Final Technical Report

A Human Factors Examination of Driver Response to a Specific Work zone Design (Design Standard #613, Duration Note 2) and Key Moderating Factors

Contract No: BD 548-18

Prepared for: Stefanie Maxwell, P.E.

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Prepared by: Aaron R. Duley, Justin F. Morgan, Gareth Conway, JingJing Wang, Julian Abich, & P.A. Hancock

Affiliations: University of Central Florida
Institute for Simulation and Training
Minds in Technology, Machines in Thought Laboratory

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16. Abstract

The purpose of this examination was to investigate whether reducing the standard taper length noted in Design Standard #613, Duration Note 2 increases accident likelihood. In addition to taper length, the presence of a visually occluding lead vehicle was considered as a key-moderating factor that might influence work zone safety. Taken together, Taper Length and Lead Vehicle formed the two primary factors under consideration for Experiment 1. A second experiment replicated the experimental conditions of the first Experiment, with the major difference that additional vehicles were included in the simulation. Generally speaking, results suggest that the proposed reduced taper work zone configuration increases accident likelihood, and that this likelihood is augmented when a lead vehicle occludes work zone entry. Examining the vehicle-to-cone area, which represents the distance from the participant's vehicle to the primary and secondary channelizing cones demarcating work zone entry, largely supports these conclusions. In addition to vehicle occlusion, such factors as day/night driving, weather, alternative work zone lengths, traffic density, personality, and driver experience should also be considered as moderating factors for work zone design. Modern competitors for driver attention should also be considered in the context of work zone design. New devices such as cell phones, navigational devices, and the like, may alter how urban work zones are planned and configured. We strongly suggest that future work in this area continue.

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Table 1. Project administration summary

Project Name:	A Human Factors Examination of Driver Response to a Specific Work zone Design (Design Standard #613, Duration Note 2) and Key Moderating Factors
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Project POC:	Aaron R. Duley, Ph.D. Institute for Simulation and Training Minds in Technology, Machines in Thought Laboratory, Research Scientist University of Central Florida 3100 Technology Parkway, Suite 333 Orlando, FL 32826 Phone: (407) 882-0313 Fax: (407) 882-1335 Peter A. Hancock, Ph.D. Department of Psychology Institute for Simulation and Training Minds in Technology, Machines in Though Laboratory, Director 3100 Technology Parkway, Suite Orlando, FL 32826 Phone: (407) 882- Fax: (407) 882-1335
Administrative POC:	Mr. Barry Wick, CPCM, C.P.M. Institute for Simulation and Training, Associate Director 3100 Technology Parkway Orlando, FL 32826 Phone: (407) 882-1316 Fax: (407) 882-1335
Report Recipients:	Peter A. Hancock, phancock@pegasus.cc.ucf.edu UCF Office of Research, OOR-DM@mail.ucf.edu Barry Wick, bwick@ist.ucf.edu Stefanie Maxwell, stefanie.maxwell@dot.state.fl.us Sandra Bell, Sandra.Bell@dot.state.fl.us Terri Vallery, tvallery@mail.ucf.edu

2.0 Executive Summary

2.1 Title

A Human Factors Examination of Driver Response to a Specific Work Zone Design (Design Standard #613, Duration Note 2) and Key Moderating Factors

2.2 Background

Both the employees who operate within and who initially set-up and configure a work zone endure significantly greater personal risk than non-work zone employees. Minimizing one's duration of exposure to traffic conditions is one of many likely strategies for mitigating this risk, and therefore, one must consider the various methods that support this end. This study evaluated the reduction of *taper length* as one such method for decreasing duration exposure. Design Standard #613, Duration Note 2 (see Appendix A for more information) specifies that under specific conditions, a 540 foot taper length is required for speed zones of 45 mph; however, a reduced 100 ft foot taper length is desirable given the decreased set-up time, and consequently, reduced exposure duration for employees. While reducing taper length may decrease the employees' risk that is responsible for setting-up the work zone, the risk to employees working within the work zone may be augmented.

2.3 Objectives

The purpose of this examination was to investigate whether reducing the standard taper length noted in Design Standard #613, Duration Note 2 increases accident likelihood. Thus, a laboratory based driving-simulation task was employed to examine key-moderating factors that might influence work zone safety. A standard and reduced work zone taper in addition to the presence or absence of a visually occluding lead vehicle were the primary factors of interest for this study. Taken together, *taper length* and *lead vehicle* formed the two primary factors under consideration for Experiment 1. A second experiment replicated the experimental conditions of the first experiment, with the major difference that additional vehicles were included in the simulation.

2.4 Findings and Conclusions

Generally speaking, the results suggest that the proposed reduced taper work zone configuration increases accident likelihood, and that this likelihood is augmented when a lead vehicle occludes work zone entry. Evidence derived from examining the vehicle-to-cone area, which represents the distance from the participant’s vehicle to the primary and secondary channelizing cones demarcating work zone entry, largely supports these conclusions.

It is important to note that our conclusions were drawn from a simulated laboratory-based driving task, and that the environmental and situational factors were carefully selected to isolate vehicle occlusion and work zone taper length as factors that could affect driver performance. While simulation is one of several key methodologies that can assist in identifying the human factors associated with human performance, such other complementary methodologies as field observations were not conducted for this initial investigation. Further, this project only evaluated limited traffic conditions, with a single work zone configuration using channelizing devices only. The simulations also did not present any advance warning signs, arrow boards or other devices that might have altered overall driver performance.

