21	Parallel	6062	6850	6850
37	11	Parallel	4878	5822	5822
38	4	Parallel	4950	4600	4950
39	19	Parallel	6896	6740	6896
40	15	Parallel	5632	5816	5816
41	16	Parallel	5400	5480	5480
42	23	Parallel	6816	6596	6816
43	8	Parallel	5434	5818	5818
44	3	Parallel	5478	4214	5478
45	20	Parallel	5006	5766	5766
46	10	Parallel	7386	7518	7518
47	22	Parallel	5350	6618	6618
48	7	Parallel	5850	5900	5900

Appendix B – Obstacle-Dodging Experiment Data

B.1 Obstacle Dodging Testing Conditions

The testing conditions for the obstacle-dodging experiment are shown in table B-1. The table represents a full factorial design for the four factors listed. The fifth factor tested, auditory cues, was randomized between subjects and is not included in table B-1. The condition sets were randomly assigned for each test set used in tables B-2 through B-22.

Table B-1: Testing conditions for the obstacle-dodging experiment.

ID	Color	Shape	Temporal	Spatial
1	Normal	Normal	Normal	Normal
2	Normal	Normal	Normal	Close
3	Normal	Normal	Normal	Far
4	Normal	Normal	Fast	Normal
5	Normal	Normal	Fast	Close
6	Normal	Normal	Fast	Far
7	Normal	Different	Normal	Normal
8	Normal	Different	Normal	Close
9	Normal	Different	Normal	Far
10	Normal	Different	Fast	Normal
11	Normal	Different	Fast	Close
12	Normal	Different	Fast	Far
13	Different	Normal	Normal	Normal
14	Different	Normal	Normal	Close
15	Different	Normal	Normal	Far
16	Different	Normal	Fast	Normal
17	Different	Normal	Fast	Close
18	Different	Normal	Fast	Far
19	Different	Different	Normal	Normal
20	Different	Different	Normal	Close
21	Different	Different	Normal	Far
22	Different	Different	Fast	Normal
23	Different	Different	Fast	Close
24	Different	Different	Fast	Far

B.2 Obstacle Dodging Results

The results for the obstacle-dodging experiment are contained in tables B-2 through B-22. Each table corresponds to the results obtained from an individual participant. The columns are labeled as follows:

- Test: Test sequence number.
- ID: Obstacle pattern used during the test.
- ColRawL: Collision time for the left object in raw frames (1 frame = 2 ms).
- ColRawR: Collision time for the right object in raw frames (1 frame = 2 ms).
- ColRealL: Individual collisions for the left object.
- ColRealR: Individual collisions for the right object.
- TotalHit: Total number of individual obstacles collided with.
- Cue: Auditory cue used during the test set.

Table B-2: Result data for dodge set 1.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	20	153	486	1	4	4	None
2	6	179	276	3	2	3	None
3	8	153	153	1	1	2	None
4	19	462	343	4	3	5	None
5	16	105	274	2	3	3	None
6	22	179	164	3	3	3	None
7	14	73	73	1	1	1	None
8	12	173	19	4	1	4	None
9	24	5	1	1	1	2	None
10	13	0	0	0	0	0	None
11	3	24	212	1	3	4	None
12	21	161	183	5	4	6	None
13	1	5	123	1	3	4	None
14	11	0	0	0	0	0	None
15	2	0	502	0	4	4	None
16	5	75	158	2	3	3	None
17	17	459	459	3	3	3	None
18	23	21	105	1	1	2	None
19	18	157	1	2	1	2	None
20	10	47	0	1	0	1	None
21	4	0	292	0	2	2	None
22	9	255	220	3	2	3	None
23	15	377	307	5	4	6	None
24	7	0	0	0	0	0	None
25	7	0	6	0	1	1	None
26	6	61	53	1	1	1	None
27	19	309	272	5	5	6	None
28	23	153	241	1	2	2	None
29	4	35	63	1	3	3	None
30	21	459	310	3	3	4	None
31	10	4	47	1	1	2	None
32	13	0	0	0	0	0	None
33	8	153	153	1	1	2	None
34	1	30	72	1	1	2	None
35	12	62	159	2	3	4	None
36	2	276	288	2	3	4	None
37	14	56	76	1	2	3	None
38	22	0	37	0	1	1	None
39	24	0	0	0	0	0	None
40	15	210	63	3	2	2	None
41	9	114	96	2	2	3	None
42	5	299	397	3	3	4	None
43	3	229	153	3	1	3	None
44	11	153	190	1	2	2	None
45	18	153	0	1	0	1	None
46	20	60	239	1	2	3	None
47	17	176	349	3	3	4	None
48	16	68	52	2	2	2	None

Table B-3: Result data for dodge set 2.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	10	115	170	4	2	5	None
2	19	145	220	3	2	3	None
3	2	143	278	1	3	3	None
4	12	199	83	3	2	3	None
5	4	0	143	0	2	1	None
6	7	0	0	0	0	0	None
7	11	204	66	2	1	2	None
8	6	153	342	1	4	3	None
9	8	58	0	1	0	1	None
10	24	0	9	0	1	1	None
11	15	380	296	6	2	3	None
12	14	204	256	2	3	3	None
13	3	195	153	2	1	1	None
14	20	186	194	3	3	4	None
15	13	0	10	0	1	1	None
16	1	94	59	1	1	2	None
17	16	0	0	0	0	0	None
18	21	152	153	3	1	3	None
19	18	0	0	0	0	0	None
20	23	0	0	0	0	0	None
21	5	153	156	1	2	2	None
22	9	0	51	0	2	2	None
23	22	0	0	0	0	0	None
24	17	8	237	1	2	2	None
25	1	0	0	0	0	0	None
26	10	0	160	0	2	2	None
27	12	0	0	0	0	0	None
28	23	0	0	0	0	0	None
29	15	0	25	0	1	1	None
30	22	0	0	0	0	0	None
31	16	0	0	0	0	0	None
32	14	0	349	0	3	2	None
33	11	0	153	0	1	1	None
34	24	76	0	3	0	2	None
35	9	206	238	5	5	5	None
36	7	0	0	0	0	0	None
37	19	0	0	0	0	0	None
38	20	153	329	1	3	3	None
39	5	0	67	0	1	1	None
40	2	43	33	1	1	2	None
41	17	0	0	0	0	0	None
42	4	0	0	0	0	0	None
43	21	0	0	0	0	0	None
44	8	153	187	1	2	3	None
45	6	0	0	0	0	0	None
46	13	0	0	0	0	0	None
47	3	0	0	0	0	0	None
48	18	0	0	0	0	0	None

