DEVELOPMENT OF ALTERNATIVE METHODS FOR DELINEATING DIVERGES IN FREEWAY WORK ZONES

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
School of School of Civil and Environmental Engineering

Georgia Institute of Technology
May, 2012

DEVELOPMENT OF ALTERNATIVE METHODS FOR DELINEATING DIVERGES IN FREEWAY WORK ZONES

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Date Approved: April 2nd, 2012

To my family.

ACKNOWLEDGEMENTS

This work has been part of a larger project for the Georgia Department of Transportation, and without the help of my project team there is no way I could have produced this work. The team, Dr. Michael Hunter, Dr. Michael Rodgers, Dr. Gregory Corso, and Chenhau Liu worked with me to develop the experimental procedure and select alternatives for testing.

Dr. Corso arranged for the participants through the School of Psychology and provided key insight, reframing a problem with a huge psychological component for a group of engineers and scientists.

Chenhau Liu developed the experimental scripts and worked with me on the data analysis. Without his help I couldn't have made heads or tails of the data we collected in this experiment.

And I can't thank my committee enough for their invaluable help with this thesis. Dr. Hunter, Dr. Rodgers, and Dr. Michael Meyer have worked with me through my unreasonably tight time constraints, and for that I am supremely grateful.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	Analysis of Variance
AADT	Annual Average Daily Traffic
LCB	Longitudinal Channelizing Barricades
PCB	Portable Concrete Barrier
MUTCD	Manual on Uniform Traffic Control Devices

SUMMARY

Work zones are visually and physically complex environments, requiring that drivers maintain control of their vehicle and comprehend atypical and often discontinuous traffic control devices to safely navigate appropriate paths. Freeway diverges represent particularly difficult work zones areas. This thesis investigates current methods of delineating diverges in freeway work zones to determine important characteristics of these methods for future research.

A virtual environment was constructed with two ramp geometries: a freeway continuing straight and one curving left. Still images of work zones on these geometries were created using drums spaced 10 ft apart, drums spaced 40 ft apart, drums spaced 40 ± 2 ft apart, and portable concrete barriers. These alternatives were used to construct temporary ramps that were either open or closed. Thirty-nine participants were asked to identify whether the ramp was open or closed and their responses were recorded to evaluate the performance of each alternative.

Results indicate the importance of the Gestalt principles of closure, proximity, and continuity in perception of temporary exit ramps in work zones. These results will be used to guide future research into methods of delineating diverges in freeway work zones.

CHAPTER 1

INTRODUCTION

Work zones are visually and physically complex environments, requiring that drivers maintain control of their vehicle and comprehend atypical and often discontinuous traffic control devices to safely navigate appropriate paths. This task is not trivial; work zones are some of the deadliest parts of our highways, with over 2% of annual roadway fatalities occurring in work zones (National Work Zone Information Clearinghouse, 2012). Efforts must be made to improve work zone safety both through physical protection and through improving driver comprehension and response.

Freeway diverges represent particularly difficult work zones areas. Diverges require that a driver identify that there are two or more valid paths, choose one, and safely navigate that path, all while travelling at speeds that range from a near stop in congestion to running speeds of up to 70 mph in free flow conditions. Drivers need to be able to quickly understand the conditions around diverges in freeway work zones without explanation because the time to read and respond to an explanation may not be available.

To successfully delineate diverges in freeway work zones, traffic control devices must allow for quick comprehension and appropriate response by all drivers. The aim of this research is to identify principles to guide future studies in the development of novel traffic control devices and configurations for use in work zones. This objective will be achieved by creating several virtual work zones and having individuals identify the ramp diverge location and whether it is open or closed. Analysis of the resulting data will elucidate key characteristics of diverge delineation that affect driver performance.

CHAPTER 2

BACKGROUND

This chapter will provide the foundation for understanding the challenges associated with the delineation of diverges in freeway work zones. This chapter will first present general work zone characteristics (Section 2.1), followed by additional focus on channelizing devices (2.1.1), portable barriers (2.1.2), and diverges in work zones (2.1.3). Then the chapter will present literature on diverges in non-work zone areas (2.2), principles of grouping which potentially underlie the ability of a driver to rapidly and correctly interpret a work zone (2.3), and work zone construction standards from several states (2.4).

2.1 Work Zones

Construction zones are visually intense, complex environments that require drivers to deviate from usual driving behavior to deal with new traffic patterns and devices to indicate an elevated level of risk. Khattak, Khattak, and Council (2002) estimate that there are approximately 24,000 non-injury crashes and 52,000 property damage-only crashes in work zones annually. The Fatality Analysis Reporting System statistics for 2010 show that there were at least 576 fatalities (2% of total reported facilities) in work zones in 2010 alone (National Work Zone Safety Clearinghouse, 2012). Several studies have shown specific dangers of work zones to drivers.

Daniel, Dixon, and Jared (2000) found that there was an elevated risk of fatal incidents in Georgia work zones. Specifically, they found that even though work zones make up a relatively small amount of overall roadway mileage, they account for more freeway fatal freeway crashes than in areas without road work. The types of collisions where fatal crashes occur are also telling: nearly half of all crashes were single-vehicle collisions, and 12.1% of collisions were rear-end collisions, compared with 56% single vehicle and 5% rear-end collisions in non-work zone fatal crashes. Most of the crashes took place in construction zones that were idle and the type of construction was typically resurfacing or roadway widening. These conditions suggest that relatively common work zones that may be perceived as being lower risk still lead to an unacceptable number of fatalities. These areas, typically delineated by drums and often having temporary diverges, could benefit from improved methods of work zone delineation.

Work zone intrusions are especially worrisome when considering diverges as the ultimate goal of an exiting driver at a diverge is to depart from the current roadway. The decision to diverge from the travelled way is, in effect, the decision to intrude upon the work zone *in the proper location*. Bryden, Andrew, and Foruniewicz (2000) evaluated 290 intrusions between 1993 and 1998 in New York State. Of these observed intrusions, 10 occurred where drivers were trying to cross the work zone to enter or exit “a driveway or other roadside location.” While this type of incident is rare, the study demonstrates that it is an issue in work zones and that there is room for improvement in delineation methods. Further, the study notes that only one of the incidents occurred when the work zone was separated by a portable concrete barrier, indicating that PCBs could effectively reduce intrusion events (although damage from impacting them is more severe).

2.1.1 Channelizing Devices in Work Zones

Work zone channelizing devices are carefully regulated in the Manual on Uniform Traffic Control Devices and have been largely standardized across the United States (FHWA, 2009). However, especially with temporary channelizing devices, research was performed prior to standardization of these devices to see if drivers wholly understood their meanings in all circumstances. Pain, McGee, and Knapp (1981) explain: "Devices described in Part VI of the *Manual on Uniform Traffic Control Devices* (MUTCD), have developed simply as an evolvement from other devices, rather than as a result of scientific testing as to what best stimulates driver awareness of work zone situations." For instance, the nearly ubiquitous channelizing drum's patent was not filed until 1976 (Kulp and Florsheim, 1978). The plastic drum was deemed a safer alternative than the filled metal 55-gallon drums previously in use. Little research has been found prior to this patent exploring how drivers interpreted these devices. Some research has been found from after the patent filing, such as a discussion of their visibility characteristics (Pain et al, 1981).

Modern research into channelizing devices has largely focused on existing systems. Several studies have looked at how channelizing devices in work zones affect driver performance, both at exit ramps and through work zones in general. Finley, Ullman, and Dudek (2001) for instance investigated how sequential flashing lights placed on top of drums aided driver comprehension of a lane closure. They evaluated driver understanding through a traditional survey after participants drove through the scene, though others have used simple computer surveys to gauge comprehension. Finley, Ullman, and Trout (2006) for instance, showed drivers still images of mobile painting operations to evaluate comprehension of signs. They used a questionnaire to evaluate the use of “Your Speed/My Speed” signs on the back of slow moving trucks, and they found that drivers were confused by the two sets of numbers.

Pain et al (1981) performed several experiments looking at driver performance with regards to channelizing devices in freeway work zones. They used instrumented vehicles to measure speed, lane position, identification distance, and other performance measures at a lane closure on a freeway closed to traffic. They ultimately found that channelizing devices are interchangeable, but lights should be used at night to increase visibility. They also performed a series of tests using a tachistoscope by flashing patterns with various orange and white ratios to determine ideal size and pattern of striping on channelizing devices.

2.1.2 Portable Barriers

Work zone research has also focused on temporary barrier walls and their impact on work zones. Finley, Theiss, Trout, Miles, and Nelson (2011) compared traditional drums to plastic barriers (referred to as Longitudinal Channelizing Barricades in their study). They found that drivers on a test track were less confused at diverges indicated with LCBs, drivers identified lane closures when they were used, and drivers preferred LCBs for delineating open driveways in work zones. This corroborates narrative data from DOT officials who said that LCBs should be used when there is a need to “provide more path guidance.” Officials were mostly concerned, however with the cost of temporary barriers. Iragavarapu and Ullman (2012) reinforce this cost issue, finding that portable barriers are only cost effective on high speed roadways (with operating speeds of 70 mph) with high volumes (around 40,000 vehicles ADT for a yearlong project) where work is happening close to the travel lanes. However, portable barriers are effective at preventing intrusion, as seen in Bryden et al (2000). Of the 290 observed intrusion collisions in New York State, only one occurred where portable barrier walls were used.

2.1.3 Diverges in Work Zones

As mentioned before, Finley et al (2011) compared drums and portable barriers at work zones. They used a combination of simulation scenes and closed-course drives to gauge driver understanding and recognition of an exit ramp constructed of drums and LCBs. They found that all-barrier alternatives out performed all-drum alternatives and combination alternatives performed intermediately, with barriers only at the tapers of the ramps performing best. They spaced drums 20 ft, 60 ft, and 120 ft apart in their alternatives, and varied between a 120 ft ramp opening and a 240 ft ramp opening. Interestingly, they found that shortening the drum spacing from 120 ft to 60 ft increased driver confusion and decreased the distance to recognition in the 120 ft opening condition. In this condition, detection distance varied from 198 ft for 60 ft spaced drums (2.25 seconds from the ramp at 60 mph) to 364 ft for portable barriers (4.14 seconds from the ramp at 60 mph). Lengthening the ramp opening from 120 ft to 240 ft increased the identification distance to 383 ft for the all-drum alternative (4.35 seconds from the ramp at 60 mph) and to 494 ft for the all-barrier alternative (5.61 seconds from the ramp at 60 mph).

2.2 Diverges

Others have looked specifically at safety issues that arise around diverges in general. While work zones add new safety challenges, existing non-work zone issues are important to understand so new treatments do not make safety issues inherent to diverges more acute.

Wang, Cao, Deng, Lu, and Zhang (2011) evaluated truck-related crashes at exit ramps in an attempt to develop a model for determining safety at diverges. They found that collisions increased as AADT increased, both for trucks and overall. They found a significant improvement on safety from an increase in the length of deceleration lanes and from using ramps without lane drops or with option lanes (in the case of 2-lane exits). Lastly, they saw a significant improvement in safety with an increase in shoulder width. These traits of safer ramps are intuitive but should be taken into great consideration when designing diverges in freeway work zones, for instance where there is little option for a shoulder in a work zone, deceleration lengths should be generous as possible, since even in diverge areas without work there is still an elevated risk of an incident.

Chen, Zhou, Zhao, and Hsu (2011) looked at left side exit ramps in Florida, and found that there was an elevated crash risk for these types of exits. While Chen et al did not explore why left exits caused an elevated crash risk, the potential exists that left hand exits could also present increased hazards in work zones. Lu, Lu, Liu, Chen, and Guo (2009) evaluated diverges in Florida, investigating how ramp type and ramp characteristics influenced safety. They found that exits without lane drops had the lowest crash rates and that free flow loop ramps significantly increased crash rate. There is value in knowing that different types of ramps can influence crash risk, and diverges in work zones should be designed knowing that underlying characteristics of the ramps themselves could contribute to collisions. Khorashadi (1998) found that 15% of incidents in the State of California between 1992 and 1994 occurred on ramps. Analyzing those incidents, he found that ramp AADT, freeway AADT, whether the ramp was urban/rural, the type (on/off), the configuration, the length of the speed change lanes, and the ramp length to be significant. Of note were that off-ramps had more collisions and more severe (injury and fatality) incidents than on-ramps.

McCartt, Northrup, and Retting (2004) examined 1,150 crashes at ramps and found that about half of crashes happened when drivers were exiting the freeway. They found that congestion and speed were contributing factors to all crash types, however. Speed was mostly a factor in run-off-the-road crashes and congestion was a strong factor in rear-end collisions. Given that work zones can often cause congestion and work zones may be designed for a lower speed than drivers are used to traveling, these types of incidents should be kept in mind when designing diverges in work zones.

2.3 Principle of Grouping

In work zones, it is often physically difficult or very costly to use a single object to indicate the perimeter of a work zone. Since it would be difficult to put something like a chain link fence up in an active travel way, most jurisdictions depend on separate channelizing devices to "simulate" a single wall of objects in the mind of drivers. These point devices, e.g. orange and white retroreflective channelizing drums, depend on the Gestalt principles of grouping for drivers to take the individual drums, panels, or other channelizing devices and mentally associate them with a group. Johnson (2010) explains the six non-moving Gestalt principles of Proximity, Similarity, Continuity, Closure, Symmetry, and Figure/Ground, demonstrated in Figure 1.

Proximity indicates to individuals that separate objects are grouped because of how close they are to each other. Similarity indicates that separate objects are grouped because they appear to be in some way the same. Continuity indicates grouping through a linear pattern common to all objects in the group. Closure makes overlapping objects appear to be grouped together and also allows separate objects appear to construct a single object. Symmetry helps group wireframe objects that overlap, and figure/ground helps individuals group objects together based on a common background.

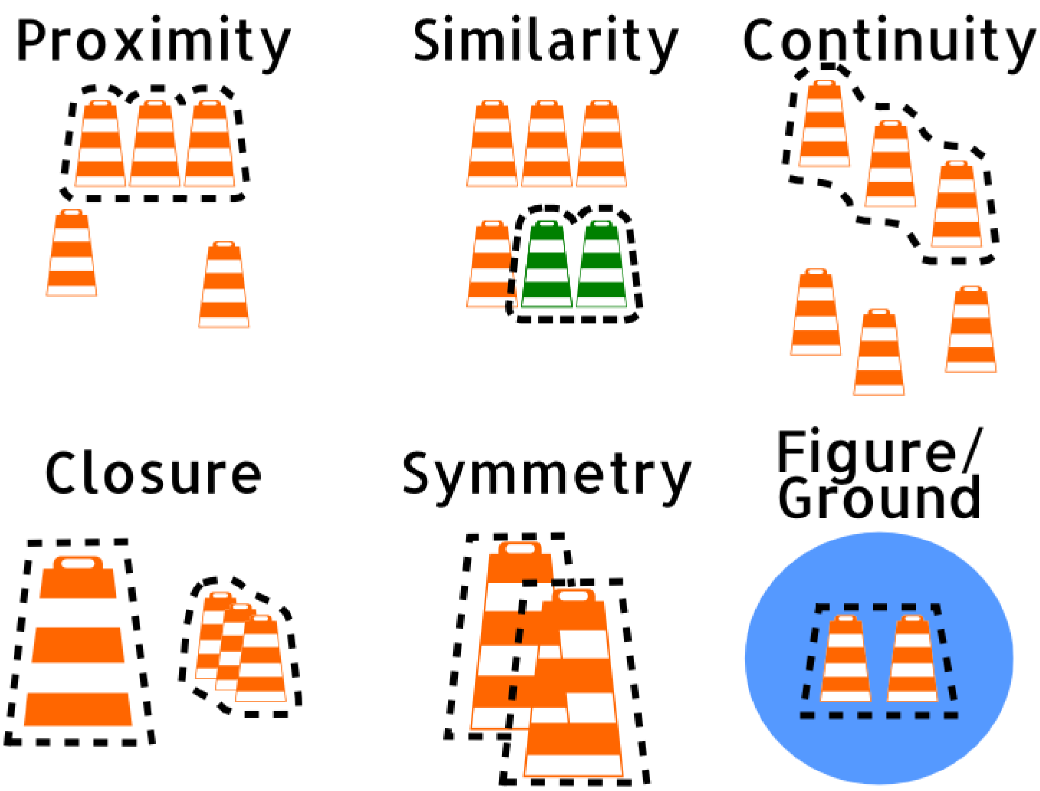


Figure 1. Gestalt Principles of Grouping (Groups Shown with Dotted Lines)

Work zone traffic control depends on these grouping principles to maintain the appearance of a single closed area through point-based channelizing devices. Several problems arise with this system, however. Different states with different standards illustrate how there is no consensus on an appropriate level of proximity. Continuity can be degraded due to variability in device placement or natural shifting from wind or traffic. Drums or cones appear closed when at a distance because they overlap in a driver's frame of view, but as the driver approaches these devices the closure is lost, shifting the burden of grouping to the other three Gestalt principles. Unique to diverges, similarity creates a problem because there are two appropriate and safe traveled ways (the main road and the ramp) that are both indicated with the same devices, making it difficult to identify that there are actually two groups of channelizing devices.

The effect these principles have on perception can significantly affect how an individual responds to stimuli in the world. In a series of five experiments, Coren and Girgus (1980) found that when some objects were grouped through Gestalt principles, the distances between objects in the group was perceived to be smaller than the distance between objects outside the groupings, even, though the distances were identical. This could have profound impacts on work zone design if perceived distances vary from actual distances in a way that negatively impacts safety. O'Shaughnessy and Kayson (1982) further investigated these concepts by including the time an individual is shown the tested scene. They found that both proximity and time had an effect on how individuals accurately assessed distances, with improved accuracy with shorter times and improved accuracy with smaller distances. They did not find the same effects with similarity and closure, however, indicating that while the Gestalt principles are a good heuristic, they cannot be applied as "laws" and testing is still necessary to predict perceptual performance.

2.4 Agency Standards

There are several states that specify standards for diverges in freeway work zones, including Michigan, California, and North Carolina. Other states, including Florida, have specifications that imply appropriate spacing by being more conservative than the FHWA's MUTCD, using drums that are spaced closer together and spacings that are less dependent on speed.

The Manual on Uniform Traffic Control Devices (FHWA, 2009) offers guidance regarding work in the vicinity of freeway interchanges, but does not include standards specific to exit ramps. The guidance in section 6G.17 (Interchanges) states:

> *Access to interchange ramps on limited-access highways should be maintained even if the work space is in the lane adjacent to the ramps. Access to exit ramps should be clearly marked and delineated with channelizing devices. For long-term projects, conflicting pavement markings should be removed and new ones placed. Early coordination with officials having jurisdiction over the affected cross streets and providing emergency services should occur before ramp closings.*

The MUTCD also includes a typical application for work near an exit ramp (Figure 2). This typical application is dependent on speed to determine tapers and does not specify any special spacing of channelizing devices. The MUTCD states that for tapers and tangent sections in general channelizing devices should be spaced at the speed limit in feet and twice the speed limit in feet, respectively. For example, for a speed limit of 50 mph, channelizing devices would be spaced 50 feet apart in tapered sections and 100 feet apart in tangent sections.

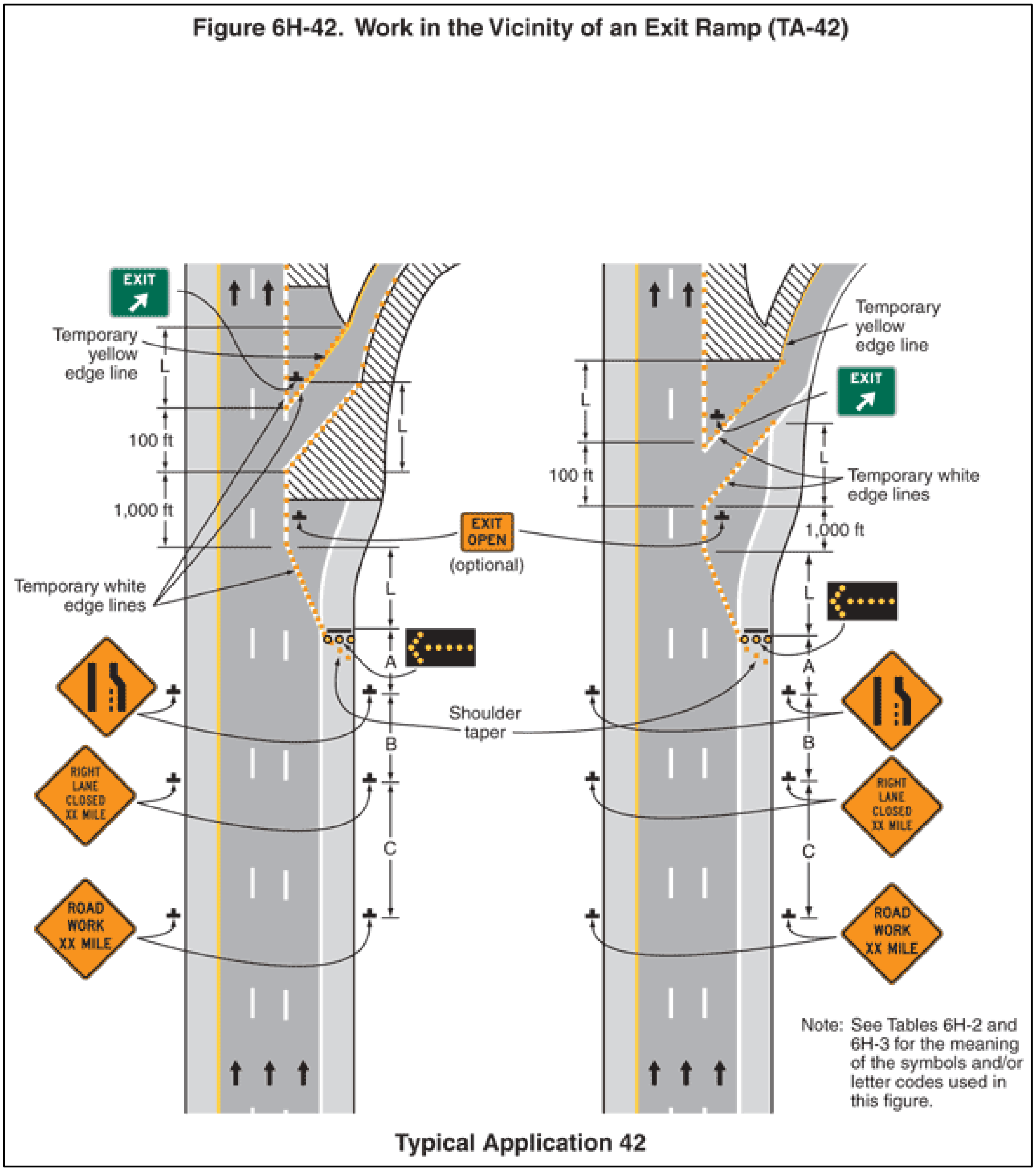


Figure 2. MUTCD Typical Application 6H-42 (FHWA, 2009)

Michigan (2008) has very extensive standard drawings specifying temporary traffic control in many situations. While their specifications do not include minor diverges at service interchanges, they do specify temporary traffic control for major diverges at system interchanges (Figure 3). Specifications for this condition call for channelizing device spacing of a minimum of 45 feet in tapers and 90 feet on tangent sections. Michigan's standards vary from the MUTCD's typical application (regarded as guidance, not a standard) by not specifying a minimum ramp opening length, but specifying that the diverge lane must be 15 ft wide. The taper in this section is specified as a minimum of 1/2 L (L = speed limit * lane shift), which is half of what the MUTCD suggests. A portion of Michigan's standard (not to scale) is in Figure 3.