Table B-4: Result data for dodge set 3.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	22	0	25	0	1	1	Different
2	21	224	187	2	3	3	Different
3	18	0	65	0	1	1	Different
4	2	20	176	2	2	3	Different
5	1	153	215	1	2	3	Different
6	16	98	98	2	2	2	Different
7	13	0	0	0	0	0	Different
8	9	249	75	3	2	3	Different
9	24	150	153	2	1	3	Different
10	6	147	177	1	2	2	Different
11	10	0	0	0	0	0	Different
12	17	325	168	3	2	3	Different
13	19	41	57	2	2	2	Different
14	8	0	0	0	0	0	Different
15	14	144	7	3	1	2	Different
16	5	153	153	1	1	2	Different
17	7	0	0	0	0	0	Different
18	23	170	58	2	1	2	Different
19	20	62	62	1	1	1	Different
20	3	71	153	1	1	1	Different
21	4	0	0	0	0	0	Different
22	15	181	168	2	3	2	Different
23	11	153	306	1	2	2	Different
24	12	0	39	0	1	1	Different
25	7	0	0	0	0	0	Different
26	16	0	0	0	0	0	Different
27	8	23	40	1	1	1	Different
28	1	0	0	0	0	0	Different
29	5	236	74	2	1	2	Different
30	12	0	23	0	1	1	Different
31	15	60	0	3	0	2	Different
32	17	0	0	0	0	0	Different
33	2	9	0	1	0	1	Different
34	22	0	0	0	0	0	Different
35	3	0	0	0	0	0	Different
36	19	22	14	2	2	2	Different
37	6	96	96	1	1	1	Different
38	18	0	0	0	0	0	Different
39	14	153	0	1	0	1	Different
40	23	0	0	0	0	0	Different
41	10	0	0	0	0	0	Different
42	4	0	0	0	0	0	Different
43	13	0	0	0	0	0	Different
44	20	0	0	0	0	0	Different
45	11	0	0	0	0	0	Different
46	21	306	306	2	2	2	Different
47	9	6	15	1	1	1	Different
48	24	50	0	1	0	1	Different

Table B-5: Result data for dodge set 4.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	13	77	71	2	1	1	None
2	12	153	314	1	3	3	None
3	3	0	42	0	1	1	None
4	11	0	11	0	1	1	None
5	16	459	409	3	3	4	None
6	5	195	467	2	4	3	None
7	10	27	0	1	0	1	None
8	24	630	323	5	3	5	None
9	17	359	612	3	4	4	None
10	9	466	414	5	3	5	None
11	21	97	74	2	1	3	None
12	8	103	31	1	1	1	None
13	14	153	11	1	1	2	None
14	18	0	0	0	0	0	None
15	4	29	120	1	1	2	None
16	19	0	84	0	1	1	None
17	20	388	265	3	2	4	None
18	23	94	350	4	4	4	None
19	15	111	147	1	3	3	None
20	22	40	0	2	0	2	None
21	2	0	27	0	1	1	None
22	7	0	0	0	0	0	None
23	1	12	0	1	0	1	None
24	6	264	245	2	3	3	None
25	9	256	278	2	2	3	None
26	2	0	153	0	1	1	None
27	21	164	25	3	1	4	None
28	1	157	36	2	1	2	None
29	12	44	61	1	1	1	None
30	19	0	10	0	1	1	None
31	23	306	459	2	3	4	None
32	15	0	41	0	2	2	None
33	10	0	129	0	1	1	None
34	24	441	0	3	0	3	None
35	13	0	153	0	1	1	None
36	16	0	215	0	2	2	None
37	6	121	352	2	4	4	None
38	3	0	0	0	0	0	None
39	22	0	61	0	1	1	None
40	18	0	109	0	1	1	None
41	8	0	0	0	0	0	None
42	4	87	1	1	1	2	None
43	5	56	115	2	2	3	None
44	17	189	176	2	3	5	None
45	20	156	269	2	2	2	None
46	7	0	103	0	1	1	None
47	11	4	168	1	2	2	None
48	14	153	153	1	1	1	None