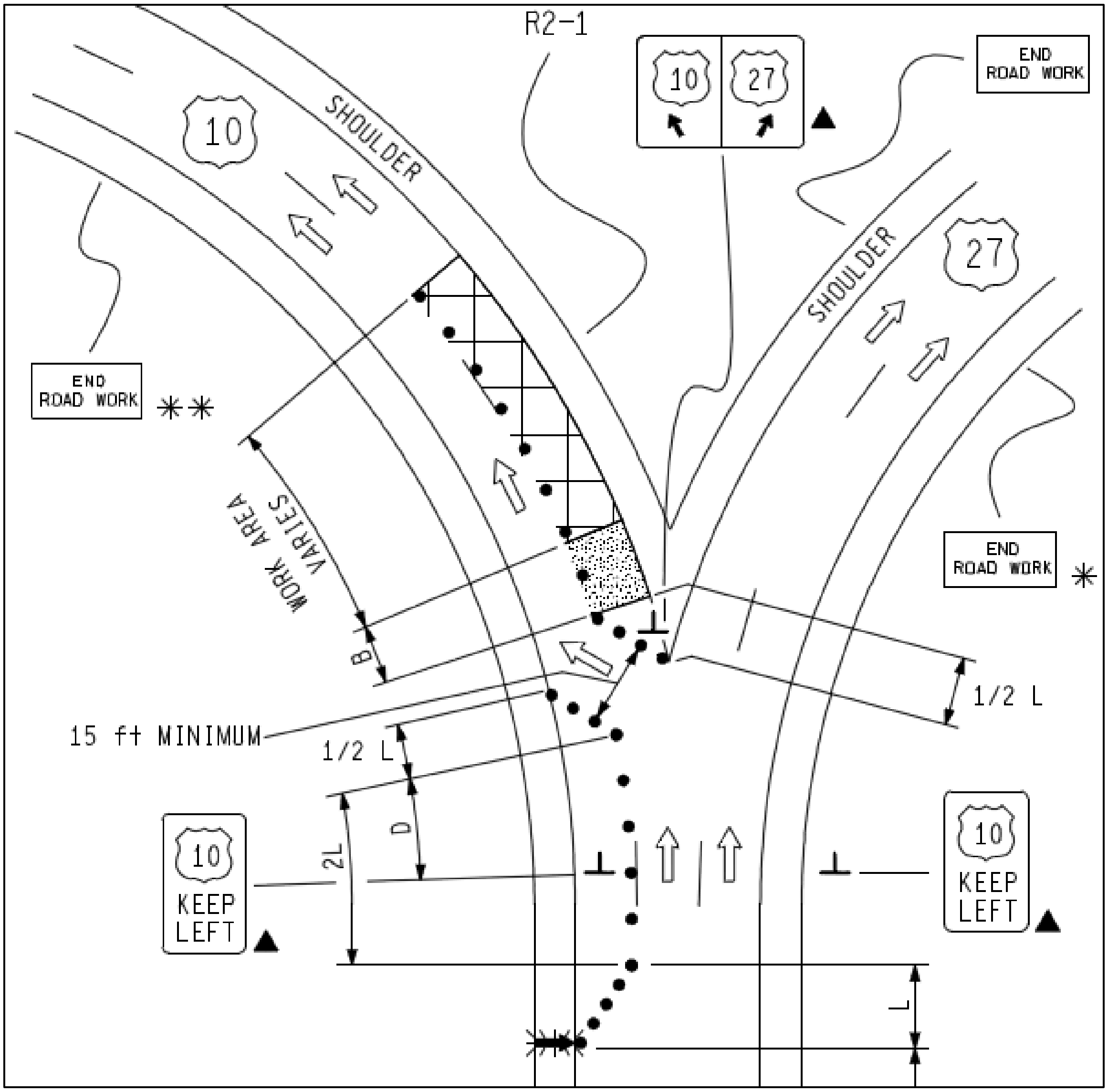


Figure 3. Portion of Michigan Diverge Standard Highlighting Ramp Area (MDOT, 2008)

Unlike Michigan, California does specify channelizing device spacing at minor diverges and along standard lane closures. California's standards (2006) call for 100 ft spacing between devices along tangent sections of a freeway lane closure and 50 ft maximum spacing in the vicinity of the ramp (Figure 4). Although the drawings appear to show the 50 ft spacing beginning 120 ft before the taper and extending 200 ft after the taper, the drawing is listed as not to scale and notes do not expressly call out the distance to start the taper (See). California does expressly call out that every 2000 ft along the tangent section of a lane closure, 3 drums should be placed perpendicular to the travel way, presumably to reinforce that the lanes are closed.

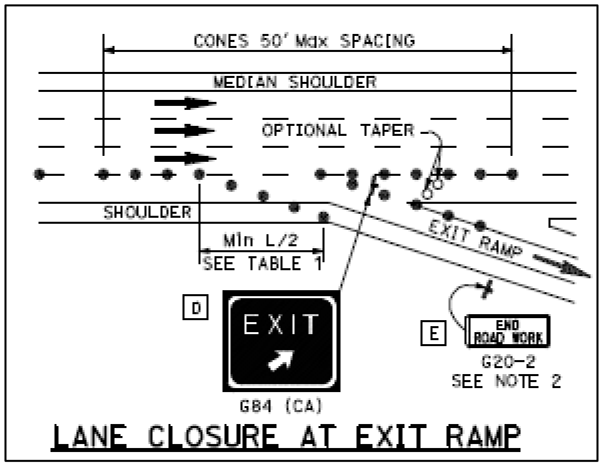


Figure 4. Portion of California Diverge Standard Highlighting Ramp Area (Caltrans, 2006)

North Carolina's (2006) standard drawings call for the use of the most channelizing devices at a diverge of any specification reviewed (Figure 5). North Carolina's standards call for 10 ft spacing between drums from 100 ft prior to the diverge to 100 ft after the diverge. In the tangent sections, spacing is allowed at two times the speed limit in feet, which for a 60 mph road would be further apart than California, Michigan, or Florida's standards. North Carolina specifies a minimum of 200 ft for the length of the ramp opening. The taper length and type varies based on the location of the work zone relative to the ramp opening, but a minimum of 120 ft for a taper is specified if work is downstream of the ramp and, like Michigan, 1/2 L if the work is upstream of the ramp.

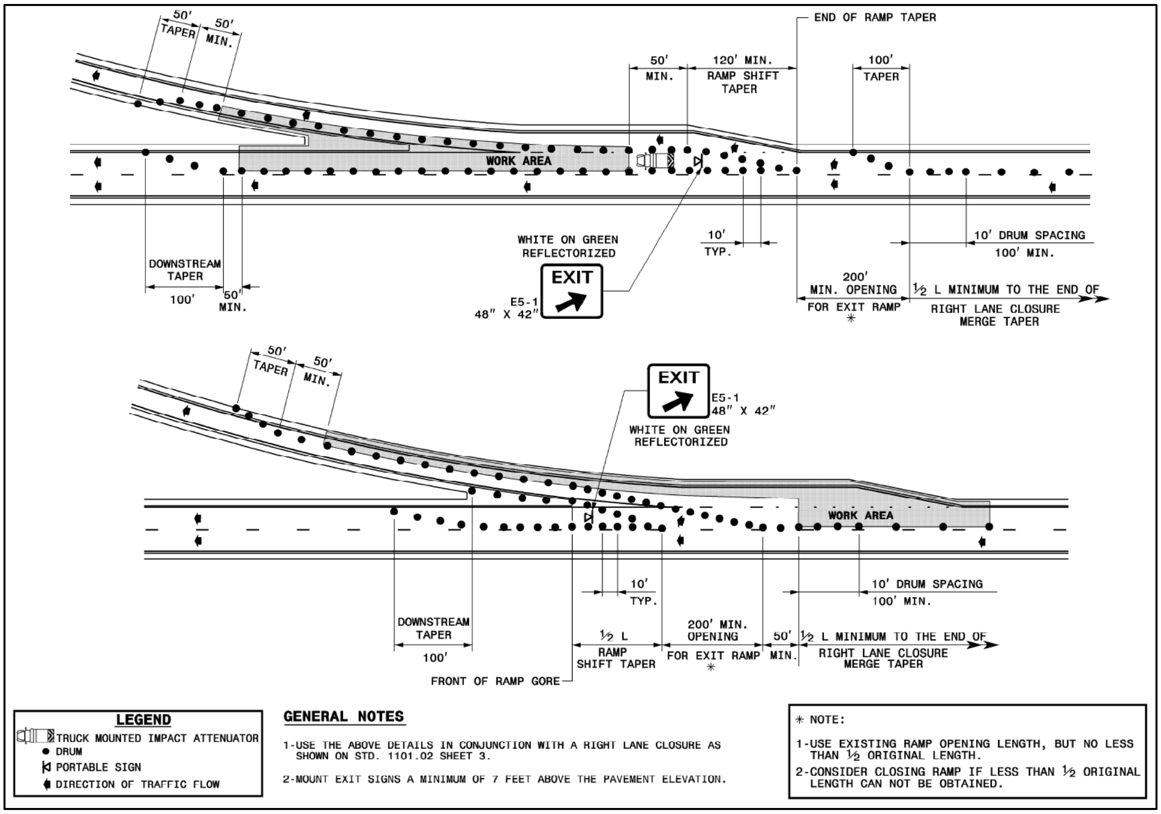


Figure 5. North Carolina Standard for Work Near Exit Ramps (NCDOT, 2006)

New York State (2009) does not differentiate between tapers and tangents with their specifications for work zones, instead stating that channelizing devices shall not exceed 40 ft center to center throughout an active work zone (Figure 6). New York also mandates taper lengths of L feet, compared with the 1/2 L of Michigan and North Carolina. Unlike California, North Carolina, New York, and Michigan, Florida does not specify specific constraints for diverges, but does require that for speeds of 50 mph to 70 mph (typical within freeways), channelizing devices should be placed no more than 50 ft apart in tapers and no more than 100 ft apart in tangents.

While the preceding discussion does not cover the temporary traffic control plans of all states it does illustrate the varied work zone requirements from state to state, largely due to the open ended requirements of the MUTCD. There are few standards pertaining to work zones in an exit ramp area, and typical application 6H-42, which is offered as guidance, is not physically possible at higher speeds, as demonstrated in Chapter 3.

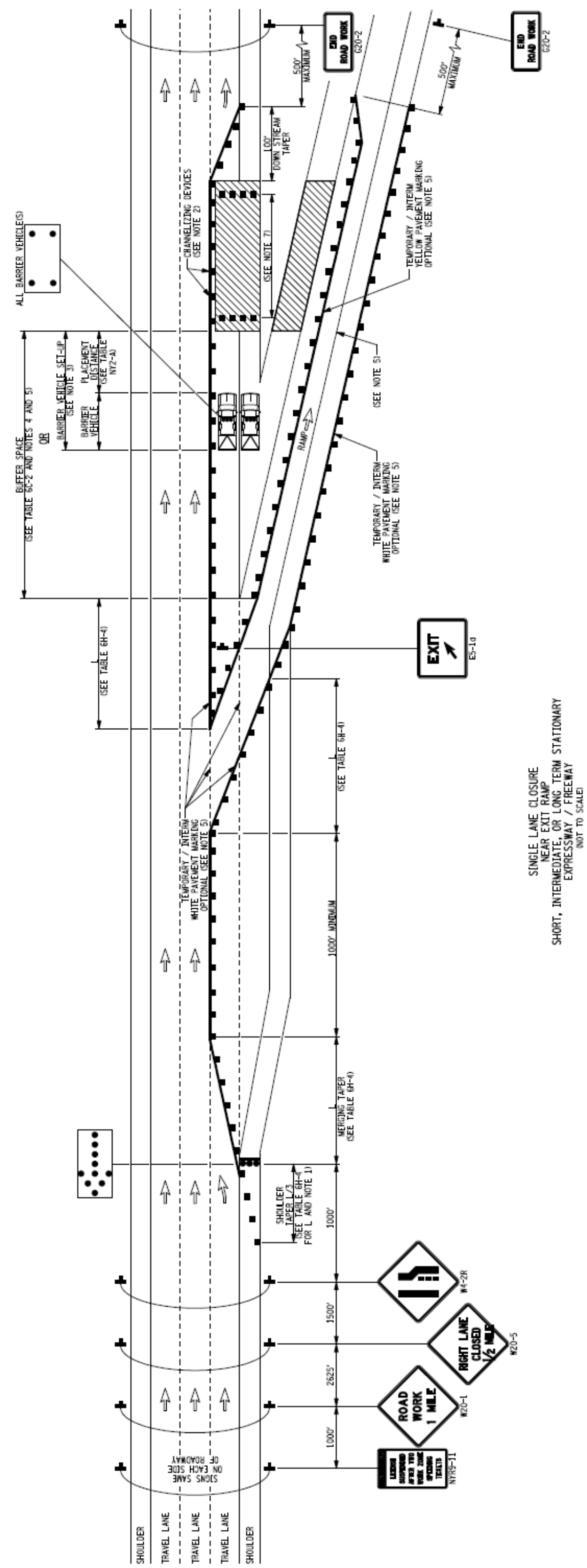


Figure 6. Portion of New York State Diverge Standard Highlighting Ramp Area (NYSDOT, 2009)

CHAPTER 3

METHODOLOGY

The method for performing this study can be divided into two phases: environment development and alternative testing. Careful consideration was made to construct an appropriate virtual environment that was sufficiently realistic and of a high enough quality that it would represent the environment such that participant behavior would be similar in a field study.

In this experiment, participants were shown images created from this environment. Each image contained a diverge area, either with a work zone configuration or a base case without a work zone. Participants were asked to indicate if the ramp was open or closed and, if open, to identify the location of the ramp entrance. Multiple alternative traffic control treatments were considered (e.g. drums at different spacings, barriers, etc.) to allow for an exploration of differences in responses indicating participants' comprehension. The following text presents the method for designing the environment and implementing the experiment. Within environment design, specific focus is placed on roadway design, virtual environment preparation, alternative generation, and rendering. This chapter also focuses on the design, instructions, and the implementation of the experiment itself.

3.1 Environment Development

Several steps went into constructing an appropriate series of environments for the experiment. These were the proper design of a test track, the preparation of the virtual environment by invisible construction lines to guide channelizing devices, setting up appropriate textures and lighting, and the rendering of the final images.

3.1.1 Roadway Design

To gather transferable results, the roadway needed to be designed according to typical standards seen by local drivers. Specifications for cross-section come from State of Georgia (2011) standards, with the exception of the shoulder widths, which replaced the 12-foot outside paved shoulder and 10-foot paved inside shoulder standards with 10-foot outside paved shoulder and 4-foot paved inside shoulders, to more closely match current roadways. Excepting that, the standards were followed to construction a 4-lane divided highway with a 70 mph design speed and a 64-foot median at a cross slope of 6:1. The basic lanes had a cross-slope of 2% with an inside shoulder cross slope of -2% and an outside shoulder cross-slope of 6%. Outside daylighting extended from the outside shoulder edge-of-pavement to the roadway over a course of 18 feet at a 4:1 grade.

Curve radii were taken from AASHTO standards for a four lane divided roadway with a superelevation rate (e) of 8%. Given the 70 mph design speed, a curve radius of 1810 feet was used on the mainline freeway. To eliminate potential secondary visual cues that could indicate where ramps were located, the grades of the freeway and the ramps were all flat, such that all roadway sections were at the same elevation.

A short track was built using Autodesk Civil 3D of the mainline freeway and two exit ramps, each extending from the same carriageway. At one ramp, the freeway curves left while the exit ramp continues straight as a taper-type ramp, extending the tangent section of the freeway (Figure 7). Such ramps are relatively common, especially where a freeway has been built in phases or near bypass routes in smaller cities. At the second ramp, the freeway continued straight and the ramp used a parallel deceleration lane of the length specified in AASHTO standards for a reduction from a 70 mph design speed to a 50 mph design speed (Figure 8).

The roadway design was then exported into Autodesk 3ds Max for processing and rendering. From here, striping was added to comply with MUTCD and Georgia Standards for freeway striping. From this point, the environment was prepared so that channelizing devices could be added and photos rendered.

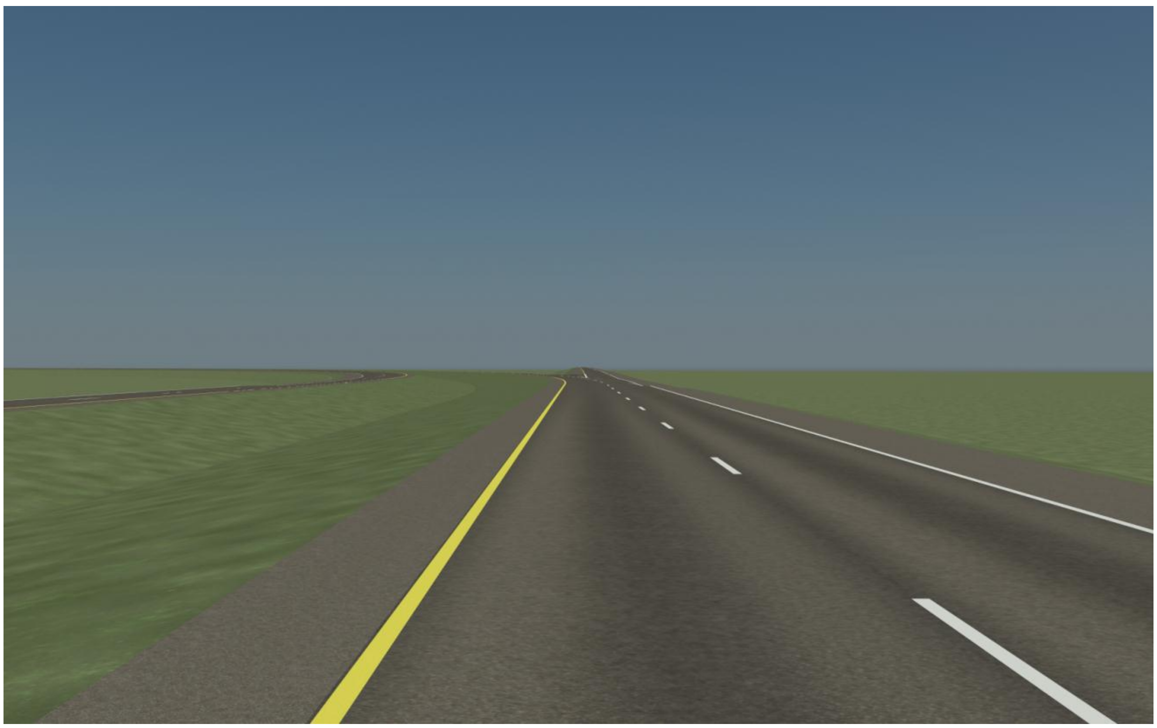


Figure 7. Curved Geometry

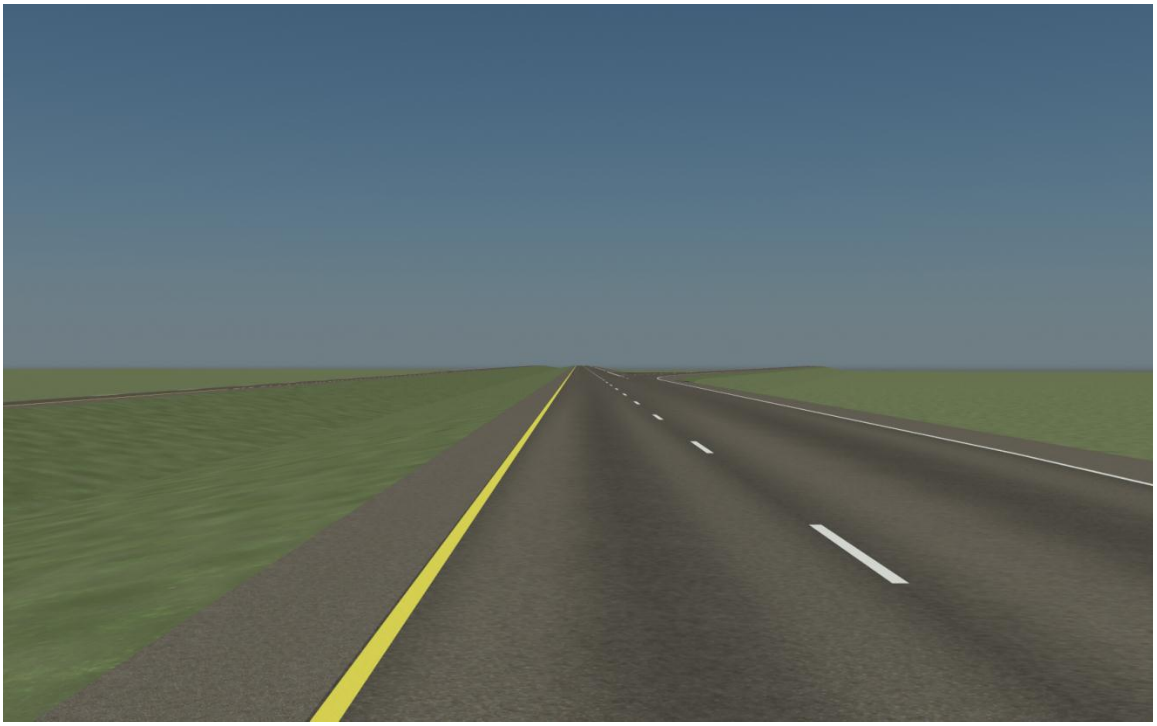


Figure 8. Straight Geometry

3.1.2 Virtual Environment Preparation

In preparation for adding the alternatives, textures and lighting were added to improve the visual quality of the scene. Of particular interest was the decision to use only low-grass vegetation in both the median and on the roadside. While many rural freeways in Georgia have tree cover outside of the right of way, the combination of the trees with a natural sky/sun system cast shadows on the roadway that could have acted as a compounding factor affecting performance. Eliminating high vegetation allowed the study to focus on the traffic control treatments without sacrificing the believability of the scene.

Once textures and lighting were added to the scene, temporary invisible construction lines (lines used to help with object placement that are not rendered in the final images) that correspond to the paths of channelizing devices were added. An invisible construction line set three feet into the inside line and 3 feet high served as the guide for the rendering camera. The temporary traffic control construction lines were set up to simulate a single lane closure of the outside lane, with channelizing devices placed one foot from the edge of the lane dividing skip lines. Both temporary exit ramps were designed as 4 degree taper-type ramps using a design speed of 60 mph.

It is important to note here that the temporary ramp guide lines do not comply with the MUTCD's typical application for road work in the vicinity of an exit ramp (Figure 6H-42) because this typical application would create an unusable environment. Specifically, using the specified 100 ft gap between barrels and an L of 720 ft would yield an angle of 0.9548 degrees. The end result would be a lane width of 1.67 feet--a physical impossibility. Because this typical application was unable to capture the scenario being tested, the temporary traffic control used the standards from AASHTO's Policy on Geometric Design of Highways and Streets. Figure 9 illustrates the resulting lane width when MUTCD standards were used.

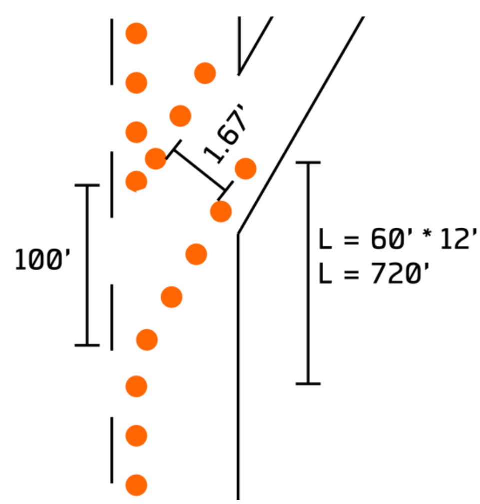


Figure 9. Demonstration of Issues with MUTCD Standards at 60 mph

3.1.3 Alternatives

Five alternatives were included in this experiment: 1) orange and white drums 10 feet apart (Figure 10 and Figure 11), 2) drums 40 feet apart (Figure 12 and Figure 13), 3) drums 40 feet apart ± 2 feet on the roadway (Figure 14 and Figure 15), 4) portable concrete barrier walls (Figure 16 and Figure 17), 5) and a “no work” condition (Figure 18 and Figure 19). Drum spacing 10 feet apart is the standard used by the North Carolina Department of Transportation. Drums 40 feet apart was observed to be in practice in the State of Georgia, and is straightforward in practice to set up as the skip lines may be used for guides in drum placement (skip lines are 10 feet long with 30 feet between, so one drum per skip measures to be 40 foot spacing). To explore the effects of imperfect drum placement the 40 ft spacing alternative was also considered with 2 feet of randomly generated drum placement (plus or minus 2 ft) error both parallel to and perpendicular to the travelled way. Finally, while currently limited in temporary use concrete barriers are included as they are used in practice for work zones, particularly for longer duration projects.. For comparison, the “No Work” condition used only the environment as built, i.e. there was no evidence of roadwork in the scene.

For each of the four channelizing device alternatives, two environments were constructed: one where the exits on the track were both closed and one where the exits on the track were both open. In the drum alternatives, drums were spaced 120 feet apart (twice the work zone speed limit, replacing mph with feet, per the MUTCD) until 100 feet prior to the start of ramp taper, where the tighter spacing began and was extended 100 feet after the temporary gore. For consistency, when the ramp was closed, channelizing spacing was the same as when it was open, except that the devices extended through what would the ramp opening and the devices showing the exit path were removed. Where portable concrete barriers were used, they followed the guide lines described in 3.1.2 and extended the length of the test track. For the no work condition, only a set of open ramps were developed.

MUTCD requirements for work zone signage were not implemented in this experiment. In order to focus participants' attention on the temporary traffic control devices and patterns, all signs were removed from all alternatives. Permanent signs typically left uncovered were removed along with portable signs what would inform drivers where an exit is or whether it was temporarily closed.