Table B-6: Result data for dodge set 5.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	23	0	242	0	3	3	Different
2	21	369	352	4	3	5	Different
3	20	153	153	1	1	1	Different
4	13	0	0	0	0	0	Different
5	22	185	0	2	0	2	Different
6	5	303	540	2	4	4	Different
7	19	306	59	2	2	4	Different
8	10	67	0	1	0	1	Different
9	7	8	0	1	0	1	Different
10	8	0	197	0	2	2	Different
11	2	320	348	3	3	4	Different
12	14	0	0	0	0	0	Different
13	6	0	0	0	0	0	Different
14	11	0	0	0	0	0	Different
15	15	116	109	2	2	2	Different
16	18	0	26	0	2	2	Different
17	12	0	153	0	1	1	Different
18	3	270	551	2	6	5	Different
19	24	153	153	1	1	1	Different
20	9	41	42	2	2	4	Different
21	1	153	153	1	1	1	Different
22	16	224	161	3	2	4	Different
23	4	43	26	1	1	1	Different
24	17	8	153	1	1	2	Different
25	23	228	347	2	3	3	Different
26	21	153	153	1	1	1	Different
27	12	17	178	1	2	3	Different
28	6	429	483	4	4	5	Different
29	22	213	0	2	0	2	Different
30	10	42	101	1	1	2	Different
31	24	23	58	1	1	2	Different
32	4	0	0	0	0	0	Different
33	15	0	0	0	0	0	Different
34	2	184	213	2	2	3	Different
35	3	357	306	3	2	3	Different
36	14	0	0	0	0	0	Different
37	19	153	169	1	2	2	Different
38	8	0	0	0	0	0	Different
39	16	154	153	2	1	2	Different
40	5	153	237	1	2	2	Different
41	1	153	153	1	1	1	Different
42	20	0	0	0	0	0	Different
43	9	0	0	0	0	0	Different
44	18	200	251	2	4	4	Different
45	17	66	0	1	0	1	Different
46	11	100	337	1	3	3	Different
47	13	153	153	1	1	1	Different
48	7	0	171	0	2	2	Different

Table B-7: Result data for dodge set 6.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	14	921	1095	8	9	12	Same
2	6	859	484	7	6	8	Same
3	5	405	642	5	5	7	Same
4	16	343	336	7	3	8	Same
5	4	22	76	1	4	5	Same
6	23	306	374	2	5	6	Same
7	19	318	148	3	3	3	Same
8	9	410	767	6	7	8	Same
9	15	883	352	7	4	8	Same
10	7	11	0	1	0	1	Same
11	18	509	264	5	4	7	Same
12	1	0	0	0	0	0	Same
13	20	612	167	4	2	5	Same
14	17	0	153	0	1	1	Same
15	13	285	17	3	1	3	Same
16	24	599	427	8	6	7	Same
17	10	153	61	1	3	4	Same
18	22	117	100	4	1	5	Same
19	21	823	570	8	5	9	Same
20	3	156	391	5	4	8	Same
21	8	175	188	2	2	4	Same
22	12	298	462	4	5	8	Same
23	11	0	298	0	5	5	Same
24	2	765	765	5	5	7	Same
25	13	288	40	4	1	4	Same
26	20	326	314	2	3	3	Same
27	10	381	153	3	1	4	Same
28	1	306	0	2	0	2	Same
29	7	459	336	3	3	4	Same
30	9	632	306	6	2	7	Same
31	17	153	306	1	2	3	Same
32	14	153	153	1	1	1	Same
33	8	153	42	1	1	2	Same
34	16	306	153	2	1	2	Same
35	21	868	479	6	4	8	Same
36	18	325	170	5	2	7	Same
37	4	153	277	1	3	4	Same
38	11	58	153	1	1	1	Same
39	2	680	628	5	5	6	Same
40	22	64	78	1	1	2	Same
41	6	548	520	6	4	9	Same
42	23	0	33	0	2	2	Same
43	24	222	205	4	2	5	Same
44	12	205	179	2	2	3	Same
45	15	546	334	5	3	6	Same
46	5	459	459	3	3	3	Same
47	3	283	367	4	4	8	Same
48	19	0	0	0	0	0	Same

Table B-8: Result data for dodge set 7.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	9	153	348	1	4	4	Same
2	11	153	0	1	0	1	Same
3	15	191	153	3	1	2	Same
4	3	152	169	1	2	3	Same
5	14	153	101	1	1	2	Same
6	8	1	91	1	4	5	Same
7	19	68	34	2	1	2	Same
8	16	9	17	1	1	1	Same
9	5	233	543	3	5	7	Same
10	24	5	93	1	1	2	Same
11	1	192	132	3	1	2	Same
12	12	0	0	0	0	0	Same
13	17	687	103	6	1	5	Same
14	20	153	306	1	2	2	Same
15	2	153	280	1	3	3	Same
16	7	0	434	0	5	5	Same
17	21	189	370	3	4	6	Same
18	6	153	218	1	7	7	Same
19	22	188	58	2	2	4	Same
20	4	0	26	0	1	1	Same
21	23	0	0	0	0	0	Same
22	18	0	13	0	1	1	Same
23	13	0	16	0	1	1	Same
24	10	0	18	0	1	1	Same
25	21	0	180	0	2	2	Same
26	5	287	459	2	3	3	Same
27	22	188	0	2	0	2	Same
28	14	0	43	0	1	1	Same
29	1	0	0	0	0	0	Same
30	10	0	9	0	1	1	Same
31	16	0	25	0	1	1	Same
32	20	153	162	1	2	2	Same
33	7	42	29	1	1	1	Same
34	2	153	153	1	1	1	Same
35	17	153	153	1	1	2	Same
36	19	49	0	2	0	1	Same
37	18	0	0	0	0	0	Same
38	11	0	0	0	0	0	Same
39	24	89	16	3	1	2	Same
40	3	0	0	0	0	0	Same
41	15	192	153	2	1	2	Same
42	6	0	178	0	3	3	Same
43	9	423	209	4	4	7	Same
44	8	289	306	2	2	3	Same
45	12	80	27	1	3	3	Same
46	13	59	13	1	1	2	Same
47	4	17	67	1	2	3	Same
48	23	0	153	0	1	1	Same

Table B-9: Result data for dodge set 8.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	16	455	405	4	6	7	Different
2	18	0	0	0	0	0	Different
3	23	223	218	2	2	3	Different
4	9	457	234	3	2	3	Different
5	22	72	136	1	2	3	Different
6	7	29	63	1	1	2	Different
7	11	153	12	1	1	2	Different
8	10	7	103	1	1	2	Different
9	19	153	153	1	1	1	Different
10	13	70	19	1	1	2	Different
11	4	0	7	0	1	1	Different
12	6	47	9	1	1	2	Different
13	12	281	230	3	3	4	Different
14	1	153	6	1	1	2	Different
15	15	186	191	3	3	3	Different
16	21	82	210	1	2	2	Different
17	5	39	231	1	3	3	Different
18	3	343	83	4	2	4	Different
19	2	221	153	3	1	3	Different
20	17	0	24	0	2	2	Different
21	8	0	72	0	1	1	Different
22	14	25	99	2	2	3	Different
23	20	211	153	2	1	2	Different
24	24	239	714	5	7	5	Different
25	5	153	153	1	1	1	Different
26	18	13	5	2	1	3	Different
27	8	0	0	0	0	0	Different
28	19	0	8	0	1	1	Different
29	13	153	200	1	2	2	Different
30	9	40	22	1	1	2	Different
31	16	67	0	2	0	2	Different
32	4	153	153	1	1	1	Different
33	1	0	0	0	0	0	Different
34	7	0	0	0	0	0	Different
35	24	0	306	0	2	2	Different
36	11	0	18	0	2	2	Different
37	14	0	0	0	0	0	Different
38	6	153	153	1	1	1	Different
39	23	0	0	0	0	0	Different
40	22	0	0	0	0	0	Different
41	15	0	25	0	1	1	Different
42	3	0	0	0	0	0	Different
43	2	125	0	2	0	2	Different
44	12	0	0	0	0	0	Different
45	17	0	24	0	2	2	Different
46	20	0	0	0	0	0	Different
47	21	0	238	0	2	2	Different
48	10	0	0	0	0	0	Different

Table B-10: Result data for dodge set 9.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	16	296	0	4	0	4	Different
2	14	0	101	0	1	1	Different
3	24	244	153	4	1	3	Different
4	4	153	355	1	3	3	Different
5	12	9	70	1	1	2	Different
6	17	100	26	1	1	2	Different
7	15	455	423	6	5	9	Different
8	8	93	33	2	1	2	Different
9	6	538	666	6	7	6	Different
10	21	331	153	4	1	3	Different
11	3	153	108	5	1	4	Different
12	5	221	507	3	6	7	Different
13	1	348	279	4	4	4	Different
14	19	187	306	2	5	5	Different
15	22	400	33	4	2	4	Different
16	10	68	35	1	2	2	Different
17	23	196	212	2	2	3	Different
18	2	322	597	4	5	6	Different
19	11	25	229	1	2	3	Different
20	9	284	177	2	4	4	Different
21	7	0	58	0	1	1	Different
22	13	133	117	1	2	1	Different
23	18	326	217	3	2	3	Different
24	20	153	363	1	4	3	Different
25	6	516	455	9	5	6	Different
26	4	8	134	1	1	2	Different
27	23	0	0	0	0	0	Different
28	19	194	83	4	2	3	Different
29	5	153	0	1	0	1	Different
30	7	0	29	0	1	1	Different
31	20	237	193	4	2	3	Different
32	14	51	0	1	0	1	Different
33	3	345	334	4	3	3	Different
34	13	0	0	0	0	0	Different
35	2	306	293	2	3	2	Different
36	24	286	0	4	0	4	Different
37	11	0	0	0	0	0	Different
38	15	114	306	1	2	3	Different
39	17	58	42	1	1	2	Different
40	10	0	0	0	0	0	Different
41	16	143	0	1	0	1	Different
42	12	0	156	0	1	1	Different
43	1	47	0	2	0	1	Different
44	21	153	48	1	1	1	Different
45	8	0	0	0	0	0	Different
46	22	92	0	2	0	1	Different
47	18	0	83	0	1	1	Different
48	9	50	0	2	0	1	Different

Table B-11: Result data for dodge set 10.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	9	315	545	6	6	9	Same
2	17	228	228	2	2	2	Same
3	7	0	0	0	0	0	Same
4	8	180	0	2	0	2	Same
5	6	217	100	2	1	2	Same
6	11	3	0	1	0	1	Same
7	18	251	0	3	0	2	Same
8	13	133	0	1	0	1	Same
9	3	76	0	1	0	2	Same
10	24	215	56	3	1	4	Same
11	22	0	39	0	1	1	Same
12	12	108	342	1	4	4	Same
13	19	152	58	3	1	3	Same
14	21	395	303	4	4	4	Same
15	4	0	180	0	3	3	Same
16	1	162	42	2	1	3	Same
17	2	344	93	4	3	5	Same
18	16	187	153	3	1	3	Same
19	5	153	223	1	3	3	Same
20	15	258	89	2	2	5	Same
21	20	117	212	1	3	3	Same
22	23	0	0	0	0	0	Same
23	10	0	153	0	1	1	Same
24	14	160	117	2	1	2	Same
25	8	153	0	1	0	1	Same
26	1	0	0	0	0	0	Same
27	17	153	153	1	1	1	Same
28	15	229	212	3	6	3	Same
29	6	153	178	1	2	1	Same
30	21	153	0	1	0	2	Same
31	24	398	459	4	3	4	Same
32	12	406	295	4	6	5	Same
33	5	306	373	2	4	3	Same
34	3	0	0	0	0	0	Same
35	11	153	9	1	1	2	Same
36	14	153	153	1	1	1	Same
37	22	25	0	1	0	1	Same
38	13	154	0	2	0	2	Same
39	7	0	0	0	0	0	Same
40	20	153	153	1	1	1	Same
41	23	9	59	1	1	2	Same
42	16	188	92	2	2	2	Same
43	18	571	392	6	4	7	Same
44	9	459	211	3	2	4	Same
45	10	0	34	0	1	1	Same
46	2	0	153	0	1	1	Same
47	19	0	0	0	0	0	Same
48	4	153	201	1	1	2	Same