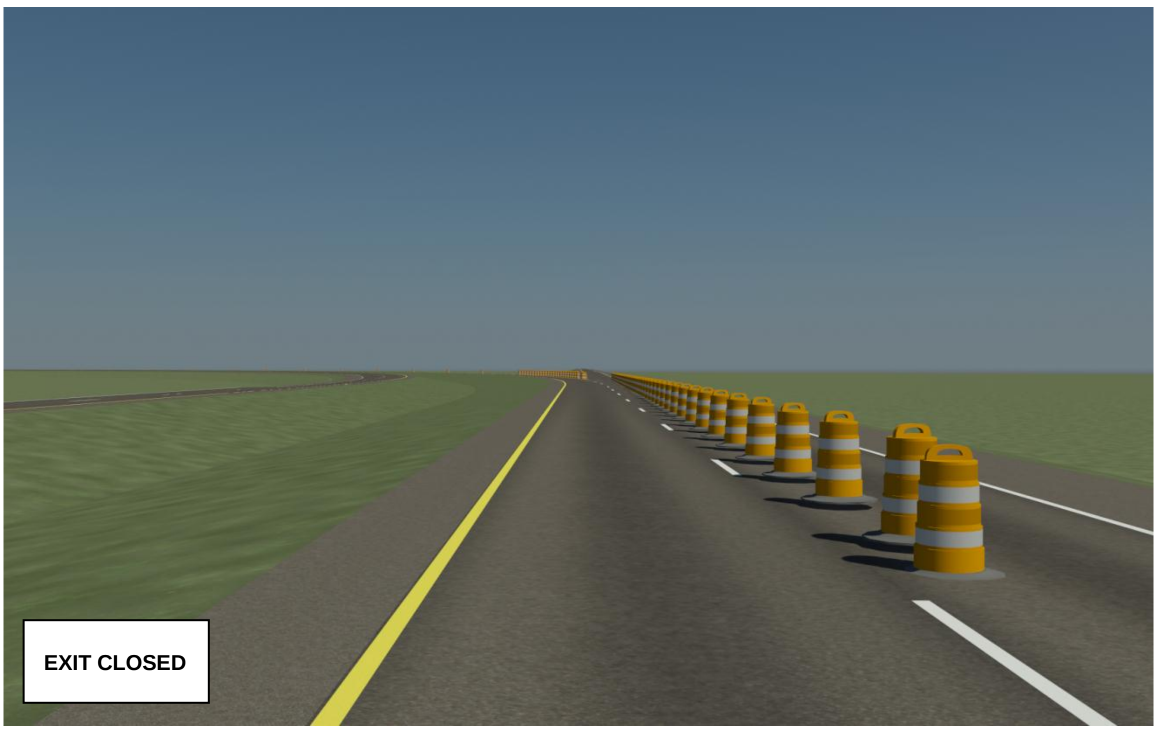


Figure 10. Curved Geometry with 10 ft Spaced Drums

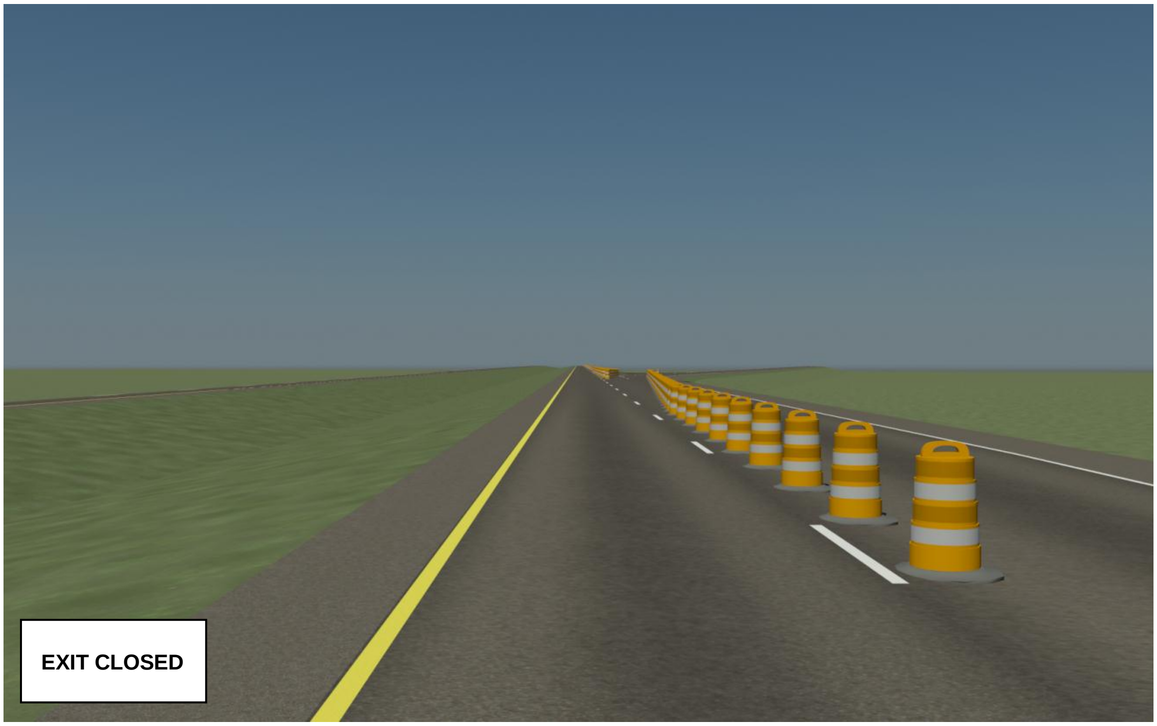


Figure 11. Straight Geometry with 10 ft Spaced Drums

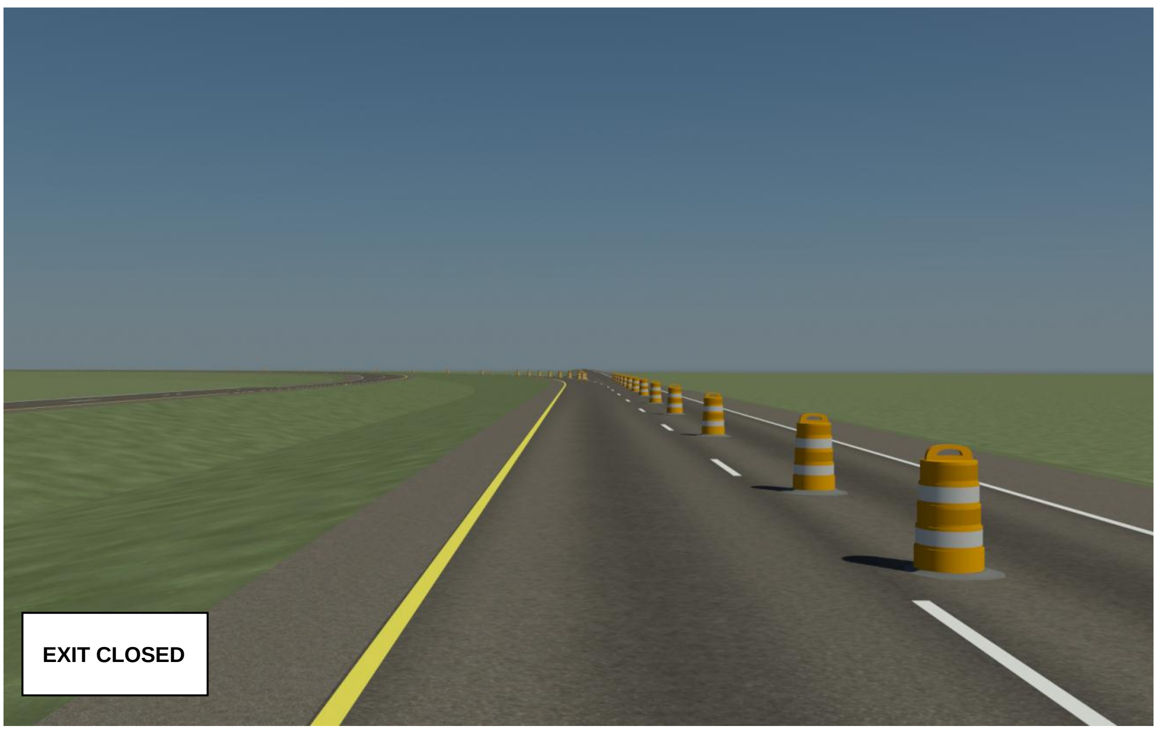


Figure 12. Curved Geometry with 40 ft Spaced Drums

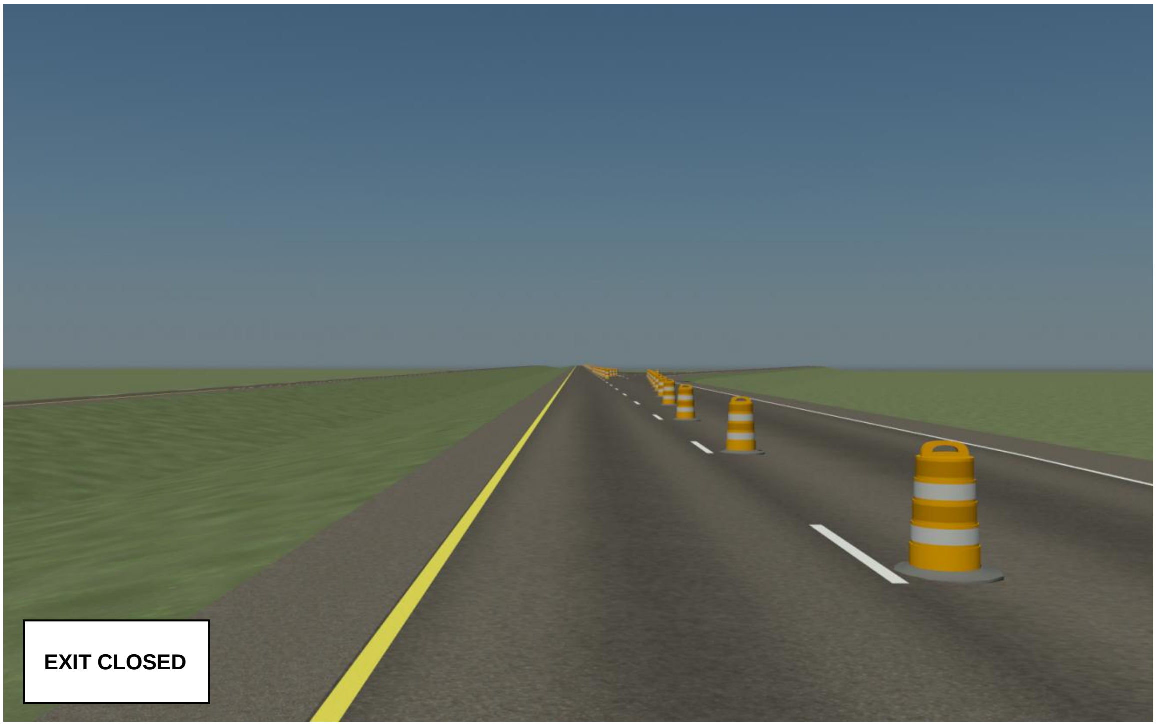


Figure 13. Straight Geometry with 40 ft Spaced Drums

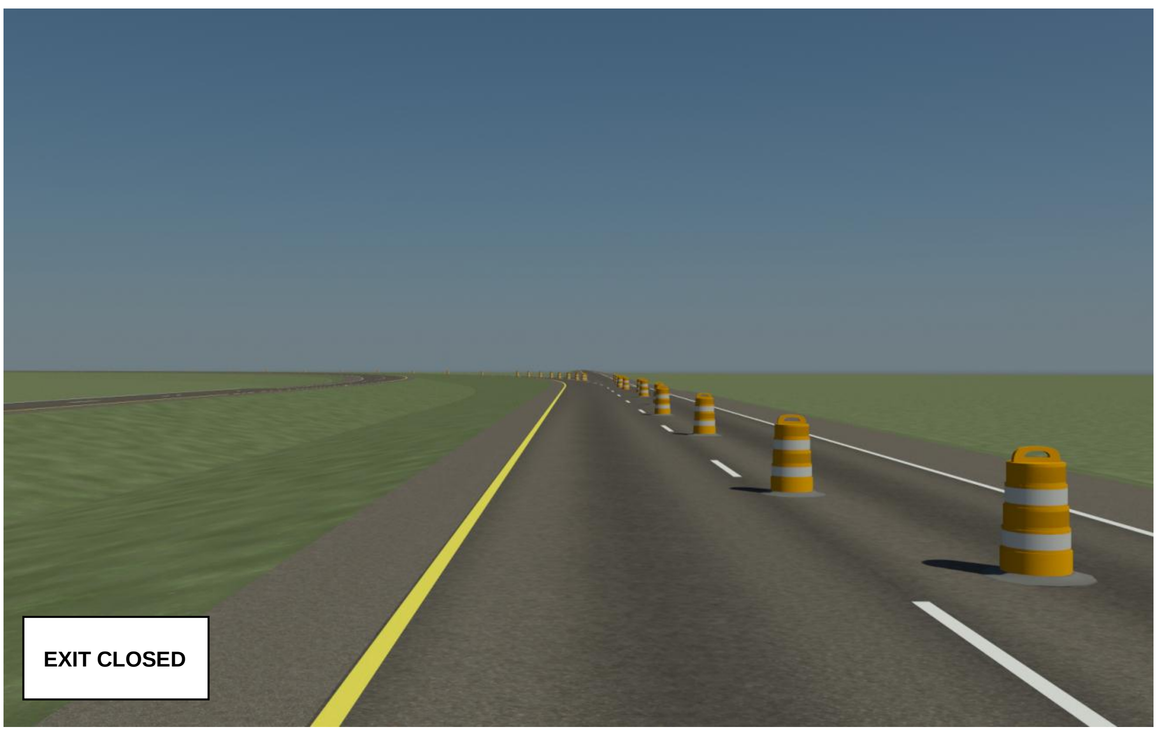


Figure 14. Curved Geometry with 40± 2 ft Spaced Drums

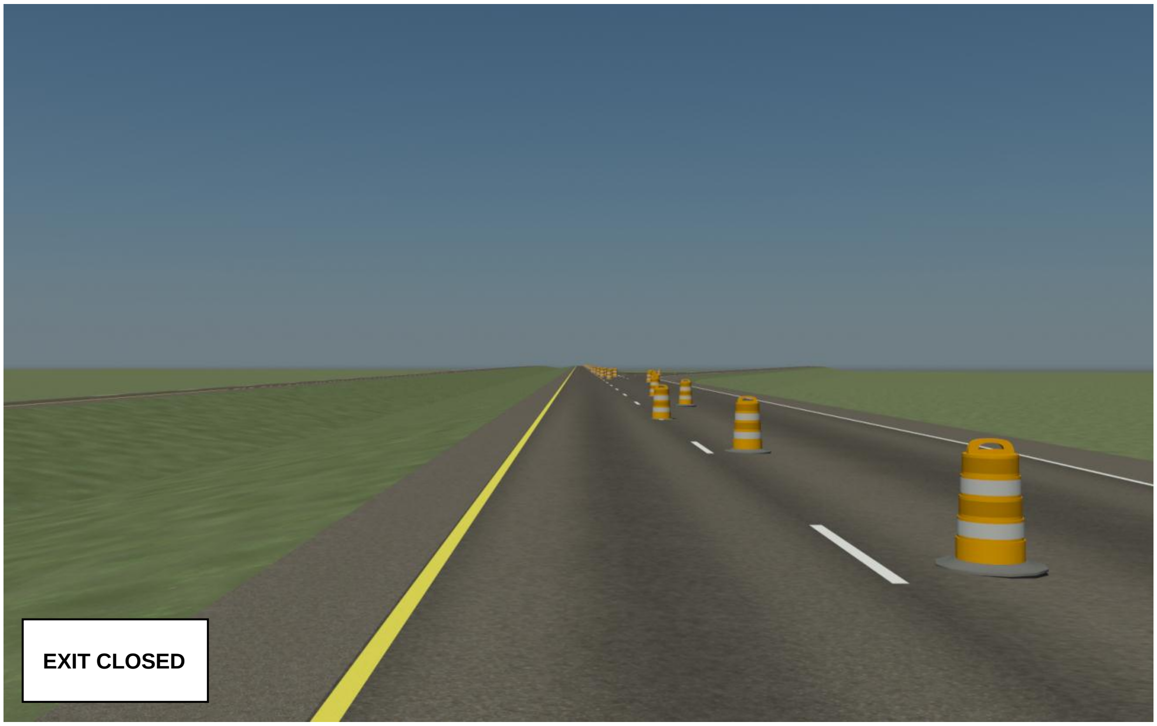


Figure 15. . Straight Geometry with 40 ± 2 ft Spaced Drums

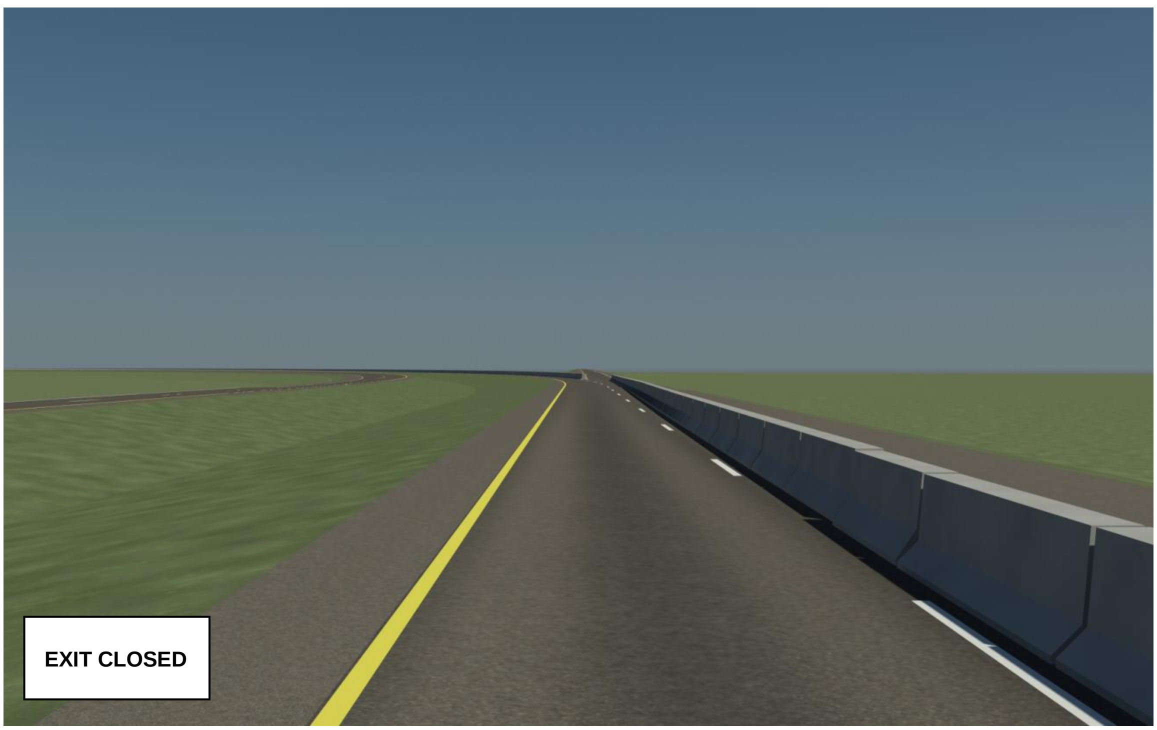


Figure 16. Curved Geometry with Portable Concrete Barriers

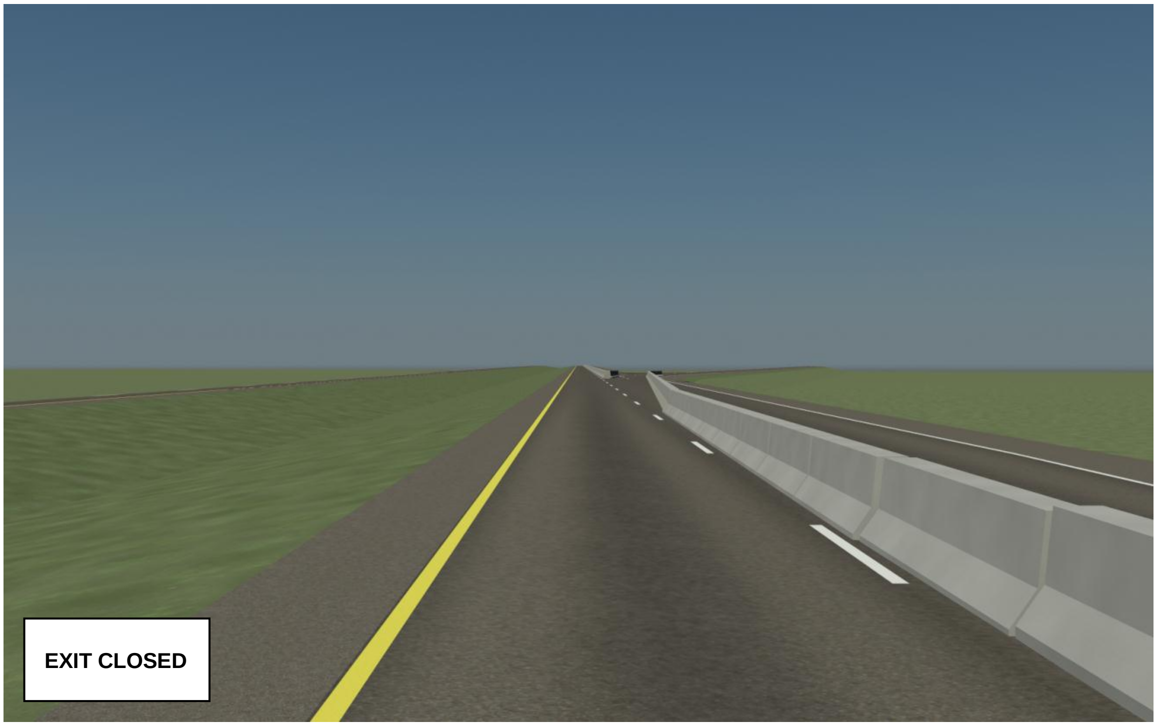


Figure 17. Straight Geometry with Portable Concrete Barriers

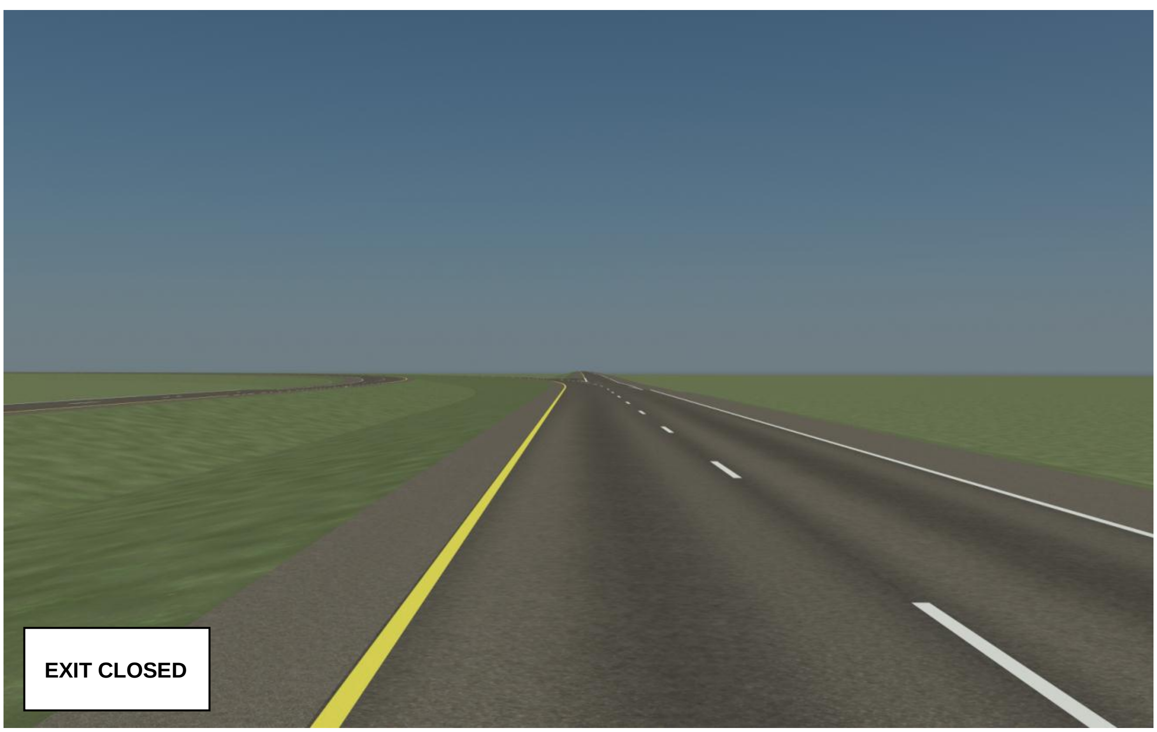


Figure 18. Curved Geometry with No Work

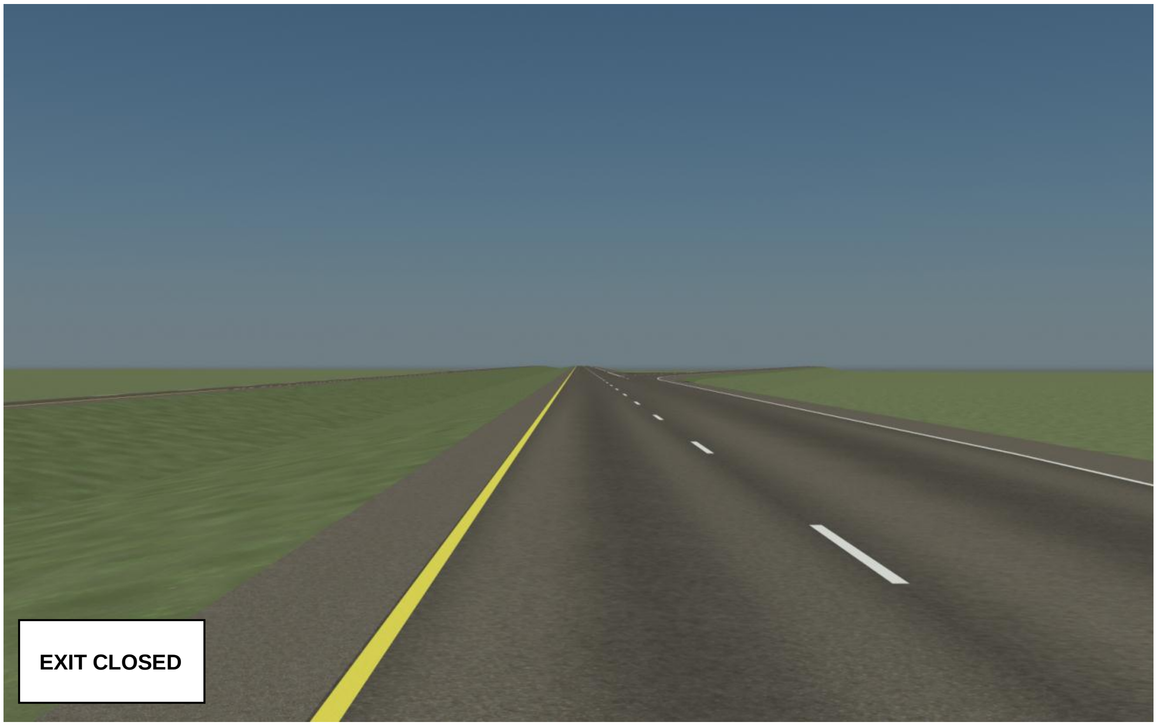


Figure 19. Straight Geometry with No Work

3.1.4 Rendering

Rendering was performed using the mental ray renderer with a high sampling rate (1 to 16 samples per pixel). Frames were taken at distances of 1 second, 2 seconds, 3 seconds, 4 seconds, and 5 seconds from the start of the ramp taper, where each second corresponded to 88 ft (assuming a vehicle would be travelling at 60 mph through the work zone). Each frame was rendered at the native resolution of the workstations where the experiment was to be performed: 1680x1050 pixels. A total of 4.5 alternatives (counting "No Work" as half since it had no closed condition) * 2 geometries * 2 open/closed states * 5 distances yielded 90 slides for the administration of the experiment.

3.2 Alternative Testing

3.1.5 Experiment Design

The experiment was designed such that each participant was shown each of the 90 slides 10 times, for a total of 900 slides. A participant was allowed three seconds to respond to a slide by clicking on the screen. If a ramp was open, the participant would indicate the location of the ramp, and if a ramp was closed the participant would click an EXIT CLOSED indication. After viewing 450 slides, participants were given a ten minute break. Each set of slides presented to each participant was randomized, with the exception that each slide was presented 5 times before the break and 5 times after the break. Slide order was randomized independently by the computer before each participant sat down at the workstation. At the end of the 900 slides, participants were shown the four channelizing device alternatives and asked to choose the one they preferred.

3.1.6 Instructions

The experiment was administered using Inquisit, a software package for recording responses from individuals in both questionnaire and timed response form. The software first displayed a slide explaining the experiment and listing instructions. These instruction slides can be found in Appendix A. The instructions then showed participants where they should click on example slides labeled with the correct responses. The system then had a trial slide to get the participants used to the timing. Participants were also instructed to click a plus sign on a slide that appeared between experiment slides. The purpose of this slide was to “reset” the pointer so that the time recorded to make a response would be comparable across slides. Once the participants had reached the end of the experiment, the system instructed them to raise their hand until the proctor came and saved the data.

3.1.7 Experiment Implementation

Individuals were brought into the testing lab and verbally given instructions on how to proceed. After listening to instructions, they were required to indicate that they had been driving for at least two years. They were then given an informed consent document (Appendix C) to review and sign if they agreed. No personal information was collected that could tie a participant to his or her results other than the sex of the individual being tested. Participants were then sat at one of several identical workstations with the experiment pre-loaded. After completing the experiment, participants were debriefed and offered a copy of their informed consent document.

3.3 Summary

This chapter highlighted the method of constructing the virtual environment for testing and the method of performing the experiment. This chapter specifically gave an overview of the roadway design, a description of the physical environment, examples of the alternatives tested, and details about the rendering. After that, the design and method of conducting the experiment were detailed. The next chapters discuss the analysis of data collected from performing these experiments and a discussion of those results.

CHAPTER 4

RESULTS

4.1 Participant Pool

The participant pool for the experiment consisted of forty-one (41) individuals spread across four testing periods, with four to more than fifteen individuals in each test period. Each participant was recruited from the pool of students taking Introductory Psychology at the Georgia Institute of Technology, a large public university in an urban setting with a predominant focus towards science and engineering. Responses from two participants were excluded when analysis indicated a failure to follow experimental instructions (i.e. fewer than 20% of their responses to open ramp conditions moved the cursor more than half the distance from the reset position to the ramp). This resulted in a final data set consisting of 39 subjects (N=39).

4.2 Response Location

In order to interpret participants' responses, a zoning system was developed for classifying where participants clicked on the screen. Figure 20 and Figure 21 illustrate the zoning on an open and closed ramp, respectively. A response was recorded as indicating the ramp was closed if the participant clicked on the zone located in the bottom left of the screen, the orange zone in Figure 20 and Figure 21. On all slides an EXIT CLOSED text box was indicated in this area. A "location error" response was registered if the participant clicked to indicate that the ramp was open but the participant selected the wrong part of the roadway in the outside lane. In Figure 20 and Figure 21, this is the red zone. A "ramp open" response was registered if the participant clicked on the ramp location, defined as a shape constructed using boundaries created by a line 2/3 of the distance from the reset position to the ramp opening centroid, a line across the horizon including a 50 pixel buffer, lines drawn from the reset position to the outside edges of the ramp opening, and lines drawn from the visible portions of the channelizing devices used to delineate the ramp opening. This is the green zone in Figure 20 and Figure 21. The final zone covered areas of the screen in the inside lane and in the sky. It was not clear what the intentions of the participants were in clicking these zones, so they were registered as "indeterminate." This is the yellow and blue areas in Figure 20 and Figure 21. Figure 22 illustrates the zoning scheme with data overlaid.

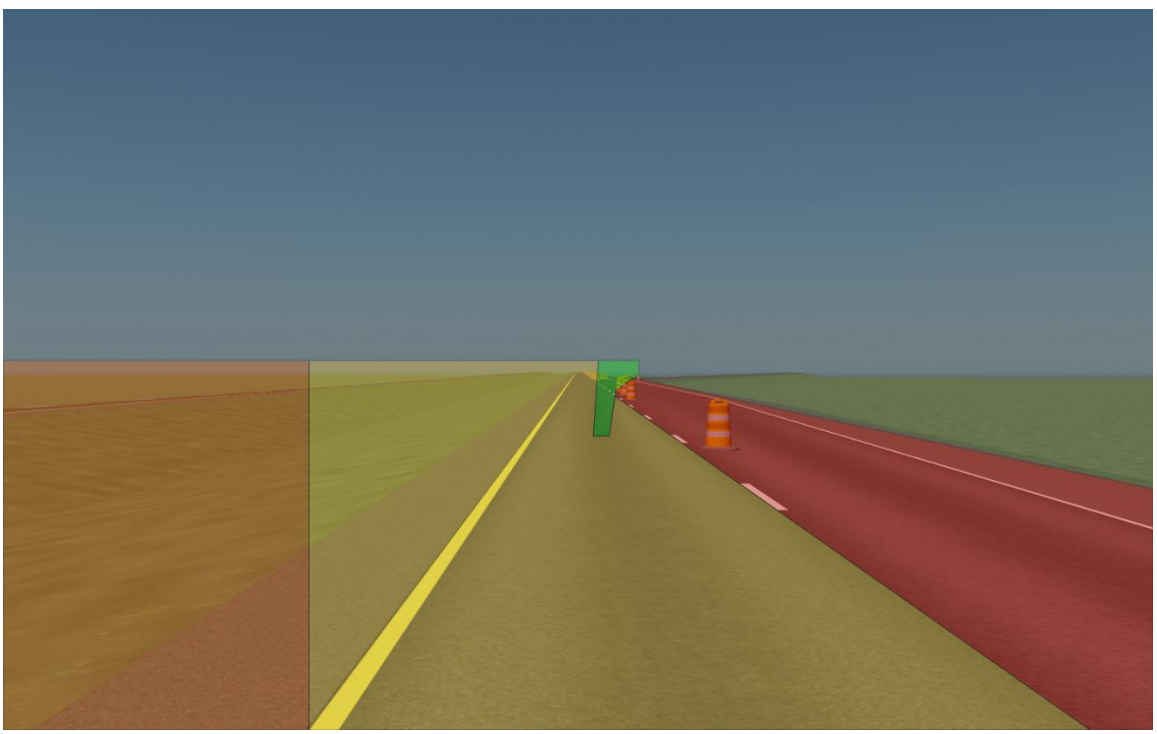


Figure 20. Zoning Scheme on 10 ft spacing, straight geometry, open ramp

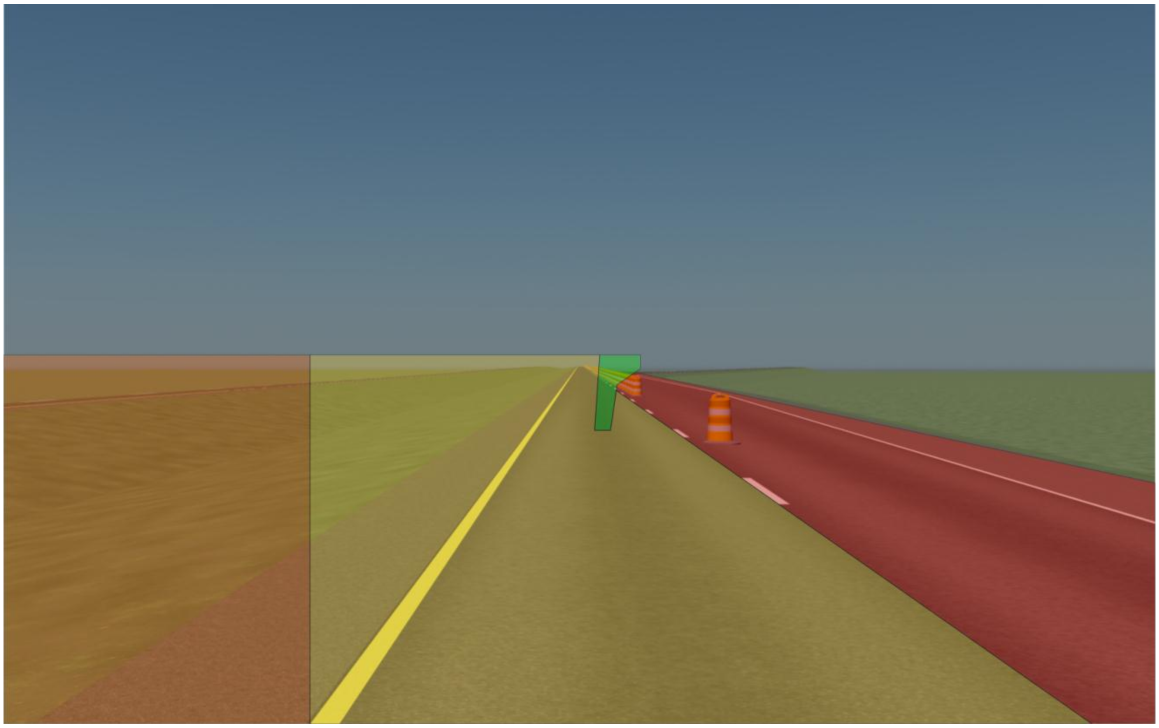


Figure 21. Zoning Scheme on 10 ft spacing, straight geometry, closed ramp

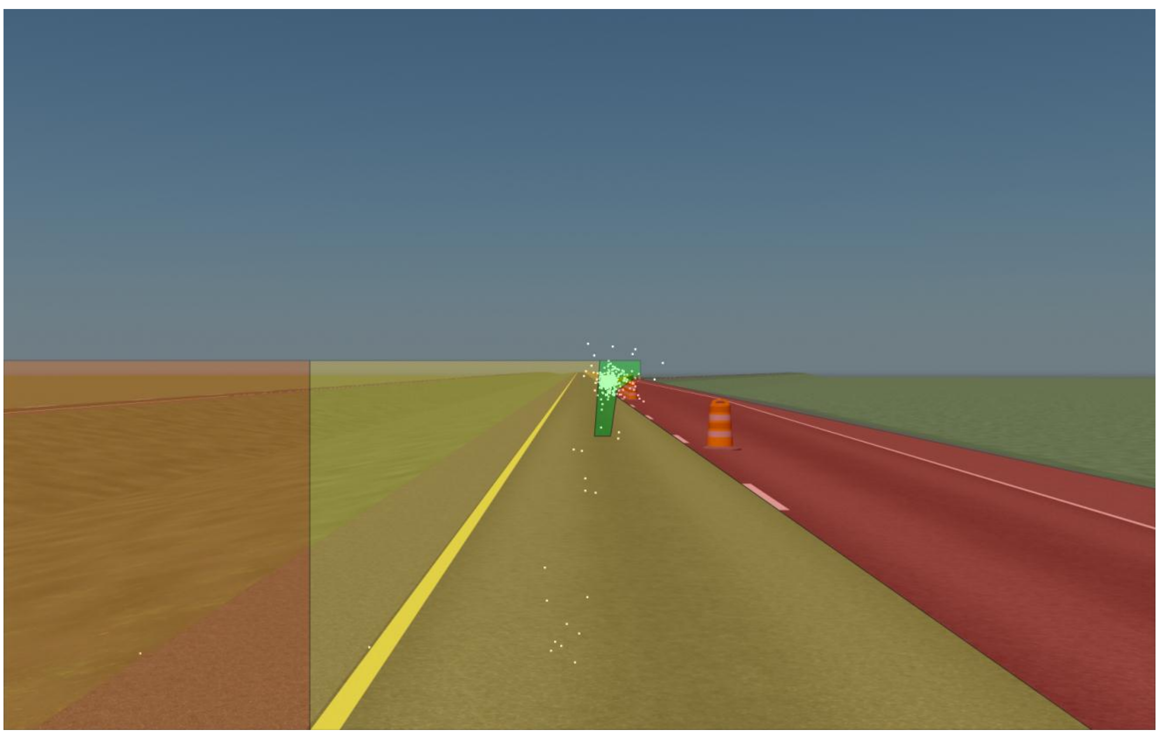


Figure 22. Zoning Scheme with Responses on 10 ft spacing, straight geometry, open ramp

To analyze differences, for each alternative combination each participant was assigned 5 scores of 0-10 corresponding to the number of responses made in each zone, tabulated depending on the alternative as correct, misidentification error, location error, indeterminate, or "gap out." Correct responses and misidentification errors were dependent on whether the ramp was open or closed in the alternative; if it was closed, a correct response was recorded if the participant clicked in the closed zone and a misidentification error was recorded if the participant clicked on the ramp. The opposite was true if the ramp was open. A "gap out" response was recorded if the participant did not respond within the allotted 3 seconds. Table 1 shows the responses that correspond to clicks in the various zones.