Table B-12: Result data for dodge set 11.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	8	66	83	1	1	2	Same
2	22	0	0	0	0	0	Same
3	15	306	153	2	1	2	Same
4	11	0	0	0	0	0	Same
5	17	306	332	2	3	3	Same
6	9	60	59	2	1	2	Same
7	5	168	220	2	3	3	Same
8	10	42	0	1	0	1	Same
9	18	0	9	0	1	1	Same
10	21	184	201	2	2	2	Same
11	24	15	0	2	0	1	Same
12	4	153	85	1	2	3	Same
13	16	76	237	1	2	2	Same
14	1	60	83	1	1	2	Same
15	6	185	306	3	2	4	Same
16	12	236	83	2	1	2	Same
17	23	0	0	0	0	0	Same
18	7	0	0	0	0	0	Same
19	2	306	237	2	2	3	Same
20	14	59	76	1	1	1	Same
21	13	0	0	0	0	0	Same
22	20	153	153	1	1	1	Same
23	3	0	41	0	4	4	Same
24	19	49	49	1	1	1	Same
25	9	18	336	2	3	3	Same
26	7	0	0	0	0	0	Same
27	16	0	0	0	0	0	Same
28	22	0	0	0	0	0	Same
29	4	0	19	0	1	1	Same
30	14	59	75	1	2	2	Same
31	21	153	23	1	2	3	Same
32	1	199	0	2	0	2	Same
33	11	0	9	0	1	1	Same
34	24	0	0	0	0	0	Same
35	8	0	153	0	1	1	Same
36	6	101	165	1	3	3	Same
37	5	153	203	1	2	3	Same
38	17	0	153	0	1	1	Same
39	20	0	153	0	1	1	Same
40	19	66	75	1	1	1	Same
41	23	0	0	0	0	0	Same
42	2	42	50	1	1	1	Same
43	15	153	153	1	1	1	Same
44	3	153	67	1	2	3	Same
45	13	100	0	1	0	1	Same
46	18	0	0	0	0	0	Same
47	10	0	0	0	0	0	Same
48	12	91	108	1	1	1	Same

Table B-13: Result data for dodge set 12.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	12	213	164	2	3	3	None
2	11	216	0	2	0	2	None
3	13	0	0	0	0	0	None
4	4	0	0	0	0	0	None
5	3	0	185	0	4	3	None
6	1	4	0	1	0	1	None
7	8	1	128	1	1	1	None
8	17	239	247	2	2	2	None
9	20	15	176	1	2	2	None
10	5	138	157	3	3	3	None
11	6	86	11	3	1	3	None
12	14	153	153	1	1	1	None
13	22	0	0	0	0	0	None
14	10	0	0	0	0	0	None
15	9	0	0	0	0	0	None
16	2	8	71	1	2	2	None
17	24	262	433	4	4	5	None
18	23	153	213	1	2	3	None
19	21	114	163	2	3	3	None
20	18	211	5	3	1	3	None
21	16	170	153	2	1	2	None
22	19	0	0	0	0	0	None
23	7	0	4	0	1	1	None
24	15	33	120	1	2	3	None
25	14	0	0	0	0	0	None
26	8	0	25	0	2	1	None
27	18	153	104	1	2	3	None
28	11	0	0	0	0	0	None
29	23	153	153	1	1	2	None
30	3	0	141	0	3	3	None
31	22	0	0	0	0	0	None
32	9	299	138	2	1	2	None
33	4	153	153	1	1	1	None
34	19	8	8	1	1	1	None
35	10	0	0	0	0	0	None
36	17	272	306	3	2	3	None
37	1	0	189	0	2	2	None
38	20	71	168	1	2	2	None
39	21	178	153	2	1	2	None
40	7	0	62	0	1	1	None
41	15	120	204	1	3	2	None
42	16	293	306	3	2	3	None
43	12	0	0	0	0	0	None
44	2	0	306	0	2	2	None
45	6	0	202	0	2	2	None
46	13	0	0	0	0	0	None
47	5	159	376	2	3	3	None
48	24	253	244	3	2	3	None

Table B-14: Result data for dodge set 13.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	18	401	363	4	3	4	Same
2	17	397	571	3	5	5	Same
3	3	17	267	1	5	3	Same
4	14	154	178	3	2	3	Same
5	2	108	142	3	2	4	Same
6	11	0	3	0	1	1	Same
7	4	0	65	0	1	1	Same
8	15	153	255	1	4	4	Same
9	8	0	0	0	0	0	Same
10	5	233	241	2	2	2	Same
11	19	83	206	1	2	2	Same
12	22	0	0	0	0	0	Same
13	9	134	262	3	4	6	Same
14	21	297	306	3	3	4	Same
15	16	153	144	2	2	3	Same
16	12	6	17	1	2	2	Same
17	6	563	462	5	7	6	Same
18	23	0	58	0	2	2	Same
19	7	0	0	0	0	0	Same
20	1	153	212	1	3	3	Same
21	24	99	178	4	3	7	Same
22	13	153	153	1	1	1	Same
23	10	29	0	1	0	1	Same
24	20	153	320	1	3	3	Same
25	2	153	153	1	1	1	Same
26	15	157	174	2	2	3	Same
27	24	54	82	2	1	3	Same
28	1	91	17	1	1	2	Same
29	9	113	232	1	2	2	Same
30	4	0	0	0	0	0	Same
31	22	0	0	0	0	0	Same
32	5	87	91	1	2	2	Same
33	11	153	153	1	1	1	Same
34	7	0	0	0	0	0	Same
35	19	45	45	1	1	1	Same
36	8	0	153	0	1	1	Same
37	3	0	0	0	0	0	Same
38	13	0	0	0	0	0	Same
39	12	0	0	0	0	0	Same
40	20	97	88	1	1	1	Same
41	18	189	345	2	4	4	Same
42	21	0	0	0	0	0	Same
43	14	70	149	3	3	3	Same
44	23	0	153	0	1	1	Same
45	6	159	153	2	1	2	Same
46	10	0	58	0	1	1	Same
47	16	153	0	1	0	1	Same
48	17	40	40	1	1	1	Same

Table B-15: Result data for dodge set 14.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	3	441	69	5	1	5	Same
2	2	75	381	1	3	3	Same
3	22	229	124	2	2	4	Same
4	18	153	59	1	1	2	Same
5	7	66	33	1	1	2	Same
6	24	260	105	2	2	4	Same
7	14	153	179	1	3	3	Same
8	6	0	161	0	2	1	Same
9	17	344	373	3	3	3	Same
10	21	0	0	0	0	0	Same
11	12	0	68	0	1	1	Same
12	11	165	153	2	1	3	Same
13	10	0	0	0	0	0	Same
14	1	0	0	0	0	0	Same
15	8	0	41	0	1	1	Same
16	5	799	459	6	3	7	Same
17	9	272	276	3	2	3	Same
18	16	0	0	0	0	0	Same
19	15	106	17	3	1	2	Same
20	4	212	47	2	2	4	Same
21	13	15	153	2	1	1	Same
22	20	278	118	2	2	3	Same
23	19	0	0	0	0	0	Same
24	23	163	200	2	2	3	Same
25	11	0	1	0	1	1	Same
26	14	134	372	3	4	5	Same
27	10	378	33	3	1	4	Same
28	4	92	0	1	0	1	Same
29	3	58	62	1	2	2	Same
30	1	0	47	0	4	2	Same
31	2	548	499	5	4	4	Same
32	24	347	483	4	4	6	Same
33	16	222	84	2	1	2	Same
34	23	153	153	1	1	1	Same
35	22	255	151	4	1	4	Same
36	8	0	0	0	0	0	Same
37	7	153	235	1	3	3	Same
38	9	146	236	2	2	2	Same
39	20	261	429	2	3	3	Same
40	13	0	0	0	0	0	Same
41	17	93	581	2	6	6	Same
42	15	190	202	3	2	4	Same
43	12	153	326	1	4	4	Same
44	5	270	459	2	3	3	Same
45	21	33	0	1	0	1	Same
46	19	1	0	1	0	1	Same
47	6	78	211	1	3	3	Same
48	18	348	0	2	0	2	Same

Table B-16: Result data for dodge set 15.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	13	92	131	1	1	2	Different
2	5	306	723	2	6	6	Different
3	21	482	398	4	3	5	Different
4	17	67	79	4	4	6	Different
5	15	458	548	5	4	8	Different
6	22	0	22	0	1	1	Different
7	24	71	25	2	1	3	Different
8	14	153	85	1	2	2	Different
9	11	0	153	0	1	1	Different
10	23	0	0	0	0	0	Different
11	6	158	306	3	2	5	Different
12	16	184	225	3	3	5	Different
13	9	26	183	1	4	4	Different
14	7	25	98	1	2	3	Different
15	1	43	214	1	3	4	Different
16	18	47	374	1	3	4	Different
17	19	162	219	2	3	5	Different
18	8	153	253	1	2	2	Different
19	20	306	220	2	2	3	Different
20	4	181	262	3	3	5	Different
21	2	306	100	2	1	2	Different
22	3	243	83	2	1	3	Different
23	10	66	76	1	1	2	Different
24	12	0	0	0	0	0	Different
25	16	440	306	4	2	4	Different
26	3	459	222	3	4	6	Different
27	13	153	31	1	1	2	Different
28	12	107	0	1	0	1	Different
29	23	245	153	2	1	2	Different
30	8	100	0	1	0	1	Different
31	4	222	245	3	2	4	Different
32	18	347	306	3	2	3	Different
33	7	97	0	2	0	2	Different
34	21	303	306	2	2	3	Different
35	15	487	153	4	1	5	Different
36	22	1	48	1	1	2	Different
37	5	211	303	2	3	3	Different
38	10	178	149	2	3	4	Different
39	9	0	190	0	3	3	Different
40	17	0	43	0	1	1	Different
41	1	263	205	3	4	6	Different
42	6	612	752	4	7	6	Different
43	19	245	23	2	1	3	Different
44	11	153	153	1	1	1	Different
45	24	612	153	4	1	4	Different
46	2	352	100	3	1	3	Different
47	20	153	126	1	2	2	Different
48	14	274	517	3	5	6	Different