Table 1. Zones and Corresponding Recorded Responses For Open and Closed Condition

Zone	Open Ramp	Closed Ramp
Orange	Misidentification Error	Correct
Green	Correct	Misidentification Error
Red	Location Error	Location Error
Yellow & No Color	Indeterminate	Indeterminate
No Response	Gap Out	Gap Out

The analysis uses a randomized block design. To analyze whether a particular treatment had an effect on participant responses, an analysis of variance (ANOVA) was performed on the data from each alternative using participant as the blocking factor. Whenever a treatment effect was found to be statistically significant, multiple comparison testing was performed using the Tukey method. This analysis was performed on each score for each alternative, and comprehensive results can be found in Appendix B.

4.2.1 Correct Responses

Results for the straight condition varied with geometry and condition, as seen in

Table 2. In the straight and open condition, there were no significant differences between the PCBs and properly located barrels, (i.e. the 10 ft spacing and the 40 ft spacing) but there were significant effects between the 40 ± 2 ft spacing and all other alternatives. Participants were less likely to correctly identify the ramp in the 40 ± 2 ft spacing than at any other alternative at the 5s, 4s, and 3s distances. This effect diminishes as the distance decreases. For distances of 2s or less there are no significant differences between any alternatives. The PCB, 10 ft spacing, and 40 ft spacing alternatives were all comparable, both between each other and in the ways that they differed from the 40 ± 2 ft alternative. For the open condition and curved geometry, there were not significant differences between alternatives.

Table 2. Effects Table for Correct Responses (Significant Differences Highlighted)

Condition	Geometry	Distance (s)	PCB- 40 ± 2 ft Drums	PCB- 40 ft Drums	PCB- 10 ft Drums	40 ± 2 ft Drums- 40 ft Drums	40 ± 2 ft Drums- 10 ft Drums	40 ft Drums- 10 ft Drums
Open	Straight	5	4.282	0.000	0.179	-4.282	-4.103	0.179
		4	3.795	0.359	0.462	-3.436	-3.333	0.103
		3	1.051	0.128	0.077	-0.923	-0.974	-0.051
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
Closed	Straight	5	3.692	3.385	3.538	-0.308	-0.154	0.154
		4	2.538	2.872	3.000	0.333	0.462	0.128
		3	2.615	3.256	3.051	0.641	0.436	-0.205
		2	2.615	3.179	3.410	0.564	0.795	0.231
		1	2.179	0.462	0.333	-1.718	-1.846	-0.128
	Curved	5	1.128	1.564	1.692	0.436	0.564	0.128
		4	1.103	1.026	1.385	-0.077	0.282	0.359
		3	0.846	1.103	1.128	0.256	0.282	0.026
		2	0.641	0.179	0.103	-0.462	-0.538	-0.077
		1	0.256	0.128	0.077	-0.128	-0.179	-0.051

(Table value indicates Average Participant Number Correct for Treatment 1 minus Average Participant Number Correct for Treatment 2)

For the closed condition, results were more comparable between geometries:

- In the straight geometry, participants were more likely to make a correct response with the portable concrete barrier alternatives.
- This effect did not decrease as distance decreased, and remained relatively constant until the 1 s distance.
- In the curved geometry, PCBs also had higher mean correct responses than all drum alternatives.

- PCBs also had statistically significant results when compared with 40 ft and 10 ft spaced drums at 3s.
- The differences were smaller in the curved geometry than in the straight geometry.

Overall it is clear from the results that the PCB proved easier to interpret than all other alternatives tested, potentially illustrating the importance of the Gestalt principles as discussed earlier.

4.2.2 Misidentification Errors

Treatment effects on misidentification errors (Table 3) only occurred in the open condition, and with the greatest effect in the straight geometries. The 40 ± 2 ft drum spacing sees more misidentification errors than any of the other alternatives in the open condition and straight geometry at the 5, 4, and 3s distances. This effect decreases with distance, paralleling the pattern of decreased correct responses seen in Table 2. In the closed condition and the straight geometry, PCBs saw fewer errors than the 40 ± 2 ft spaced drums at 5s, and both PCBs and the 40 ft spacing saw fewer errors than the 40 ± 2 ft alternative at 4s and 3s.

Table 3. Effects Table for Misidentification Errors (Significant Differences Highlighted)

Condition	Geometry	Distance (s)	PCB-40 ± 2 ft Drums	PCB-40 ft Drums	PCB-10 ft Drums	40 ± 2 ft Drums-40 ft Drums	40 ± 2 ft Drums-10 ft Drums	40 ft Drums-10 ft Drums
Open	Straight	5	-4.974	-0.333	-0.282	4.641	4.692	0.051
		4	-3.641	-0.154	-0.128	3.487	3.513	0.026
		3	-0.462	-0.026	0.000	0.436	0.462	0.026
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
Closed	Straight	5	-0.769	-0.410	-0.410	0.359	0.359	0.000
		4	-0.590	-0.154	-0.205	0.436	0.385	-0.051
		3	-0.513	-0.128	-0.231	0.385	0.282	-0.103
		2	No Significant Differences					
		1	-0.667	-0.231	0.000	0.436	0.667	0.231
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					

(Table value indicates average number of participant responses for Treatment 1 minus average number of participant responses for Treatment 2)

4.2.3 Location Errors

Effects of location errors (Table 4) were only significant in the closed condition. In the straight geometry, the PCB alternative saw fewer errors than any of the drum alternatives. For the comparison between drum alternatives the 40 ± 2 ft spacing alternative outperformed the others at 5,4, 3, and 2 seconds however the differences were both statistically and practically insignificant. For the 1 s spacing, the pattern switched to show the 10 ft spacing alternative and the 40 ft spacing alternative seeing fewer errors than the 40 ± 2 ft spacing alternative. In the curved geometry, PCBs saw fewer statistically significant errors than the 10 ft spacing and 40 ft spacing alternatives at 5, 4, and 3 seconds. PCBs saw fewer errors than the 40 ± 2 ft spacing at 4s and 2s. However, the effects were small in all of these cases.

Table 4. Effects Table for Location Errors (Significant Differences Highlighted)

Condition	Geometry	Distance (s)	PCB- 40 ± 2 ft Drums	PCB- 40 ft Drums	PCB- 10 ft Drums	40 ± 2 ft Drums- 40 ft Drums	40 ± 2 ft Drums- 10 ft Drums	40 ft Drums- 10 ft Drums
Open	Straight	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
Closed	Straight	5	-2.564	-2.744	-2.718	-0.179	-0.154	0.026
		4	-1.513	-2.282	-2.154	-0.769	-0.641	0.128
		3	-1.846	-2.718	-2.359	-0.872	-0.513	0.359
		2	-1.974	-2.846	-2.923	-0.872	-0.949	-0.077
		1	-1.333	-0.128	0.000	1.205	1.333	0.128
	Curved	5	-0.769	-1.205	-1.205	-0.436	-0.436	0.000
		4	-0.846	-0.974	-1.282	-0.128	-0.436	-0.308
		3	-0.538	-0.923	-1.026	-0.385	-0.487	-0.103
		2	-0.385	-0.128	-0.026	0.256	0.359	0.103
		1	No Significant Differences					

(Table value indicates average number of participant responses for Treatment 1 minus average number of participant responses for Treatment 2)

4.2.4 Indeterminate Responses

Indeterminate response effects did not appear to show any clear pattern. Some effects were significant, but these effects were small and inconsistent. Results are presented in Table 5.

Table 5. Effects Table for Indeterminate Responses (Significant Differences Highlighted)

Condition	Geometry	Distance (s)	PCB-40 ± 2 ft Drums	PCB-40 ft Drums	PCB-10 ft Drums	40 ± 2 ft Drums-40 ft Drums	40 ± 2 ft Drums-10 ft Drums	40 ft Drums-10 ft Drums
Open	Straight	5	1.385	0.769	0.590	-0.615	-0.795	-0.179
		4	No Significant Differences					
		3	-0.333	0.077	0.205	0.410	0.538	0.128
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	0.667	0.564	0.462	-0.103	-0.205	-0.103
		4	No Significant Differences					
		3	No Significant Differences					
		2	0.590	0.564	0.538	-0.026	-0.051	-0.026
		1	No Significant Differences					
Closed	Straight	5	No Significant Differences					
		4	-0.282	-0.410	-0.641	-0.128	-0.359	-0.231
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					

(Table value indicates average number of participant responses for Treatment 1 minus average number of participant responses for Treatment 2)

4.2.5 Gap Outs

There were very few significant differences related to the likelihood of available time to elapsing before a response could be made relative to the treatment scenario (See Table 6). Combined with the small number of these errors, it is not reasonable to draw conclusions based on these responses.

Table 6. Effects Table for Gap Outs (Significant Differences Highlighted)

Condition	Geometry	Distance (s)	PCB-40 ± 2 ft Drums	PCB-40 ft Drums	PCB-10 ft Drums	40 ± 2 ft Drums-40 ft Drums	40 ± 2 ft Drums-10 ft Drums	40 ft Drums-10 ft Drums
Open	Straight	5	-0.256	-0.051	-0.026	0.205	0.231	0.026
		4	-0.282	0.026	0.000	0.308	0.282	-0.026
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
Closed	Straight	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					
	Curved	5	No Significant Differences					
		4	No Significant Differences					
		3	No Significant Differences					
		2	No Significant Differences					
		1	No Significant Differences					

(Table value indicates average number of participant responses for Treatment 1 minus average number of participant responses for Treatment 2)

4.3 Aggregated Results

4.3.1 Open Condition

Several trends appear when considering aggregated data for the open ramp condition. These results are illustrated in Figure 23 and Figure 24. The correct responses for the PCBs, 10 ft drums, and 40 ft drums are similar at all distances for both the straight and curved geometries. In contrast, the 40 ±2 ft spacing, at the five second distance sees fewer than 150 correct responses in the straight geometry and fewer than 200 correct responses at 4s in the curved geometry. Errors for the 40 ± 2 ft spacing alternative are largely misidentification errors, indicating that participants identified the ramp as closed even though it was open.

For the straight geometry a trend is evident in the number of location errors, which is elevated for the drum alternatives over the PCB alternatives for the longer distances. This is most apparent at the 5 s distance, but is also present, to a lesser extent, at the 4s and 3s distances. These errors indicate that participants knew the ramp was open but indicated an incorrect location for the exit. It is also important to note that performance was comparable across all alternatives in the curved geometry. These results parallel the individual effects explored above.

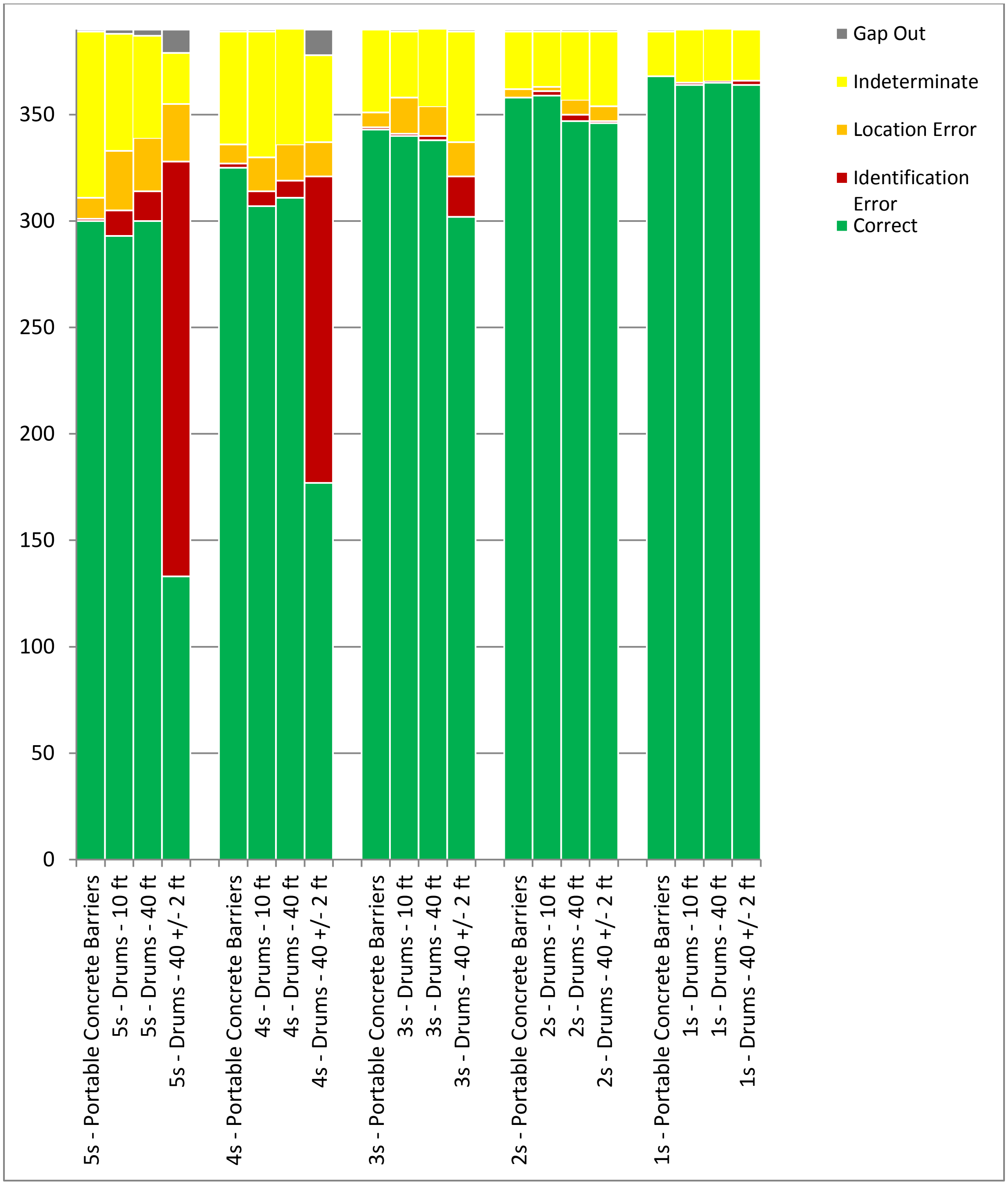


Figure 23. Responses for Straight Geometry, Open Condition

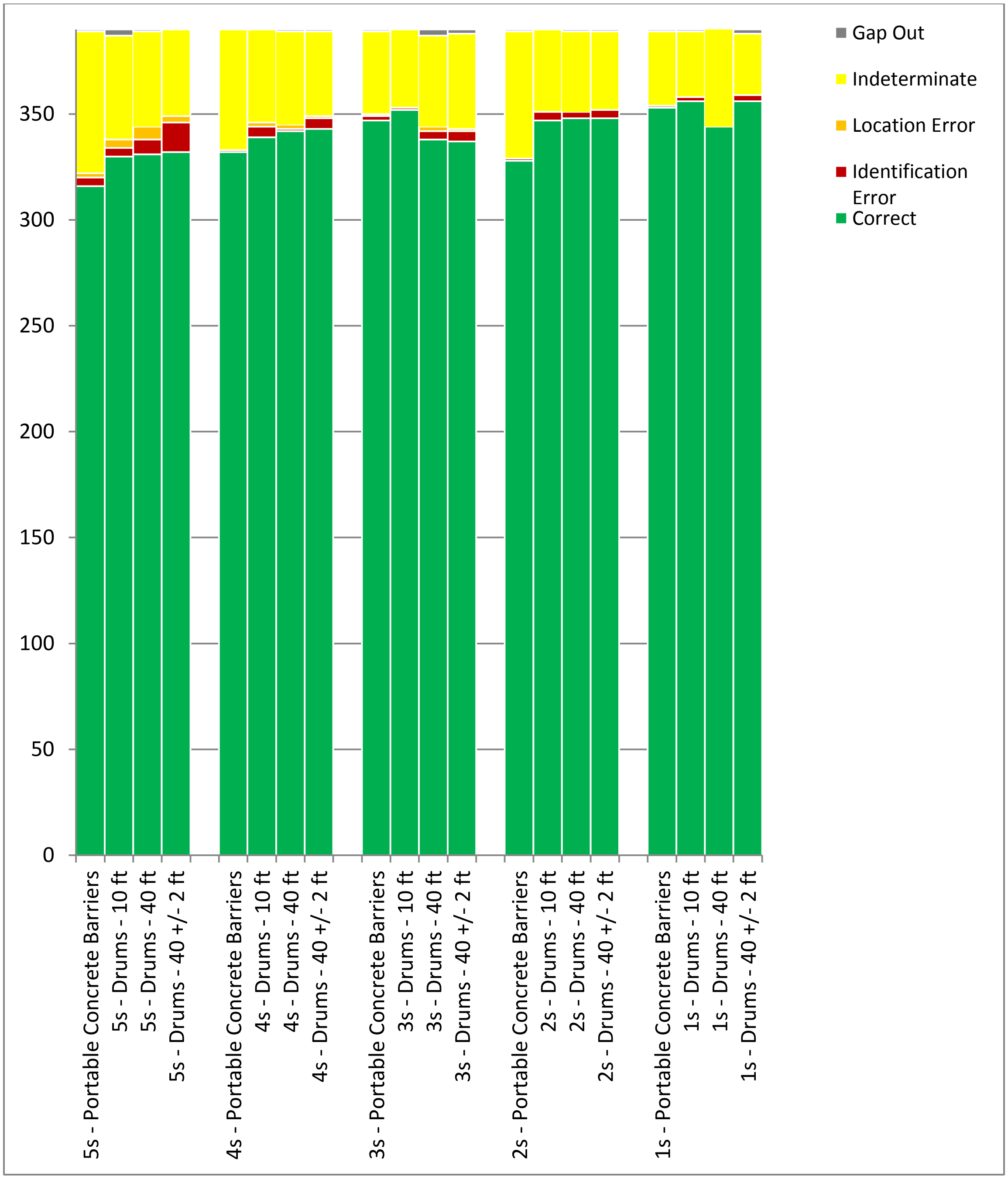


Figure 24. Responses for Curved Geometry, Open Condition

4.3.2 Closed Condition

Differences between alternatives in the closed condition varied both in type and magnitude from the open condition, indicated in Figure 25 and Figure 26. PCBs clearly outperformed all other alternatives at every distance in both geometries. In this closed condition with straight geometry, all drum based alternatives produced more than one hundred errors for all distances greater than 1 s. These errors were largely location errors, indicating that the participants believed the ramp was open when it was closed, and they selected gaps between drums as the opening for the ramp. While these errors diminished for the 10 ft spacing and 40 ft spacing alternatives at the 1 second distance, they were still pronounced in the 40 ± 2 ft spacing alternative. These types of errors were not as severe in the curved geometry and were largely corrected by 2s, but are still noteworthy.