Table B-17: Result data for dodge set 16.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	11	54	133	2	1	3	None
2	20	220	264	2	2	3	None
3	8	75	392	1	5	4	None
4	4	271	153	3	1	4	None
5	21	86	187	3	2	3	None
6	17	532	550	4	4	6	None
7	10	0	93	0	2	2	None
8	13	127	83	1	2	2	None
9	3	7	0	1	0	1	None
10	23	154	25	2	2	3	None
11	1	0	109	0	1	1	None
12	14	0	153	0	1	1	None
13	9	93	10	2	1	2	None
14	12	266	184	4	3	4	None
15	19	0	0	0	0	0	None
16	6	33	16	2	1	2	None
17	22	0	0	0	0	0	None
18	16	128	33	2	1	1	None
19	7	0	0	0	0	0	None
20	18	5	0	1	0	1	None
21	24	0	0	0	0	0	None
22	2	162	236	2	3	3	None
23	5	0	34	0	1	1	None
24	15	153	153	1	1	1	None
25	5	279	175	3	3	3	None
26	8	0	0	0	0	0	None
27	13	0	0	0	0	0	None
28	22	17	0	1	0	1	None
29	10	0	0	0	0	0	None
30	20	153	0	1	0	1	None
31	2	170	93	2	3	2	None
32	14	0	25	0	1	1	None
33	7	0	0	0	0	0	None
34	9	9	16	1	1	1	None
35	1	209	153	2	1	2	None
36	4	0	0	0	0	0	None
37	3	0	0	0	0	0	None
38	24	0	0	0	0	0	None
39	21	0	170	0	2	2	None
40	17	0	0	0	0	0	None
41	15	30	8	1	1	2	None
42	11	0	0	0	0	0	None
43	19	133	127	1	2	1	None
44	12	84	67	2	1	2	None
45	16	19	0	1	0	1	None
46	23	134	42	2	2	2	None
47	6	0	0	0	0	0	None
48	18	0	0	0	0	0	None

Table B-18: Result data for dodge set 17.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	14	117	399	2	5	6	Different
2	10	0	105	0	2	1	Different
3	9	386	484	4	4	5	Different
4	5	313	160	3	4	5	Different
5	19	227	153	2	1	2	Different
6	4	350	216	4	3	6	Different
7	12	0	0	0	0	0	Different
8	7	0	0	0	0	0	Different
9	8	112	120	2	1	2	Different
10	22	0	16	0	1	1	Different
11	24	303	312	2	3	3	Different
12	15	24	0	1	0	1	Different
13	6	202	192	4	5	5	Different
14	16	161	25	4	1	4	Different
15	1	131	84	2	2	3	Different
16	13	108	142	1	2	2	Different
17	21	455	510	7	5	6	Different
18	17	0	0	0	0	0	Different
19	3	184	200	2	3	2	Different
20	2	186	193	2	1	1	Different
21	18	84	0	3	0	2	Different
22	20	0	0	0	0	0	Different
23	11	0	0	0	0	0	Different
24	23	0	0	0	0	0	Different
25	20	153	178	1	2	1	Different
26	21	259	281	3	5	3	Different
27	5	347	485	4	4	4	Different
28	15	0	137	0	2	2	Different
29	11	92	92	1	1	1	Different
30	4	0	0	0	0	0	Different
31	3	211	367	2	3	3	Different
32	9	67	133	1	2	2	Different
33	1	100	203	1	2	2	Different
34	23	153	101	1	1	1	Different
35	10	0	0	0	0	0	Different
36	2	178	135	2	2	1	Different
37	14	0	0	0	0	0	Different
38	22	0	0	0	0	0	Different
39	18	101	118	2	1	2	Different
40	6	340	446	4	4	4	Different
41	24	38	163	2	1	3	Different
42	17	124	250	2	3	3	Different
43	19	185	199	2	2	3	Different
44	7	26	0	1	0	1	Different
45	16	0	0	0	0	0	Different
46	8	0	19	0	1	1	Different
47	12	41	58	1	1	1	Different
48	13	25	33	1	2	2	Different

Table B-19: Result data for dodge set 18.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	2	306	321	2	2	3	Same
2	10	37	0	1	0	1	Same
3	15	230	428	4	3	5	Same
4	20	0	43	0	1	1	Same
5	16	153	150	2	1	2	Same
6	5	0	306	0	2	2	Same
7	6	493	459	4	3	5	Same
8	1	0	0	0	0	0	Same
9	7	0	118	0	2	2	Same
10	14	153	262	1	2	2	Same
11	12	153	154	1	2	2	Same
12	23	153	153	1	1	1	Same
13	24	285	0	2	0	2	Same
14	19	207	306	3	2	3	Same
15	21	325	301	3	5	3	Same
16	4	306	153	2	1	2	Same
17	17	119	67	3	1	3	Same
18	13	153	153	1	1	1	Same
19	11	204	50	2	1	3	Same
20	8	0	0	0	0	0	Same
21	3	74	73	2	3	5	Same
22	9	60	236	1	3	3	Same
23	22	84	0	1	0	1	Same
24	18	153	153	1	1	1	Same
25	20	153	153	1	1	1	Same
26	3	387	373	4	3	4	Same
27	6	437	585	4	7	7	Same
28	15	24	0	1	0	1	Same
29	18	301	306	3	2	3	Same
30	4	0	0	0	0	0	Same
31	23	0	25	0	1	1	Same
32	12	89	0	1	0	1	Same
33	13	0	0	0	0	0	Same
34	7	0	0	0	0	0	Same
35	16	0	0	0	0	0	Same
36	2	228	407	2	3	3	Same
37	17	0	0	0	0	0	Same
38	10	33	0	1	0	1	Same
39	19	153	203	1	2	2	Same
40	22	0	0	0	0	0	Same
41	14	167	75	1	1	2	Same
42	8	0	0	0	0	0	Same
43	24	282	348	3	3	3	Same
44	21	111	127	2	2	2	Same
45	5	0	0	0	0	0	Same
46	11	150	0	1	0	1	Same
47	1	143	192	2	2	3	Same
48	9	0	153	0	1	1	Same