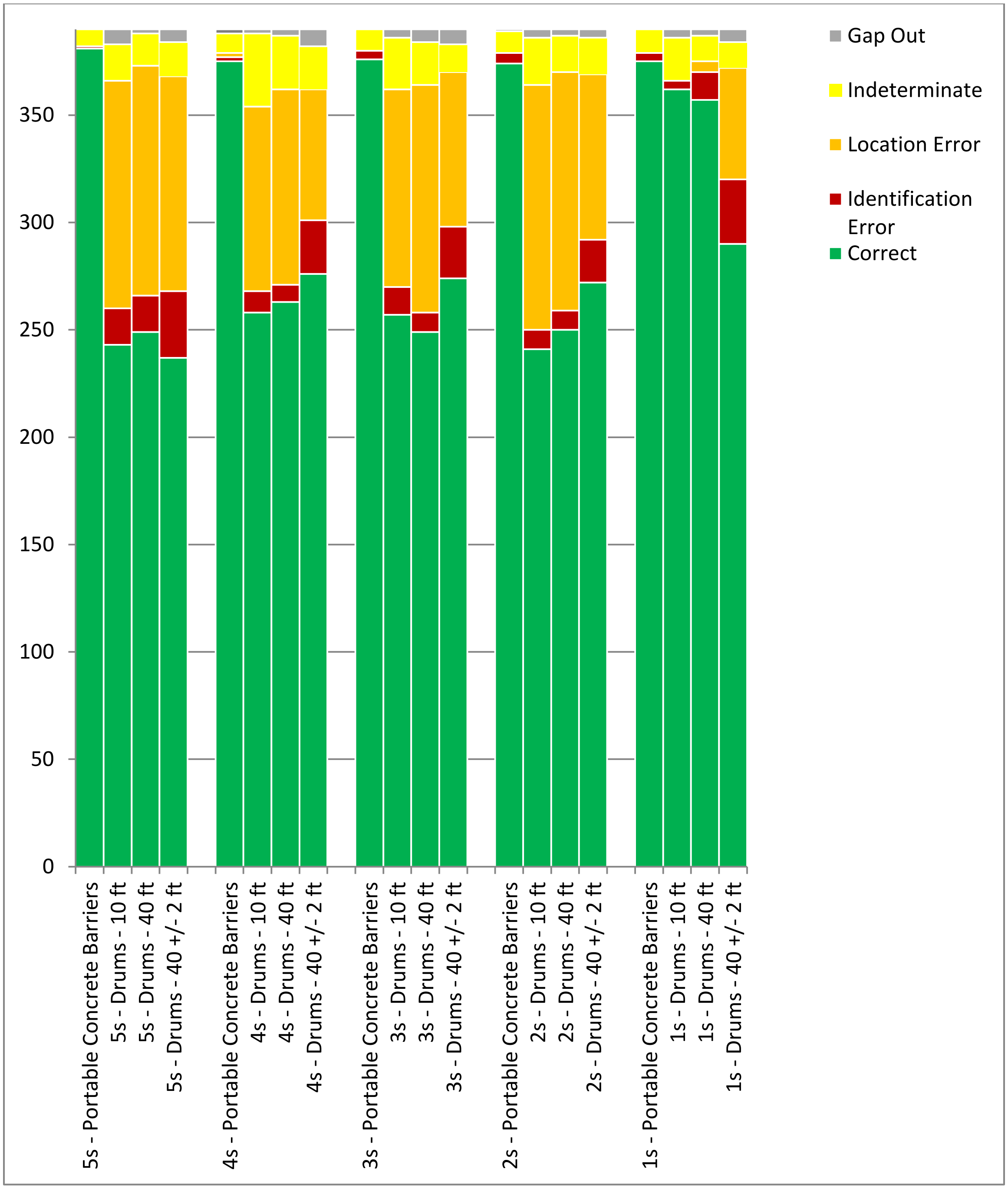


Figure 25. Responses for Straight Geometry, Closed Condition

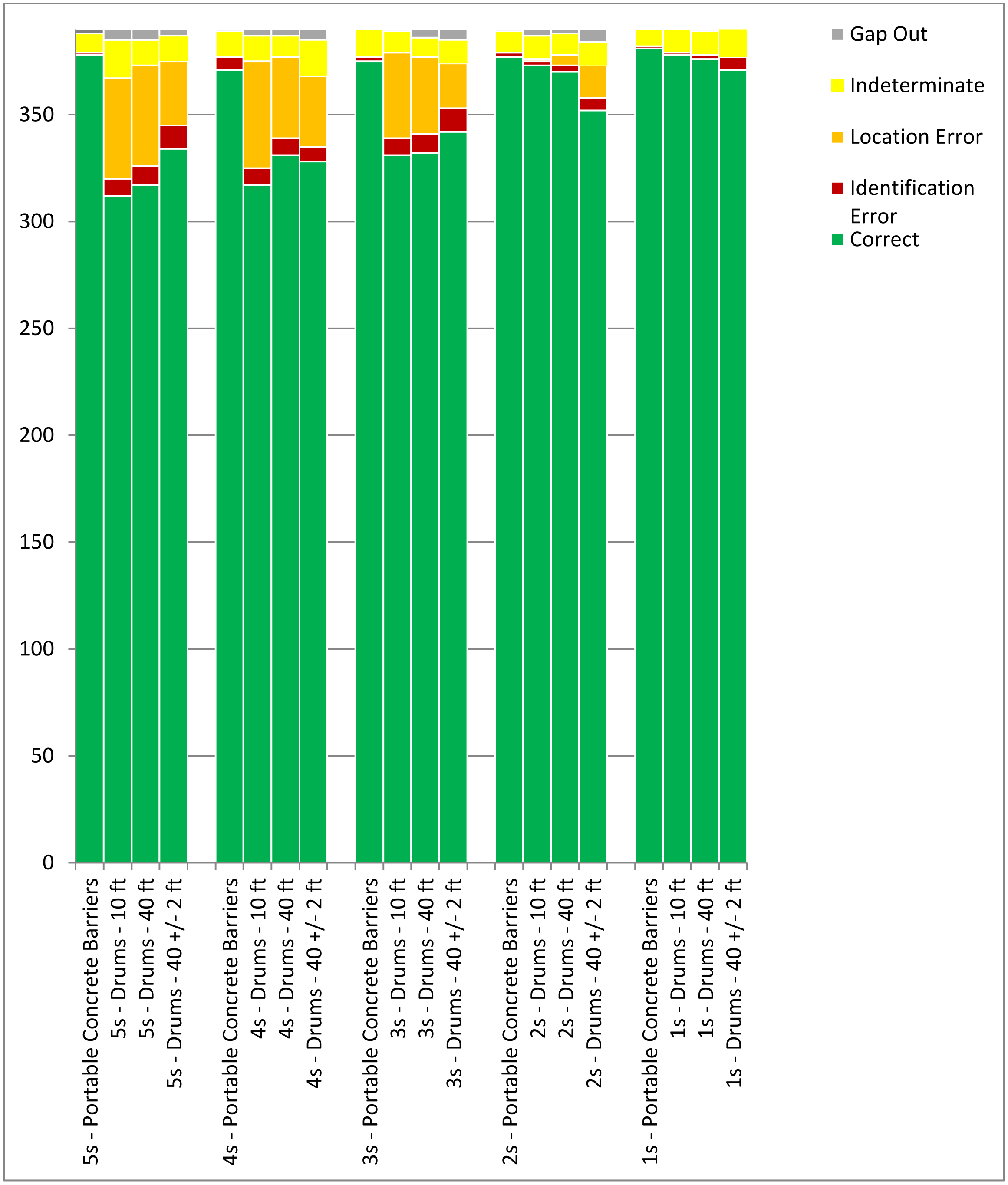


Figure 26. Response for Curved Geometry, Closed Condition

4.4 Stated Preference

At the end of each test run, individuals were shown four images of each alternative in the straight condition at 2 seconds away from the ramp and asked to select the alternative that they preferred. The presentation order was randomized for each participant. About 2/3 of participants preferred the portable concrete barriers and about 1/3 preferred the 10 ft spaced drums. One participant preferred the 40 ft spaced drums and no participants preferred the 40 ± 2 ft drums. Figure 27 shows the stated preferences for participants.

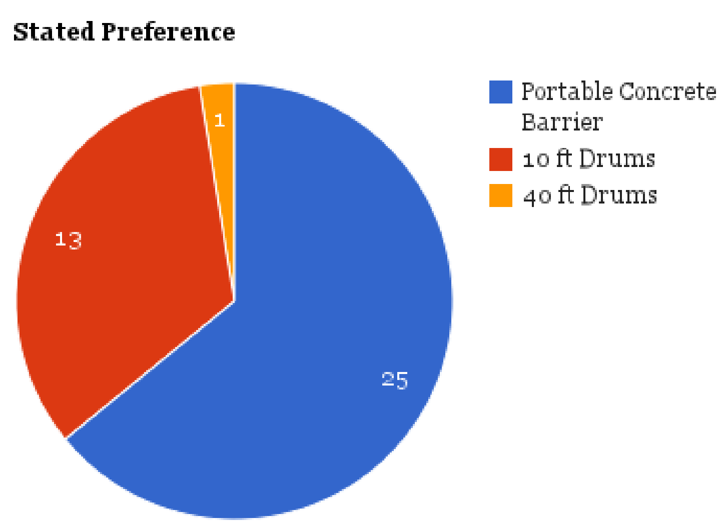


Figure 27. Stated Preference of Delineation Alternatives.

CHAPTER 5

DISCUSSION

Ultimately, the objective of this research is to evaluate characteristics of methods of delineating diverges in freeway work zones to inform future development of devices and configurations that improve drivers' ability to accurately identify appropriate paths. This discussion will focus on those characteristics of the alternatives in this experiment which affected participant performance.

5.1 Continuity

Continuity is the principle that objects forming a linear pattern will be subconsciously grouped as a single entity. One advantage to using a computer generated environment is that using the invisible construction lines, channelizing devices in the PCB, 10 ft and 40 ft drum spacing alternatives could be placed in a perfect line with exactly the same spacing between each device. Only the 40 ± 2 ft drum alternative was not perfectly linear; in that alternative drums deviated by a set pattern by up to a few feet in each direction.

The decrease in continuity for the 40 ± 2 ft alternative significantly affected the number of correct responses in several ways. The clearest example of this was the open condition of the straight geometry, where the 40 ± 2 ft alternative had over a hundred more misidentification errors at the 5s distance than any other alternative. This problem of increased misidentification errors continued through the 4s and 3s distances as well.

In a driving environment, misunderstanding the state of an exit ramp even for a short time period could have a negative impact on safety.

To a lesser extent, this discontinuity may have also contributed to elevated misidentification error rates and elevated location error rates on the straight and closed condition, but only at the 1s distance. This could indicate an issue with perception caused by a lack of continuity in the immediate vicinity of the ramp, although further study is required.

This issue of continuity is important since a number of effects can result in device placement that is not perfectly continuous. Wind and gusts from traffic can shift drums as they are sitting on the road surface and minor differences in drum placement can mean drums start in places that break an ideal placement pattern. The data from this experiment is not sufficiently comprehensive to draw firm conclusions, but they do imply that even a relatively small variation in channelizing device continuity may decrease the ability of drivers to immediately comprehend the condition of an exit ramp.

5.2 Closure

The principle of closure, as it applies to these circumstances, dictates that images that overlap in the visual scene may be perceived as a group. The portable concrete barriers always overlap one another and thus create the sense of being a single object. Similarly, the drums overlap each other when they are far down the road, but do not overlap at shorter distances. This can even be the case where the ramp opening is intended to be placed: if drums from the taper sections overlap with drums from the tangent section, they could give the impression that there is a single mass of drums. Finley et al (2011) reported this feedback when using closely spaced drums.

The impact of closure (or lack of closure) can be most easily seen in the closed condition. Here, the PCB alternatives had participants make fewer errors in the 5, 4, 3, and 2s distances on the straight geometry. The elevated error rates in the drum alternatives were dominated by location errors, where participants selected a part of the closed lane as the ramp. However, these errors were not nearly as prevalent in the open condition, and no statistical differences existed between alternatives. This suggests that the break in closure from nearby drums incorrectly cued some participants that the opening was the ramp location.

The elevated number of location errors in areas without solid closure can both direct future research and also raise issues with existing standards. A short review of state standards and of the MUTCD suggest that states have focused on special ramp treatments in the immediate vicinity of a ramp, especially when the ramp is open. But these errors occurred when the ramp was closed, several hundred feet from the start of ramp treatment. These errors suggest that not only is closure an important issue, but also that a temporary ramp configuration could have impacts on driver understanding at greater distances than existing delineation methods account for.

5.3 Proximity

It may also be possible that some of the errors from locations could be attributed to channelizing devices too far apart to be mentally grouped through the principle of proximity. The principle of proximity suggests that items which are close together will be subconsciously aggregated as a single entity. However, in the conditions where location errors occurred in both the straight and curved geometries of the closed condition, the drums were spaced 120 feet apart. This distance may have been too great for individuals to connect as a single entity, especially when comparing to more closely spaced drums several hundred feet down the roadway. If the drums were seen as separate entities, the gap between them may have seemed like an appropriate path.

Proximity does not seem to have an effect on correct responses in all situations, however. The 10 ft spaced drums and the 40 ft spaced drums saw no significant differences in any of the five responses at any of the 90 alternatives. While the difference between 10 ft spacing and 40 ft spacing is not enough to discount proximity as an important principle in channelizing device configurations, it is important to note that simply decreasing the drum spacing is not necessarily sufficient to impact driver performance.

5.4 Summary

The principles of proximity, closure, and continuity explain much of the performance difference between the alternatives in this experiment. This chapter discussed the results in the context of these principles. Diminished continuity could explain the comparably worse performance of the 40 ± 2 ft spaced drums at the further distances from the ramp. Breaks in closure could explain the higher number of errors recorded with drum alternatives (rather than PCBs) in the closed condition. Proximity could also explain some of this poor performance, but did not appear to have an impact in the immediate ramp vicinity.

While proximity, closure, and continuity explain some of the results, they do not provide a full explanation for differences in alternative performance. Several other issues, such as line of sight, lighting conditions, etc., potentially influence performance. . These results are not sufficient to draw broad conclusions, but could certainly inform future research into work zone diverge delineation.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

The purpose of this study was to gain insight into the characteristics of various methods of delineating diverges in freeway work zones and their impact on driver performance. This chapter will highlight the results from the experiment and make recommendations for future studies.

6.1 Conclusions

This experiment evaluated roadway conditions in a laboratory environment with no physical risk and a "clean" physical environment with no distractions in the roadside environment. Given that all work zones are unique and all work zones bring physical risk, it is not prudent to make broadly generalizable statements about driver performance based on these data. However, the results elucidate some noteworthy trends.

First, portable concrete barrier alternatives saw a higher correct response rate than any drum alternative in closed conditions at 5,4,3, and 2 seconds away from the ramp in the straight condition, and 5 and 4 seconds away in the curved condition. These differences are largely because of location errors, where participants selected a gap between drums that was not the ramp. This same difference was not present in open conditions. These errors could be attributed to lack of closure between devices and/or a lack of proximity from the distance between drums.

Second, the 40 ± 2 ft spaced drums saw higher misidentification error rates than any other alternative at 5, 4, and 3 seconds from the ramp in the open condition with the straight geometry, and saw higher misidentification error rates than the PCB alternative in the closed and straight condition at 5, 4, 3, and 1 second from the ramp. There were also higher misidentification error rates than the drum alternatives at 1 second form the ramp in the closed and straight condition. These results suggest that a combination of closure created by the drums creating a "sea of barrels" (Finley et al, 2011) and discontinuity impacted participants ability to quickly identify whether the ramp was open or closed.

Lastly, participant performance seemed also to be linked to ramp geometry, with higher error rates in the straight geometry. This, along with better performance at shorter distances, reinforces that line of sight may contribute to increased understanding of a freeway exit type, despite the devices used to delineate the diverge.

6.2 Recommendations for Future Studies

This experiment looked mainly at current methods of delineating diverges in freeway work zones. While ultimately the goal of this research was to interpret characteristics of those methods as guidance for future methods of delineation, future research is needed into understanding driver performance with novel methods of delineating diverges. Future research should build off of the lessons learned here about the importance of continuity, proximity, and closure to test innovative channelizing devices and patterns.

- Results indicate that participant performance significantly declined with distance in the closed condition. Future studies should investigate whether drivers are confused about ramp location in this case specifically, and whether changing the spacing of channelizing devices further away from the immediate ramp area would improve performance.

- The impact of small random variations in the placement of channelizing devices appears to have a significant impact in driver understanding of a work zone configuration. This may indicate increased importance in the implementation of work zone setup and maintenance. Future research should investigate the degree of variations found in existing work zones and also investigate allowable tolerances.
- Continuous walls outperformed discontinuous drum alternatives in closed conditions and the effect of this continuity should be investigated further, especially to see if the continuous effect can be created without the use of large and potentially hazardous concrete barriers.
- Introducing ± 2 ft of error has a significant effect on performance, but it is not clear if this effect is attributable to issues of closure, continuity or both. It should be further investigated to see if it is the break in continuity or the increased closure from a distance that is causing this effect.
- The participant pool in this experiment consisted of undergraduate students. Future research should also investigate the effects of work zone treatments on a sample made of the general population and/or high risk groups, such as older adults or new drivers.

- All images in this experiment were rendered to simulate afternoon sunlight. Future research should also investigate work zone diverge treatments in other weather and lighting conditions, such as low-light conditions or fog.
- Performance measures of decision time and accuracy of clicking may indicate how well a driver understands the layout of devices to indicate an exit ramp, but not how well a driver will control a vehicle in that same condition. Further research should be conducted in an environment where performance metrics of control can be measured, including speed, intensity of braking and acceleration, number of steering reversals, etc. A driving simulator could serve as bridge from this study to real-world performance, offering the precision of scenarios afforded by a laboratory environment without the risk associated with field testing a novel treatment.

APPENDIX A: INSTRUCTIONS

Please read the instructions carefully.

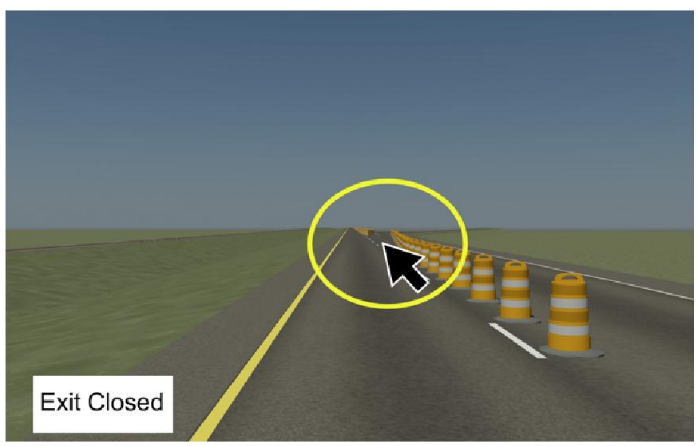
In this experiment, you will see pictures displayed on the screen one after another. Each picture shows an "exit ramp".

Each slide will be displayed for 3 seconds before advancing to the next slide. The "exit ramp" could be open or closed. If the "exit ramp" is open, click on the "exit ramp" as soon as you are sure that it is open; if the "exit ramp" is closed, click on the "Exit Closed" sign as soon as you are sure that it is closed.

Press on the 'n' key to continue to the next instruction page.

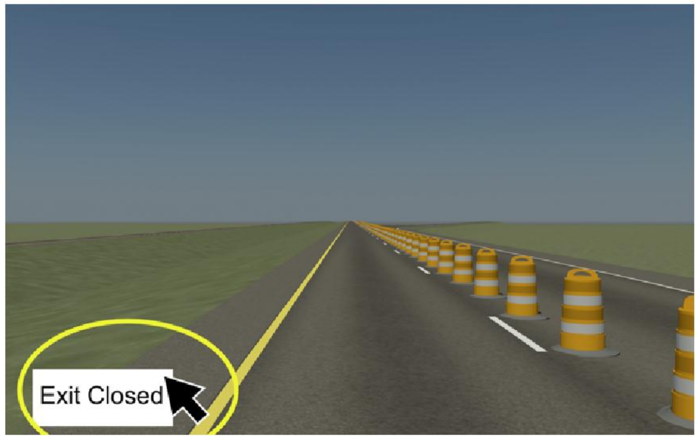
Press [n] to continue

Here's an example of an open ramp, and where you should click.



Press the 'n' key to proceed to the next page

Here's an example of a closed ramp. In this case, you should click 'Exit Closed'.



Press the 'n' key to proceed to the next page

Between slides, you will be shown this screen. Click on the '+' sign to proceed to the next slide.

Click on

+

to continue

Press the 'n' key to proceed to the next page

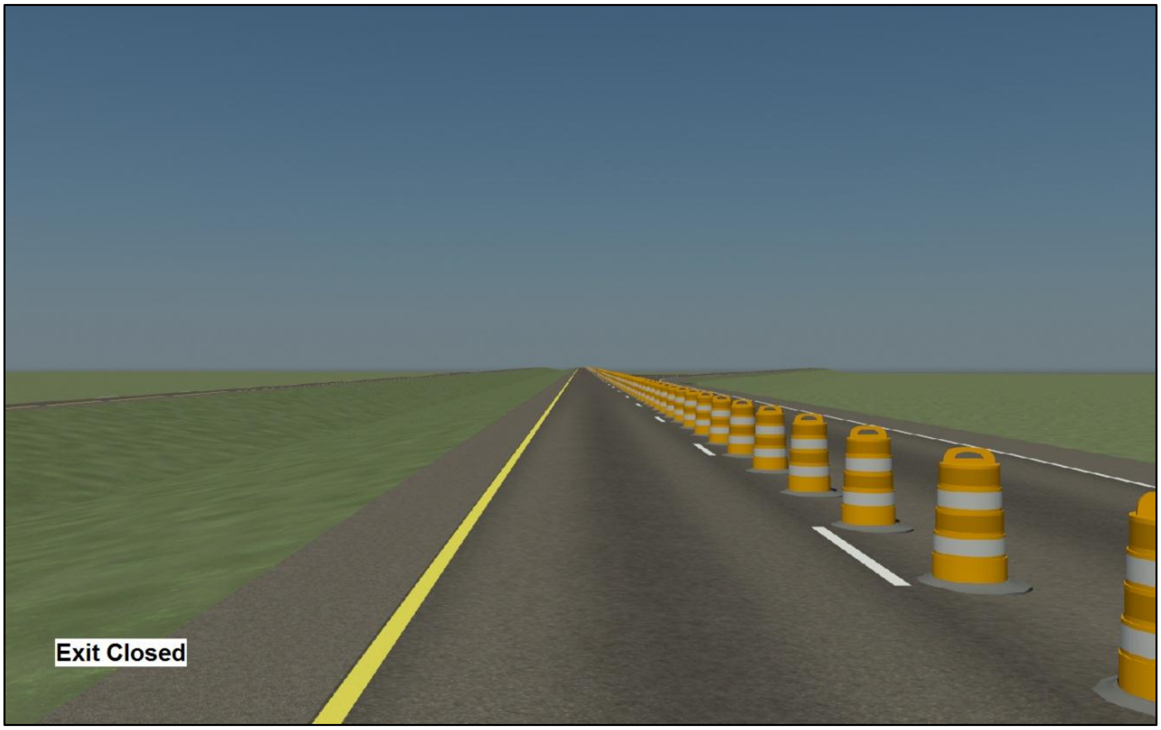
Let's do a couple 'warm-up' examples before we officially start.

Press the 'n' key again to proceed.

Click on

+

to continue



We are now ready to begin the experiment. Please press the 'n' key again to proceed.

APPENDIX B: STATISTICAL COMPARISONS OF ALTERANTIVES

B.1 Correct Responses

Table 7. ANOVA for Correct Responses in the Open Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	522.3	174.09	46.4	< 2e-16	***
participant	38	834.1	21.95	5.85	1.09E-13	***
Residuals	114	427.7	3.75			

Table 8. Tukey Method Comparison for Correct Responses in the Open Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	4.282051	3.138369	5.425734	0
PCB-40 ft Drums	1.77636E-15	-1.143682	1.143682	1
PCB-10 ft Drums	0.1794872	-0.964195	1.323169	0.976765
40 ± 2 ft Drums-40 ft Drums	-4.282051	-5.425734	-3.138369	0
40 ± 2 ft Drums-10 ft Drums	-4.102564	-5.246246	-2.958882	0
40 ft Drums-10 ft Drums	0.1794872	-0.964195	1.323169	0.976765

Table 9. ANOVA for Correct Responses in the Open Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	367.3	122.43	39.97	< 2e-16	***
participant	38	710.5	18.7	6.103	2.80E-14	***
Residuals	114	349.2	3.06			

Table 10. Tukey Method Comparison for Correct Responses in the Open Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	3.7948718	2.7614564	4.828287	0
PCB-40 ft Drums	0.3589744	-0.674441	1.39239	0.80183
PCB-10 ft Drums	0.4615385	-0.571877	1.494954	0.650398
40 ± 2 ft Drums-40 ft Drums	-3.4358974	-4.469313	-2.402482	0
40 ± 2 ft Drums-10 ft Drums	-3.3333333	-4.366749	-2.299918	0
40 ft Drums-10 ft Drums	0.1025641	-0.930851	1.13598	0.993894

Table 11. ANOVA for Correct Responses in the Open Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	28.6	9.528	6.803	0.00029	***
participant	38	526.7	13.86	9.896	< 2e-16	***
Residuals	114	159.7	1.401			

Table 12. Tukey Method Comparison for Correct Responses in the Open Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	1.05128205	0.3525128	1.7500513	0.000854
PCB-40 ft Drums	0.12820513	-0.570564	0.8269744	0.963726
PCB-10 ft Drums	0.07692308	-0.621846	0.7756923	0.991717
40 ± 2 ft Drums-40 ft Drums	-0.92307692	-1.621846	-0.2243077	0.004401
40 ± 2 ft Drums-10 ft Drums	-0.97435897	-1.673128	-0.2755897	0.002331
40 ft Drums-10 ft Drums	-0.05128205	-0.750051	0.6474872	0.997502

Table 13. ANOVA for Correct Responses in the Open Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	3.7	1.239	2.324	0.0786	.
participant	38	473.3	12.454	23.36	<2e-16	***
Residuals	114	60.8	0.533			

Table 14. ANOVA for Correct Responses in the Open Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.3	0.092	0.456	0.714	
participant	38	354.9	9.34	46.35	<2e-16	***
Residuals	114	23	0.202			

Table 15. ANOVA for Correct Responses in the Closed Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	368.1	122.69	29.21	4.39E-14	***
participant	38	1264.9	33.29	7.924	< 2e-16	***
Residuals	114	478.9	4.2			

Table 16. Tukey Method Comparison for Correct Responses in the Closed Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	3.6923077	2.482101	4.9025144	0
PCB-40 ft Drums	3.3846154	2.174409	4.5948221	0
PCB-10 ft Drums	3.5384615	2.328255	4.7486682	0
40 ± 2 ft Drums-40 ft Drums	-0.3076923	-1.517899	0.9025144	0.91077
40 ± 2 ft Drums-10 ft Drums	-0.1538462	-1.364053	1.0563605	0.987378
40 ft Drums-10 ft Drums	0.1538462	-1.056361	1.3640528	0.987378

Table 17. ANOVA for Correct Responses in the Closed Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	234.3	78.1	20.63	9.55E-11	***
participant	38	1235	32.5	8.582	< 2e-16	***
Residuals	114	431.7	3.79			

Table 18. Tukey Method Comparison for Correct Responses in the Closed Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	2.5384615	1.389478	3.687445	4E-07
PCB-40 ft Drums	2.8717949	1.7228113	4.020778	0
PCB-10 ft Drums	3	1.8510164	4.148984	0
40 ± 2 ft Drums-40 ft Drums	0.3333333	-0.81565	1.482317	0.873742
40 ± 2 ft Drums-10 ft Drums	0.4615385	-0.687445	1.610522	0.72199
40 ft Drums-10 ft Drums	0.1282051	-1.020779	1.277189	0.991382

Table 19. ANOVA for Correct Responses in the Closed Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	267.1	89.04	22.1	2.37E-11	***
participant	38	1145.2	30.14	7.479	< 2e-16	***
Residuals	114	459.4	4.03			

Table 20. Tukey Method Comparison for Correct Responses in the Closed Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	2.6153846	1.4301377	3.8006315	4E-07
PCB-40 ft Drums	3.2564103	2.0711634	4.4416572	0
PCB-10 ft Drums	3.0512821	1.8660351	4.236529	0
40 ± 2 ft Drums-40 ft Drums	0.6410256	-0.544221	1.8262725	0.495665
40 ± 2 ft Drums-10 ft Drums	0.4358974	-0.74935	1.6211443	0.772958
40 ft Drums-10 ft Drums	-0.2051282	-1.390375	0.9801187	0.969263

Table 21. ANOVA for Correct Responses in the Closed Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	288.4	96.14	21.46	4.33E-11	***
participant	38	1170.8	30.81	6.876	5.22E-16	***
Residuals	114	510.8	4.48			

Table 22. Tukey Method Comparison for Correct Responses in the Closed Condition, Straight Geometry, 2s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	2.6153846	1.3655262	3.865243	1.7E-06
PCB-40 ft Drums	3.1794872	1.9296287	4.429346	0
PCB-10 ft Drums	3.4102564	2.160398	4.660115	0
40 ± 2 ft Drums-40 ft Drums	0.5641026	-0.685756	1.813961	0.642699
40 ± 2 ft Drums-10 ft Drums	0.7948718	-0.454987	2.04473	0.350637
40 ft Drums-10 ft Drums	0.2307692	-1.019089	1.480628	0.963072

Table 23. ANOVA for Correct Responses in the Closed Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	111.6	37.21	14.66	3.87E-08	***
participant	38	262.4	6.91	2.721	2.32E-05	***
Residuals	114	289.4	2.54			

Table 24. Tukey Method Comparison for Correct Responses in the Closed Condition, Straight Geometry, 1s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	2.1794872	1.2388002	3.1201742	1E-07
PCB-40 ft Drums	0.4615385	-0.479149	1.4022255	0.57797
PCB-10 ft Drums	0.3333333	-0.607354	1.2740203	0.792116
40 ± 2 ft Drums-40 ft Drums	-1.7179487	-2.658636	-0.7772617	3.35E-05
40 ± 2 ft Drums-10 ft Drums	-1.8461538	-2.786841	-0.9054668	7.5E-06
40 ft Drums-10 ft Drums	-0.1282051	-1.068892	0.8124819	0.984543

Table 25. ANOVA for Correct Responses in the Open Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	4.4	1.459	1.571	0.2	
participant	38	506.9	13.339	14.36	<2e-16	***
Residuals	114	105.9	0.929			

Table 26. ANOVA for Correct Responses in the Open Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.9	0.632	0.895	0.446	
participant	38	444.7	11.703	16.55	<2e-16	***
Residuals	114	80.6	0.707			

Table 27. ANOVA for Correct Responses in the Open Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	4	1.342	1.437	0.236	
participant	38	427.7	11.256	12.05	<2e-16	***
Residuals	114	106.5	0.934			

Table 28. ANOVA for Correct Responses in the Open Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	7.5	2.485	2.839	0.0411	*
participant	38	416.8	10.968	12.53	<2e-16	***
Residuals	114	99.8	0.875			

Table 29. Tukey Method Comparison for Correct Responses in the Open Condition, Curved Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.51282051	-1.065255	0.03961397	0.07896
PCB-40 ft Drums	-0.51282051	-1.065255	0.03961397	0.07896
PCB-10 ft Drums	-0.48717949	-1.039614	0.065255	0.104209
40 ± 2 ft Drums-40 ft Drums	0	-0.552435	0.55243448	1
40 ± 2 ft Drums-10 ft Drums	0.02564103	-0.526794	0.57807551	0.999363
40 ft Drums-10 ft Drums	0.02564103	-0.526794	0.57807551	0.999363

Table 30. ANOVA for Correct Responses in the Open Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	2.5	0.827	1.204	0.311	
participant	38	370.1	9.739	14.19	<2e-16	***
Residuals	114	78.3	0.687			

Table 31. ANOVA for Correct Responses in the Closed Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	69.3	23.1	9.921	7.29E-06	***
participant	38	652.8	17.179	7.378	< 2e-16	***
Residuals	114	265.4	2.328			

Table 32. Tukey Method Comparison for Correct Responses in the Closed Condition, Curved Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	1.1282051	0.2272213	2.029189	0.007785
PCB-40 ft Drums	1.5641026	0.6631188	2.465086	8.66E-05
PCB-10 ft Drums	1.6923077	0.7913239	2.593291	1.91E-05
40 ± 2 ft Drums-40 ft Drums	0.4358974	-0.465086	1.336881	0.589269
40 ± 2 ft Drums-10 ft Drums	0.5641026	-0.336881	1.465086	0.364667
40 ft Drums-10 ft Drums	0.1282051	-0.772779	1.029189	0.982484

Table 33. ANOVA for Correct Responses in the Closed Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	42.9	14.297	6.309	0.00054	***
participant	38	644.9	16.972	7.489	< 2e-16	***
Residuals	114	258.4	2.266			

Table 34. Tukey Method Comparison for Correct Responses in the Closed Condition, Curved Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	1.1025641	0.2136937	1.9914345	0.008562
PCB-40 ft Drums	1.02564103	0.1367706	1.9145114	0.01681
PCB-10 ft Drums	1.38461538	0.495745	2.2734858	0.000515
40 ± 2 ft Drums-40 ft Drums	-0.07692308	-0.965794	0.8119473	0.995927
40 ± 2 ft Drums-10 ft Drums	0.28205128	-0.606819	1.1709217	0.841396
40 ft Drums-10 ft Drums	0.35897436	-0.529896	1.2478448	0.718636

Table 35. ANOVA for Correct Responses in the Closed Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	32.7	10.889	4.969	0.00281	**
participant	38	535.8	14.1	6.434	4.94E-15	***
Residuals	114	249.8	2.192			

Table 36. Tukey Method Comparison for Correct Responses in the Closed Condition, Curved Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	0.84615385	-0.027928	1.7202352	0.061545
PCB-40 ft Drums	1.1025641	0.2284827	1.9766455	0.007224
PCB-10 ft Drums	1.12820513	0.2541238	2.0022865	0.005674
40 ± 2 ft Drums-40 ft Drums	0.25641026	-0.617671	1.1304916	0.870079
40 ± 2 ft Drums-10 ft Drums	0.28205128	-0.59203	1.1561326	0.834609
40 ft Drums-10 ft Drums	0.02564103	-0.84844	0.8997224	0.999839

Table 37. ANOVA for Correct Responses in the Closed Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	9.38	3.128	4.877	0.00315	**
participant	38	209.86	5.523	8.611	< 2e-16	***
Residuals	114	73.12	0.641			

Table 38. Tukey Method Comparison for Correct Responses in the Closed Condition, Curved Geometry, 2s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	0.64102564	0.1681673	1.11388398	0.003271
PCB-40 ft Drums	0.17948718	-0.293371	0.65234552	0.755597
PCB-10 ft Drums	0.1025641	-0.370294	0.57542244	0.942078
40 ± 2 ft Drums-40 ft Drums	-0.46153846	-0.934397	0.01131988	0.058458
40 ± 2 ft Drums-10 ft Drums	-0.53846154	-1.01132	-0.0656032	0.018831
40 ft Drums-10 ft Drums	-0.07692308	-0.549781	0.39593526	0.974244

Table 39. ANOVA for Correct Responses in the Closed Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.36	0.453	3.652	0.0147	*
participant	38	163.81	4.311	34.75	<2e-16	***
Residuals	114	14.14	0.124			

Table 40. Tukey Method Comparison for Correct Responses in the Closed Condition, Curved Geometry, 1s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	0.25641026	0.0484563	0.46436418	0.009085
PCB-40 ft Drums	0.12820513	-0.079749	0.33615905	0.378555
PCB-10 ft Drums	0.07692308	-0.131031	0.284877	0.769852
40 ± 2 ft Drums-40 ft Drums	-0.12820513	-0.336159	0.0797488	0.378555
40 ± 2 ft Drums-10 ft Drums	-0.17948718	-0.387441	0.02846675	0.116094
40 ft Drums-10 ft Drums	-0.05128205	-0.259236	0.15667187	0.917791

B.2 Indeterminate Responses

Table 41. ANOVA for Indeterminate Responses in the Open Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	38	12.67	9.459	1.24E-05	***
participant	38	408.9	10.76	8.031	< 2e-16	***
Residuals	114	152.7	1.34			

Table 42. Tukey Method Comparison for Indeterminate Responses in the Open Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	1.3846154	0.70119184	2.06803893	0.0000037
PCB-40 ft Drums	0.7692308	0.08580722	1.45265431	0.020766
PCB-10 ft Drums	0.5897436	-0.09367995	1.27316713	0.116216
40 ± 2 ft Drums-40 ft Drums	-0.6153846	-1.29880816	0.06803893	0.0934261
40 ± 2 ft Drums-10 ft Drums	-0.7948718	-1.47829534	-0.11144825	0.0156775
40 ft Drums-10 ft Drums	-0.1794872	-0.86291072	0.50393636	0.9027147

Table 43. ANOVA for Indeterminate Responses in the Open Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	4.5	1.494	1.61	0.191	
participant	38	426.1	11.213	12.09	<2e-16	***
Residuals	114	105.8	0.928			

Table 44. ANOVA for Indeterminate Responses in the Open Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	6.2	2.06	3.27	0.0239	*
participant	38	452	11.89	18.88	<2e-16	***
Residuals	114	71.8	0.63			

Table 45. Tukey Method Comparison for Indeterminate Responses in the Open Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.33333333	-0.80198581	0.1353191	0.2536264
PCB-40 ft Drums	0.07692308	-0.3917294	0.5455756	0.9735763
PCB-10 ft Drums	0.20512821	-0.26352427	0.6737807	0.6648748
40 ± 2 ft Drums-40 ft Drums	0.41025641	-0.05839607	0.8789089	0.1081994
40 ± 2 ft Drums-10 ft Drums	0.53846154	0.06980906	1.007114	0.0174434
40 ft Drums-10 ft Drums	0.12820513	-0.34044735	0.5968576	0.8916541

Table 46. ANOVA for Indeterminate Responses in the Open Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.4	0.462	1.328	0.269	
participant	38	420.7	11.071	31.858	<2e-16	***
Residuals	114	39.6	0.348			

Table 47. ANOVA for Indeterminate Responses in the Open Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.2	0.077	0.433	0.73	
participant	38	354.9	9.338	52.522	<2e-16	***
Residuals	114	20.3	0.178			

Table 48. ANOVA for Indeterminate Responses in the Closed Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.28	0.427	1.424	2.40E-01	
participant	38	146.4	3.853	12.835	<2e-16	***
Residuals	114	34.22	0.3			

Table 49. ANOVA for Indeterminate Responses in the Closed Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	8.36	2.786	5.031	2.60E-03	**
participant	38	188.86	4.97	8.973	<2e-16	***
Residuals	114	63.14	0.554			

Table 50. Tukey Method Comparison for Indeterminate Responses in the Closed Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.2820513	-0.721474	0.15737141	0.3423899
PCB-40 ft Drums	-0.4102564	-0.8496791	0.02916628	0.0764106
PCB-10 ft Drums	-0.6410256	-1.0804483	-0.20160295	0.0013049
40 ± 2 ft Drums-40 ft Drums	-0.1282051	-0.5676278	0.31121757	0.8718852
40 ± 2 ft Drums-10 ft Drums	-0.3589744	-0.7983971	0.08044834	0.1498592
40 ft Drums-10 ft Drums	-0.2307692	-0.6701919	0.20865346	0.5211476

Table 51. ANOVA for Indeterminate Responses in the Closed Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	3.15	1.049	2.231	0.0884 .	
participant	38	153.47	4.039	8.59	<2e-16	***
Residuals	114	53.6	0.47			

Table 52. ANOVA for Indeterminate Responses in the Closed Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.87	0.624	1.419	2.41E-01	
participant	38	130.08	3.423	7.785	<2e-16	***
Residuals	114	50.13	0.44			

Table 53. ANOVA for Indeterminate Responses in the Closed Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.35	0.451	1.051	3.73E-01	
participant	38	147.36	3.878	9.041	<2e-16	***
Residuals	114	48.9	0.429			

Table 54. ANOVA for Indeterminate Responses in the Open Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	10.1	3.376	4.482	0.00517	**
participant	38	452.4	11.906	15.806	< 2e-16	***
Residuals	114	85.9	0.753			

Table 55. Tukey Method Comparison for Indeterminate Responses in the Open Condition, Curved Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	0.6666667	0.15421615	1.1791172	0.0052106
PCB-40 ft Drums	0.5641026	0.05165205	1.0765531	0.0248848
PCB-10 ft Drums	0.4615385	-0.05091206	0.973989	0.0933118
40 ± 2 ft Drums-40 ft Drums	-0.1025641	-0.61501462	0.4098864	0.9536758
40 ± 2 ft Drums-10 ft Drums	-0.2051282	-0.71757872	0.3073223	0.7241622
40 ft Drums-10 ft Drums	-0.1025641	-0.61501462	0.4098864	0.9536758

Table 56. ANOVA for Indeterminate Responses in the Open Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	4.2	1.408	2.527	0.061	.
participant	38	437.9	11.523	20.678	<2e-16	***
Residuals	114	63.5	0.557			

Table 57. ANOVA for Indeterminate Responses in the Open Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1	0.342	0.497	0.685	
participant	38	402.1	10.581	15.372	<2e-16	***
Residuals	114	78.5	0.688			

Table 58. ANOVA for Indeterminate Responses in the Open Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	9.4	3.12	3.924	0.0104	*
participant	38	393.9	10.366	13.038	<2e-16	***
Residuals	114	90.6	0.795			

Table 59. Tukey Method Comparison for Indeterminate Responses in the Open Condition, Curved Geometry, 2s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	0.58974359	0.06325487	1.1162323	0.0216102
PCB-40 ft Drums	0.56410256	0.03761384	1.0905913	0.0306904
PCB-10 ft Drums	0.53846154	0.01197282	1.0649503	0.042955
40 ± 2 ft Drums-40 ft Drums	-0.02564103	-0.55212975	0.5008477	0.9992643
40 ± 2 ft Drums-10 ft Drums	-0.05128205	-0.57777077	0.4752067	0.9942228
40 ft Drums-10 ft Drums	-0.02564103	-0.55212975	0.5008477	0.9992643

Table 60. ANOVA for Indeterminate Responses in the Open Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	4.4	1.476	2.577	0.0572	.
participant	38	365.8	9.627	16.801	<2e-16	***
Residuals	114	65.3	0.573			

Table 61. ANOVA for Indeterminate Responses in the Closed Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.1	0.365	1.88	1.37E-01	
participant	38	131.08	3.449	17.75	<2e-16	***
Residuals	114	22.15	0.194			

Table 62. ANOVA for Indeterminate Responses in the Closed Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.69	0.2286	1.299	0.278	
participant	38	119.58	3.1468	17.879	<2e-16	***
Residuals	114	20.06	0.176			

Table 63. ANOVA for Indeterminate Responses in the Closed Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.22	0.075	0.516	0.672	
participant	38	126.4	3.326	22.946	<2e-16	***
Residuals	114	16.53	0.145			

Table 64. ANOVA for Indeterminate Responses in the Closed Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.03	0.009	0.081	0.97	
participant	38	142.69	3.755	35.749	<2e-16	***
Residuals	114	11.97	0.105			

Table 65. ANOVA for Indeterminate Responses in the Closed Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.33	0.109	1.088	0.357	
participant	38	139.4	3.668	36.609	<2e-16	***
Residuals	114	11.42	0.1			

B.3 Location Errors

Table 66. ANOVA for Location Errors in the Open Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	5.46	1.8205	2.822	0.042	*
participant	38	73.08	1.9231	2.981	4.10E-06	***
Residuals	114	73.54	0.6451			

Table 67. Tukey Method Comparison for Location Errors in the Open Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.43589744	-0.9101219	0.03832701	0.0834765
PCB-40 ft Drums	-0.38461538	-0.8588398	0.08960906	0.1546434
PCB-10 ft Drums	-0.46153846	-0.9357629	0.01268598	0.0595263
40 ± 2 ft Drums-40 ft Drums	0.05128205	-0.4229424	0.5255065	0.9921397
40 ± 2 ft Drums-10 ft Drums	-0.02564103	-0.4998655	0.44858342	0.9989948
40 ft Drums-10 ft Drums	-0.07692308	-0.5511475	0.39730137	0.9744555

Table 68. ANOVA for Location Errors in the Open Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	######	0.3504	0.964	0.412	
participant	38	######	1.8404	5.062	9.08E-12	***
Residuals	114	######	0.3636			

Table 69. ANOVA for Location Errors in the Open Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.56	0.5214	1.953	0.125	
participant	38	47.31	1.2449	4.663	9.49E-11	***
Residuals	114	30.44	0.267			

Table 70. ANOVA for Location Errors in the Open Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.462	0.1538	1.166	0.326	
participant	38	19.936	0.5246	3.977	6.40E-09	***
Residuals	114	15.038	0.1319			

Table 71. ANOVA for Location Errors in the Open Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0	0			
participant	38	0	0			
Residuals	114	0	0			

Table 72. ANOVA for Location Errors in the Closed Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	210.1	70.02	20.459	1.12E-10	***
participant	38	988.7	26.02	7.602	< 2e-16	***
Residuals	114	390.2	3.42			

Table 73. Tukey Method Comparison for Location Errors in the Closed Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-2.56410256	-3.656445	-1.4717599	0.0000001
PCB-40 ft Drums	-2.74358974	-3.835932	-1.6512471	0
PCB-10 ft Drums	-2.71794872	-3.810291	-1.6256061	0
40 ± 2 ft Drums-40 ft Drums	-0.17948718	-1.27183	0.9128555	0.9734946
40 ± 2 ft Drums-10 ft Drums	-0.15384615	-1.246189	0.9384965	0.9829974
40 ft Drums-10 ft Drums	0.02564103	-1.066702	1.1179837	0.9999172

Table 74. ANOVA for Location Errors in the Closed Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	128.3	42.75	14.871	3.10E-08	***
participant	38	768.8	20.23	7.037	2.35E-16	***
Residuals	114	327.7	2.87			

Table 75. Tukey Method Comparison for Location Errors in the Closed Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-1.5128205	-2.5139581	-0.5116829	0.0008029
PCB-40 ft Drums	-2.2820513	-3.2831889	-1.2809137	0.0000002
PCB-10 ft Drums	-2.1538462	-3.1549837	-1.1527086	0.0000009
40 ± 2 ft Drums-40 ft Drums	-0.7692308	-1.7703684	0.2319068	0.19281
40 ± 2 ft Drums-10 ft Drums	-0.6410256	-1.6421632	0.360112	0.3445757
40 ft Drums-10 ft Drums	0.1282051	-0.8729325	1.1293427	0.9871048

Table 76. ANOVA for Location Errors in the Closed Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	170.7	56.91	15.796	1.18E-08	***
participant	38	841.2	22.14	6.144	2.26E-14	***
Residuals	114	410.8	3.6			

Table 77. Tukey Method Comparison for Location Errors in the Closed Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-1.8461538	-2.9669299	-0.7253778	0.0002141
PCB-40 ft Drums	-2.7179487	-3.8387248	-1.5971727	0
PCB-10 ft Drums	-2.3589744	-3.4797504	-1.2381983	0.0000015
40 ± 2 ft Drums-40 ft Drums	-0.8717949	-1.9925709	0.2489812	0.1837898
40 ± 2 ft Drums-10 ft Drums	-0.5128205	-1.6335966	0.6079555	0.6325079
40 ft Drums-10 ft Drums	0.3589744	-0.7618017	1.4797504	0.837649

Table 78. ANOVA for Location Errors in the Closed Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	216.5	72.18	17.472	2.12E-09	***
participant	38	957.9	25.21	6.102	2.83E-14	***
Residuals	114	471	4.13			

Table 79. Tukey Method Comparison for Location Errors in the Closed Condition, Straight Geometry, 2s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-1.97435897	-3.174464	-0.7742536	0.0002185
PCB-40 ft Drums	-2.84615385	-4.046259	-1.6460485	0.0000001
PCB-10 ft Drums	-2.92307692	-4.123182	-1.7229715	0
40 ± 2 ft Drums-40 ft Drums	-0.87179487	-2.0719	0.3283105	0.2363649
40 ± 2 ft Drums-10 ft Drums	-0.94871795	-2.148823	0.2513874	0.1722197
40 ft Drums-10 ft Drums	-0.07692308	-1.277028	1.1231823	0.9983305

Table 80. ANOVA for Location Errors in the Closed Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	49.15	16.382	10.696	3.00E-06	***
participant	38	72.42	1.906	1.244	0.189	
Residuals	114	174.6	1.532			