Table B-20: Result data for dodge set 19.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	24	338	27	3	1	4	None
2	17	585	457	4	4	5	None
3	10	118	0	1	0	1	None
4	7	0	35	0	1	1	None
5	20	381	144	3	3	3	None
6	23	288	444	2	5	4	None
7	16	221	178	2	2	3	None
8	22	24	7	1	1	2	None
9	8	0	0	0	0	0	None
10	14	171	154	2	2	3	None
11	21	277	267	4	3	5	None
12	9	268	238	2	4	5	None
13	1	0	100	0	2	2	None
14	12	220	250	2	5	3	None
15	4	0	0	0	0	0	None
16	2	459	178	3	3	4	None
17	15	809	373	9	5	3	None
18	19	119	112	2	2	3	None
19	6	65	396	2	4	4	None
20	13	77	0	1	0	1	None
21	3	154	206	2	4	3	None
22	18	9	0	1	0	1	None
23	11	0	0	0	0	0	None
24	5	303	373	4	3	4	None
25	24	375	353	4	4	3	None
26	17	252	170	3	4	3	None
27	14	50	155	1	2	3	None
28	21	153	257	1	3	2	None
29	5	201	462	2	5	5	None
30	1	16	153	1	1	1	None
31	10	16	0	1	0	1	None
32	23	0	43	0	1	1	None
33	22	68	75	2	1	3	None
34	2	152	108	3	1	2	None
35	13	33	17	1	1	2	None
36	3	74	27	1	2	2	None
37	16	635	212	8	2	5	None
38	12	33	41	1	2	1	None
39	15	272	78	5	4	5	None
40	11	306	82	2	2	3	None
41	9	191	139	3	6	4	None
42	18	0	36	0	3	2	None
43	19	153	136	1	2	1	None
44	20	42	281	3	4	5	None
45	6	153	163	1	3	3	None
46	4	0	51	0	1	1	None
47	8	0	0	0	0	0	None
48	7	101	57	2	2	3	None

Table B-21: Result data for dodge set 20.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	2	195	306	2	2	3	Different
2	21	354	459	4	3	5	Different
3	7	415	313	3	4	4	Different
4	15	556	253	4	4	6	Different
5	13	0	162	0	3	3	Different
6	11	119	70	2	2	4	Different
7	23	0	111	0	2	2	Different
8	6	400	185	3	2	4	Different
9	5	306	459	2	3	3	Different
10	1	0	0	0	0	0	Different
11	10	0	12	0	2	2	Different
12	4	156	9	2	1	3	Different
13	12	88	176	2	2	3	Different
14	22	287	38	3	2	5	Different
15	19	150	227	1	2	2	Different
16	14	0	25	0	1	1	Different
17	9	159	404	2	4	4	Different
18	24	130	33	3	3	5	Different
19	17	153	321	1	4	2	Different
20	20	0	0	0	0	0	Different
21	3	450	581	4	8	8	Different
22	8	153	0	1	0	1	Different
23	16	262	343	2	3	4	Different
24	18	325	249	4	4	7	Different
25	6	647	703	6	9	9	Different
26	19	292	153	5	1	4	Different
27	5	127	211	2	3	3	Different
28	15	136	56	4	1	5	Different
29	1	306	497	2	4	4	Different
30	14	0	320	0	3	2	Different
31	23	306	339	2	3	4	Different
32	21	0	139	0	3	3	Different
33	22	153	344	1	3	3	Different
34	11	153	278	1	2	2	Different
35	18	70	38	3	3	4	Different
36	8	75	0	1	0	1	Different
37	17	397	270	3	3	5	Different
38	16	50	8	1	1	2	Different
39	9	184	153	2	1	2	Different
40	10	0	59	0	2	1	Different
41	2	1	0	1	0	1	Different
42	7	41	205	1	3	4	Different
43	24	23	125	1	2	3	Different
44	13	306	378	3	4	5	Different
45	4	26	2	1	1	2	Different
46	12	142	498	1	5	4	Different
47	3	439	478	3	5	5	Different
48	20	228	396	2	2	3	Different

Table B-22: Result data for dodge set 21.

Test	ID	ColRawL	ColRawR	ColRealL	ColRealR	TotalHit	Cue
1	20	577	361	4	3	5	None
2	8	128	100	3	1	4	None
3	16	288	163	3	2	3	None
4	11	153	0	1	0	1	None
5	14	0	187	0	2	2	None
6	21	352	426	3	3	4	None
7	3	36	0	3	0	2	None
8	19	279	282	4	4	5	None
9	12	84	276	1	3	3	None
10	5	150	116	2	3	3	None
11	7	0	0	0	0	0	None
12	18	52	23	2	1	3	None
13	6	488	598	6	5	8	None
14	9	293	461	4	4	5	None
15	4	0	0	0	0	0	None
16	17	194	415	2	4	4	None
17	2	0	0	0	0	0	None
18	15	218	225	5	3	5	None
19	10	0	0	0	0	0	None
20	24	283	34	3	2	4	None
21	1	0	84	0	1	1	None
22	22	58	9	1	1	2	None
23	23	68	0	1	0	1	None
24	13	0	92	0	1	1	None
25	13	0	0	0	0	0	None
26	2	153	153	1	1	1	None
27	21	381	400	4	4	5	None
28	17	194	50	2	1	2	None
29	9	179	306	3	2	3	None
30	16	68	76	1	1	1	None
31	19	176	171	3	3	2	None
32	15	73	23	1	2	3	None
33	11	0	0	0	0	0	None
34	10	0	0	0	0	0	None
35	22	0	0	0	0	0	None
36	18	14	0	1	0	1	None
37	23	0	0	0	0	0	None
38	7	0	0	0	0	0	None
39	4	0	0	0	0	0	None
40	1	0	76	0	1	1	None
41	8	0	0	0	0	0	None
42	3	0	39	0	2	2	None
43	24	40	0	1	0	1	None
44	12	0	0	0	0	0	None
45	6	83	154	1	2	2	None
46	20	220	189	2	3	2	None
47	5	245	108	2	2	3	None
48	14	153	153	1	1	1	None