Table 81. Tukey Method Comparison for Location Errors in the Closed Condition, Straight Geometry, 1s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-1.333333	-2.064055	-0.6026117	0.000034
PCB-40 ft Drums	-0.1282051	-0.8589268	0.6025165	0.9680443
PCB-10 ft Drums	-1.85037E-16	-0.7307217	0.7307217	1
40 ± 2 ft Drums-40 ft Drums	1.205128	0.4744066	1.9358499	0.0002098
40 ± 2 ft Drums-10 ft Drums	1.333333	0.6026117	2.064055	0.000034
40 ft Drums-10 ft Drums	0.1282051	-0.6025165	0.8589268	0.9680443

Table 82. ANOVA for Location Errors in the Open Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.224	0.07479	1.133	0.339	
participant	38	11.808	0.31073	4.707	7.30E-11	***
Residuals	114	7.526	0.06601			

Table 83. ANOVA for Location Errors in the Open Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.071	0.0235	0.843	0.4732
participant	38	1.59	0.04184	1.5	0.0528 .
Residuals	114	3.179	0.02789		

Table 84. ANOVA for Location Errors in the Open Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0513	0.01709	0.661	0.578
participant	38	0.8974	0.02362	0.913	0.616
Residuals	114	2.9487	0.02587		

Table 85. ANOVA for Location Errors in the Open Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0	0		
participant	38	0	0		
Residuals	114	0	0		

Table 86. ANOVA for Location Errors in the Open Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0	0		
participant	38	0	0		
Residuals	114	0	0		

Table 87. ANOVA for Location Errors in the Closed Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	37.8	12.598	6.612	0.000369	***
participant	38	480.4	12.643	6.636	1.75E-15	***
Residuals	114	217.2	1.905			

Table 88. Tukey Method Comparison for Location Errors in the Closed Condition, Curved Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.7692308	-1.5842385	0.04577692	0.0717217
PCB-40 ft Drums	-1.205128	-2.0201359	-0.39012052	0.0010866
PCB-10 ft Drums	-1.205128	-2.0201359	-0.39012052	0.0010866
40 ± 2 ft Drums-40 ft Drums	-0.4358974	-1.2509051	0.37911025	0.5053851
40 ± 2 ft Drums-10 ft Drums	-0.4358974	-1.2509051	0.37911025	0.5053851
40 ft Drums-10 ft Drums	-2.22045E-15	-0.8150077	0.81500769	1

Table 89. ANOVA for Location Errors in the Closed Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	35.2	11.733	6.571	0.000389	***
participant	38	508.4	13.379	7.493	< 2e-16	***
Residuals	114	203.6	1.786			

Table 90. Tukey Method Comparison for Location Errors in the Closed Condition, Curved Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.8461538	-1.6351295	-0.05717822	0.0304684
PCB-40 ft Drums	-0.974359	-1.7633346	-0.18538335	0.0089437
PCB-10 ft Drums	-1.2820513	-2.0710269	-0.49307565	0.0002672
40 ± 2 ft Drums-40 ft Drums	-0.1282051	-0.9171808	0.6607705	0.9743256
40 ± 2 ft Drums-10 ft Drums	-0.4358974	-1.2248731	0.35307819	0.4769292
40 ft Drums-10 ft Drums	-0.3076923	-1.0966679	0.48128332	0.7399425

Table 91. ANOVA for Location Errors in the Closed Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	25.2	8.417	5.272	0.00193	**
participant	38	351.4	9.248	5.793	1.49E-13	***
Residuals	114	182	1.596			

Table 92. Tukey Method Comparison for Location Errors in the Closed Condition, Curved Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.5384615	-1.284502	0.2075789	0.2415963
PCB-40 ft Drums	-0.9230769	-1.6691173	-0.1770365	0.0087779
PCB-10 ft Drums	-1.025641	-1.7716815	-0.2796006	0.0027695
40 ± 2 ft Drums-40 ft Drums	-0.3846154	-1.1306558	0.361425	0.5369142
40 ± 2 ft Drums-10 ft Drums	-0.4871795	-1.2332199	0.2588609	0.3270822
40 ft Drums-10 ft Drums	-0.1025641	-0.8486045	0.6434763	0.984148

Table 93. ANOVA for Location Errors in the Closed Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	3.61	1.203	2.909	0.03764	*
participant	38	29.42	0.7743	1.872	0.00594	**
Residuals	114	47.14	0.4135			

Table 94. Tukey Method Comparison for Location Errors in the Closed Condition, Curved Geometry, 1s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.38461538	-0.76430278	-0.004927989	0.045867
PCB-40 ft Drums	-0.12820513	-0.50789252	0.251482268	0.815018
PCB-10 ft Drums	-0.02564103	-0.40532842	0.35404637	0.998050
40 ± 2 ft Drums-40 ft Drums	0.25641026	-0.12327714	0.636097652	0.297640
40 ± 2 ft Drums-10 ft Drums	0.35897436	-0.02071304	0.738661755	0.071002
40 ft Drums-10 ft Drums	0.1025641	-0.27712329	0.482251498	0.895195

Table 95. ANOVA for Location Errors in the Closed Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0	0		
participant	38	0	0		
Residuals	114	0	0		

B.4 Misidentification Errors

Table 96. ANOVA for Misidentification Errors in the Open Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	667.8	222.61	66.142	< 2e-16	***
participant	38	232.6	6.12	1.819	0.00829	**
Residuals	114	383.7	3.37			

Table 97. Tukey Method Comparison for Misidentification Errors in the Open Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-4.97435897	-6.057565	-3.8911532	0
PCB-40 ft Drums	-0.33333333	-1.416539	0.7498724	0.853192
PCB-10 ft Drums	-0.28205128	-1.365257	0.8011545	0.904908
40 ± 2 ft Drums-40 ft Drums	4.64102564	3.55782	5.7242314	0
40 ± 2 ft Drums-10 ft Drums	4.69230769	3.609102	5.7755134	0
40 ft Drums-10 ft Drums	0.05128205	-1.031924	1.1344878	0.999324

Table 98. ANOVA for Misidentification Errors in the Open Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	368.5	122.84	44.008	<2e-16	***
participant	38	172.1	4.53	1.622	0.0266	*
Residuals	114	318.2	2.79			

Table 99. Tukey Method Comparison for Misidentification Errors in the Open Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-3.64102564	-4.627507	-2.654544	0
PCB-40 ft Drums	-0.15384615	-1.140328	0.8326355	0.977181
PCB-10 ft Drums	-0.12820513	-1.114687	0.8582765	0.986539
40 ± 2 ft Drums-40 ft Drums	3.48717949	2.5006979	4.4736611	0
40 ± 2 ft Drums-10 ft Drums	3.51282051	2.5263389	4.4993021	0
40 ft Drums-10 ft Drums	0.02564103	-0.960841	1.0121227	0.999888

Table 100. ANOVA for Misidentification Errors in the Open Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	6.02	2.0064	5.291	0.00188	**
participant	38	14.36	0.3779	0.996	0.48769	
Residuals	114	43.23	0.3792			

Table 101. Tukey Method Comparison for Misidentification Errors in the Open Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.4615385	-0.825138	-0.0979391	0.006768
PCB-40 ft Drums	-0.02564103	-0.38924	0.33795837	0.997782
PCB-10 ft Drums	8.67362E-17	-0.363599	0.36359939	1
40 ± 2 ft Drums-40 ft Drums	0.4358974	0.072298	0.79949683	0.011902
40 ± 2 ft Drums-10 ft Drums	0.4615385	0.0979391	0.82513785	0.006768
40 ft Drums-10 ft Drums	0.02564103	-0.337958	0.38924042	0.997782

Table 102. ANOVA for Misidentification Errors in the Open Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.128	0.04274	0.83	0.48
participant	38	1.769	0.04656	0.904	0.63
Residuals	114	5.872	0.05151		

Table 103. ANOVA for Misidentification Errors in the Open Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0513	0.01709	0.661	0.578
participant	38	0.8974	0.02362	0.913	0.616
Residuals	114	2.9487	0.02587		

Table 104. ANOVA for Misidentification Errors in the Closed Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	11.56	3.855	5.825	0.000971	***
participant	38	111.08	2.923	4.417	4.18E-10	***
Residuals	114	75.44	0.662			

Table 105. Tukey Method Comparison for Misidentification Errors in the Closed Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.7692308	-1.249534	-0.2889273	0.000337
PCB-40 ft Drums	-0.4102564	-0.89056	0.07004703	0.122124
PCB-10 ft Drums	-0.4102564	-0.89056	0.07004703	0.122124
40 ± 2 ft Drums-40 ft Drums	0.3589744	-0.121329	0.8392778	0.213831
40 ± 2 ft Drums-10 ft Drums	0.3589744	-0.121329	0.8392778	0.213831
40 ft Drums-10 ft Drums	1.11022E-15	-0.480303	0.48030344	1

Table 106. ANOVA for Misidentification Errors in the Closed Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	7.35	2.4509	5.773	0.00104	**
participant	38	74.27	1.9545	4.604	1.35E-10	***
Residuals	114	48.4	0.4245			

Table 107. Tukey Method Comparison for Misidentification Errors in the Closed Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.58974359	-0.974458	-0.2050297	0.000653
PCB-40 ft Drums	-0.15384615	-0.53856	0.2308677	0.724767
PCB-10 ft Drums	-0.20512821	-0.589842	0.1795857	0.508053
40 ± 2 ft Drums-40 ft Drums	0.43589744	0.0511836	0.8206113	0.019646
40 ± 2 ft Drums-10 ft Drums	0.38461538	-9.85E-05	0.7693293	0.050085
40 ft Drums-10 ft Drums	-0.05128205	-0.435996	0.3334318	0.985508

Table 108. ANOVA for Misidentification Errors in the Closed Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	5.56	1.8547	4.505	0.00503	**
participant	38	101.47	2.6704	6.486	3.78E-15	***
Residuals	114	46.94	0.4117			

Table 109. Tukey Method Comparison for Misidentification Errors in the Closed Condition, Straight Geometry, 3s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.5128205	-0.891681	-0.1339601	0.00333
PCB-40 ft Drums	-0.1282051	-0.507066	0.2506553	0.81403
PCB-10 ft Drums	-0.2307692	-0.60963	0.1480912	0.389432
40 ± 2 ft Drums-40 ft Drums	0.3846154	0.005755	0.7634758	0.045193
40 ± 2 ft Drums-10 ft Drums	0.2820513	-0.096809	0.6609117	0.216877
40 ft Drums-10 ft Drums	-0.1025641	-0.481425	0.2762963	0.894591

Table 110. ANOVA for Misidentification Errors in the Closed Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	3.2	1.0662	2.208	0.091	.
participant	38	112.9	2.971	6.152	2.16E-14	***
Residuals	114	55.05	0.4829			

Table 111. ANOVA for Misidentification Errors in the Closed Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	11.56	3.853	7.613	0.00011	***
participant	38	121.08	3.186	6.296	1.01E-14	***
Residuals	114	57.69	0.506			

Table 112. Tukey Method Comparison for Misidentification Errors in the Closed Condition, Straight Geometry, 1s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.6666667	-1.086702	-0.2466315	0.000387
PCB-40 ft Drums	-0.2307692	-0.650804	0.1892659	0.481865
PCB-10 ft Drums	2.08167E-16	-0.420035	0.4200351	1
40 ± 2 ft Drums-40 ft Drums	0.4358974	0.0158623	0.8559326	0.038785
40 ± 2 ft Drums-10 ft Drums	0.6666667	0.2466315	1.0867018	0.000387
40 ft Drums-10 ft Drums	0.2307692	-0.189266	0.6508044	0.481865

Table 113. ANOVA for Misidentification Errors in the Open Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.71	0.5705	2.03	0.1136	
participant	38	15.86	0.4173	1.485	0.0573	.
Residuals	114	32.04	0.281			

Table 114. ANOVA for Misidentification Errors in the Open Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.41	0.13675	1.626	0.187
participant	38	3.077	0.08097	0.963	0.539
Residuals	114	9.59	0.08412		

Table 115. ANOVA for Misidentification Errors in the Open Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.256	0.08547	0.736	0.532814	
participant	38	9.577	0.25202	2.169	0.000894	***
Residuals	114	13.244	0.11617			

Table 116. ANOVA for Misidentification Errors in the Open Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.154	0.05128	0.796	0.498664	
participant	38	5.577	0.14676	2.277	0.000441	***
Residuals	114	7.346	0.06444			

Table 117. ANOVA for Misidentification Errors in the Open Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.128	0.04274	1.258	0.292
participant	38	1.769	0.04656	1.371	0.104
Residuals	114	3.872	0.03396		

Table 118. ANOVA for Misidentification Errors in the Closed Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.46	0.485	2.186	0.0935	.
participant	38	44.86	1.1805	5.32	2.07E-12	***
Residuals	114	25.29	0.2219			

Table 119. ANOVA for Misidentification Errors in the Closed Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.07	0.0235	0.13	0.942	
participant	38	50.86	1.3384	7.378	<2e-16	***
Residuals	114	20.68	0.1814			

Table 120. ANOVA for Misidentification Errors in the Closed Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.15	0.3846	1.664	0.179	
participant	38	86.73	2.2824	9.876	<2e-16	***
Residuals	114	26.35	0.2311			

Table 121. ANOVA for Misidentification Errors in the Closed Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.276	0.0919	2.106	0.103	
participant	38	16.667	0.4386	10.052	<2e-16	***
Residuals	114	4.974	0.0436			

Table 122. ANOVA for Misidentification Errors in the Closed Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.436	0.1453	2.345	0.0766	.
participant	38	15.859	0.4173	6.735	1.06E-15	***
Residuals	114	7.064	0.062			

B.5 Gap Outs

Table 123. ANOVA for Gap Outs in the Open Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	1.609	0.5363	3.466	0.0186	*
participant	38	5.897	0.1552	1.003	0.478	
Residuals	114	17.641	0.1547			

Table 124. Tukey Method Comparison for Gap Outs in the Open Condition, Straight Geometry, 5s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.25641026	-0.48867783	-0.02414268	0.024324
PCB-40 ft Drums	-0.05128205	-0.283549625	0.18098552	0.939172
PCB-10 ft Drums	-0.02564103	-0.257908599	0.20662655	0.991648
40 ± 2 ft Drums-40 ft Drums	0.20512821	-0.027139368	0.43739578	0.103437
40 ± 2 ft Drums-10 ft Drums	0.23076923	-0.001498343	0.4630368	0.052170
40 ft Drums-10 ft Drums	0.02564103	-0.206626548	0.2579086	0.991648

Table 125. ANOVA for Gap Outs in the Open Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	2.487	0.8291	9.935	7.17E-06	***
participant	38	4.744	0.1248	1.496	5.40E-02	.
Residuals	114	9.513	0.0834			

Table 126. Tukey Method Comparison for Gap Outs in the Open Condition, Straight Geometry, 4s Distance

	difference	CI - Lower	CI - Upper	p-adj
PCB-40 ± 2 ft Drums	-0.2820513	-0.4526129	-0.1114897	0.0002007
PCB-40 ft Drums	0.02564103	-0.1449206	0.1962026	0.9794697
PCB-10 ft Drums	-3.81639E-17	-0.1705616	0.1705616	1
40 ± 2 ft Drums-40 ft Drums	0.3076923	0.1371307	0.4782539	0.0000424
40 ± 2 ft Drums-10 ft Drums	0.2820513	0.1114897	0.4526129	0.0002007
40 ft Drums-10 ft Drums	-0.02564103	-0.1962026	0.1449206	0.9794697

Table 127. ANOVA for Gap Outs in the Open Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0256	0.00854	7 0.66	1 0.578
participant	38	0.4744	0.01248	3 0.96	5 0.535
Residuals	114	1.4744	0.01293	3	

Table 128. ANOVA for Gap Outs in the Open Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0	0	0	1	
participant	38	1.397	0.03677	1.677	0.0194	*
Residuals	114	2.5	0.02193			

Table 129. ANOVA for Gap Outs in the Open Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0192	0.00641	1	0.396
participant	38	0.2436	0.00641	1	0.482
Residuals	114	0.7308	0.00641		

Table 130. ANOVA for Gap Outs in the Closed Condition, Straight Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.84	0.2799	2.571	0.05765	.
participant	38	8.308	0.2186	2.008	0.00253	**
Residuals	114	12.41	0.1089			

Table 131. ANOVA for Gap Outs in the Closed Condition, Straight Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.635	0.21154	2.384	0.07296	.
participant	38	6.808	0.17915	2.019	0.00236	**
Residuals	114	10.115	0.08873			

Table 132. ANOVA for Gap Outs in the Closed Condition, Straight Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.737	0.2457	1.999	0.118
participant	38	6.397	0.1683	1.37	0.104
Residuals	114	14.013	0.1229		

Table 133. ANOVA for Gap Outs in the Closed Condition, Straight Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.154	0.05128	0.565	0.639
participant	38	2.577	0.06781	0.747	0.847
Residuals	114	10.346	0.09076		

Table 134. ANOVA for Gap Outs in the Closed Condition, Straight Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.481	0.1603	1.87	0.1386	
participant	38	5.667	0.1491	1.74	0.0133	*
Residuals	114	9.769	0.0857			

Table 135. ANOVA for Gap Outs in the Open Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.1218	0.0406	2.175	0.0949	.
participant	38	2.5897	0.06815	3.651	5.12E-08	***
Residuals	114	2.1282	0.01867			

Table 136. ANOVA for Gap Outs in the Open Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0256	0.00854	7 0.66	1 0.578
participant	38	0.4744	0.01248	3 0.96	5 0.535
Residuals	114	1.4744	0.01293	3	

Table 137. ANOVA for Gap Outs in the Open Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.128	0.04274	1.445	0.23348	
participant	38	2.269	0.05972	2.019	0.00236	**
Residuals	114	3.372	0.02958			

Table 138. ANOVA for Gap Outs in the Open Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0192	0.00641	0.328	0.805
participant	38	0.6923	0.01822	0.931	0.588
Residuals	114	2.2308	0.01957		

Table 139. ANOVA for Gap Outs in the Open Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.0513	0.01709	1.345	0.263	
participant	38	2.3974	0.06309	4.965	1.60E-11	***
Residuals	114	1.4487	0.01271			

Table 140. ANOVA for Gap Outs in the Closed Condition, Curved Geometry, 5s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.173	0.05769	0.594	0.6203	
participant	38	6.308	0.16599	1.708	0.0161	*
Residuals	114	11.077	0.09717			

Table 141. ANOVA for Gap Outs in the Closed Condition, Curved Geometry, 4s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.205	0.06838	1	0.396
participant	38	3.077	0.08097	1.184	0.245
Residuals	114	7.795	0.06838		

Table 142. ANOVA for Gap Outs in the Closed Condition, Curved Geometry, 3s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.436	0.1453	1.646	0.183
participant	38	2.859	0.07524	0.852	0.708
Residuals	114	10.064	0.08828		

Table 143. ANOVA for Gap Outs in the Closed Condition, Curved Geometry, 2s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
treatment	3	0.359	0.1197	1.579	0.198	
participant	38	10.077	0.2652	3.499	1.37E-07	***
Residuals	114	8.641	0.0758			

Table 144. ANOVA for Gap Outs in the Closed Condition, Curved Geometry, 1s Distance

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
treatment	3	0.0192	0.00641	1	0.396
participant	38	0.2436	0.00641	1	0.482
Residuals	114	0.7308	0.00641		

APPENDIX C: INFORMED CONSENT FORM

INFORMED CONSENT

Georgia Institute of Technology
Project Title: Work Zone Markings

<u>Investigators:</u> Michael P. Hunter, Gregory M. Corso, Michael O. Rodgers. Aaron T. Greenwood, Alison Marie Williams, Chenhao Liu, Cristina Danielle Holt, Eleanor Marie Mentonelli, Lance Dale Ballard, Laura Ellen Schmitt

<u>Protocol and Consent Title:</u> Improved Methods for Delineating Diverges in Work Zones (10/12/2011v3)

You are being asked to be a volunteer in a research study investigating the ability of people to identify a highway exit ramp within a roadway construction zone. This research study is funded by the Georgia Department of Transportation. The experiment in which you will participate involves minimal risk. We anticipate collecting data from 100 participants.

<u>Purpose:</u> The purpose for this study is to determine the ability of people to identify the location of an exit ramp hidden by roadway markings (barrels, walls, trees, etc) along a stretch of highway. Exit ramps within highway construction zones are poorly marked and many people have a difficult time identifying their location. We are attempting to identify better ways of indicating the location of the exit ramps when roadway construction is occurring. This research study is funded by the Georgia Department of Transportation.

<u>Exclusion/Inclusion Criteria:</u> To be a participant in this research study, you must have a valid driver's license and have been driving for at least 2 years. Non drivers are excluded

<u>Procedures:</u>

If you decide to be in this study, your part will require a one-hour session. For the initial part of the session, which will take about 10 minutes, we will complete the required paper work (this consent form) and have a short training period. You may stop at any time and for any reason. For the next 45 minutes you will complete about 900 trials. At the end of the session you will be debriefed about the experiment. Once again, the total amount of time you will be in the laboratory is no more than 1 hour. Remember, you may stop at any time.

You task will be to view a series of slides containing a scene of highway, construction markings along the side of the highway, and in most cases an exit ramp. If you see an exit ramp on the side of the highway, your task is to mark the location of the exit ramp using the keys on the mouse. On some trials the exit ramp will be closed. For those trials the correct response is to click the sign on the screen that says "Exit Closed." For those trials that have an exit ramp the correct response will be to click the location of the ramp. We will change the distance where the ramp is located, the viewing distance, and the types of construction marking. Each slide will last about 2 to 3 seconds. We will be recording the time it takes you to click the mouse and the accuracy of your response. The total amount of time you will be in the laboratory will be no more than 1 hour. Remember, you may stop at any time.

Risks or Discomforts:

The risks involved are no greater than those involved in daily activities such as watching TV or playing a video game

Benefits:

You are not likely to benefit in any way from participating in this study. We do hope that our research will be used to modify existing construction site markings thereby reducing accidents and saving lives.

Compensation to You:

You will receive 1.0 Experimetrix credits for each hour of participation. If you complete this study you will receive a total of 1.0 Experimetrix credits. If you leave the study before completing the 1 hr requirement you will be compensated at .25 credit per 15 minutes.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent allowed by law. To protect your privacy, there will be no link between your name and your performance. There will be no way for anyone to link your performance to you. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look over study records during any required reviews.

Costs to You:

There are no costs to you, other than your time, for being in this study.

In Case of Injury/Harm:

If you are injured as a result of being in this study, please contact Dr. Michael Hunter at telephone (404) 385-1243. Neither Michael Hunter nor the Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting from participation in this study.

Participant Rights:

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

Questions about the Study:

If you have any questions about the study, you may contact Dr. Michael Hunter at telephone (404) 385-1243 or michael.hunter@ce.gatech.edu

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact

Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Compliance, at (404) 385- 2175.

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

____
Participant Name (printed)

____ ____________
Participant Signature Date

____ ____________
Signature of Person Obtaining Consent Date

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