Several key moderating factors need to be seriously considered to fully appreciate contemporary driver behavior in work zones. While such factors as day/night driving, weather, work zone length, traffic density, personality, and driver experience each need to be understood in the context of work zone operations, other competitors for driver attention, such as cell phones and navigational devices, may also be considered when planning and configuring urban work zones. We strongly suggest that future work in this area continue.

2.5 Benefits

The findings from this study do not lend support for a reduced taper length of 100 feet. While the taper length reduction could reduce cost and exposure time of employees setting up lane closure, increased risk for human injury and death may be a likely consequence. However, only future research can isolate the suitable reduction in taper length that decreases the risk for employees who set-up a given work zone while not inflating the employees risk who actively work within that work zone.

2.6 Author Note

This research project was principally conducted by Drs. Aaron R. Duley, Gareth Conway, and Peter A. Hancock of the University of Central Florida and the Institute for Simulation and Training. This project could not have been completed without the support of Justin F. Morgan, JingJing Wang, and Julian Abich. For more information about this project, please contact Dr. Peter A. Hancock at phancock@pegasus.cc.ucf.edu

2.7 Special Note on Percent Completed

Originally this project was funded $89,469. In June 2006 we received an additional $84,624 and the scope of the work was changed. The total funded amount is currently $174,093. Based on the total of $174,093 this project is now 100% complete.

2.8 Timeline

The projected tasks and their progression are presented in Table 2.1.

3.0 Budget

3.1 Current Expenditures

Please contact Barry Wick for the final expenditure report.

Table 2.   Task summary

ID	Task	Start	End	Duration	Completed	DP
0	Project Timeline	8/10/06	10/1/07	14mo 3w 2d	100%	
1	FDOT Project	8/10/06	10/1/07	14mo 3w 2d	95%	
1.1	Project Kickoff	8/10/06	9/1/06	3w 2d	100%	1.2SF
1.2	Literature Review	9/1/06	3/2/07	> 6mo 2w	100%	
1.3	Simulator Hardware Upgrade	9/7/06	9/19/06	1w 4d	100%	
1.4	SimInterface Application Development	10/3/06	12/4/06	2mo 1w	100%	
1.5	Analysis Application	1/19/07	2/2/07	2w 1d	100%	1.8.7SF
1.6	Informed Consent	12/14/06	1/2/07	2w 4d	100%	1.7SF
1.7	Register Experimentrak	1/2/07	1/3/07	2d	100%	
1.8	Experiment 1	11/24/06	3/30/07	4mo 2w 1d	100%	
1.8.1	Experimental Design	11/24/06	12/5/06	1w 3d	100%	
1.8.2	Scenario Development	11/24/06	1/5/07	1mo 2w 1d	100%	1.8.3SF
1.8.3	Pilot Testing	1/5/07	1/16/07	1w 3d	100%	1.8.6SF
1.8.4	Prepare Data Analysis Spreadsheet	11/24/06	11/30/06	1w	100%	
1.8.5	Prepare Questionnaires	11/24/06	11/24/06	1d	100%	
1.8.6	Data Collection	1/17/07	2/6/07	3w	100%	
1.8.7	Data Entry	2/5/07	2/19/07	2w 1d	100%	1.8.8SF
1.8.8	Data Analysis	2/20/07	3/12/07	3w	100%	1.8.9SF
1.8.9	Results Summary	3/13/07	3/30/07	2w 4d	100%	
1.9	Experiment 2	11/23/06	4/23/07	5mo 1w 3d	100%	
1.9.1	Experimental Design	11/23/06	12/4/06	1w 3d	100%	
1.9.2	Scenario Development	12/25/06	2/5/07	1mo 2w 1d	100%	1.9.4SF
1.9.3	Secondary Task Application Development	1/17/07	2/5/07	2w 4d	100%	1.9.4SF
1.9.4	Pilot Testing	2/6/07	2/15/07	1w 3d	100%	1.9.7SF
1.9.5	Prepare Data Analysis Spreadsheet	12/5/06	12/11/06	1w	100%	
1.9.6	Prepare Questionnaires	11/23/06	11/23/06	1d	100%	
1.9.7	Data Collection	2/15/07	3/7/07	3w	100%	
1.9.8	Data Entry	3/1/07	3/15/07	2w 1d	100%	1.9.9SF
1.9.9	Data Analysis	3/15/07	4/4/07	3w	100%	1.9.10SF
1.9.10	Results Summary	4/4/07	4/23/07	2w 4d	100%	
1.10	Reports	10/15/06	10/1/07	12mo 2w	100%	
1.10.1	Q1	10/15/06	10/15/06		100%	
1.10.2	Q2	1/15/07	1/15/07		100%	
1.10.3	Q3	4/15/07	4/15/07		100%	
1.10.4	Draft Final Report	5/2/07	9/28/07	5mo 1w 3d	100%	
1.10.5	Final Report	10/1/07	9/23/07		100%	

4.0 Review of Literature

New road construction and repairs are both critical elements for maintaining the nation's transportation infrastructure. Urban and rural development coupled with population growth requires dedicated support to meet the public's transportation demands. These demands have become commonplace in urban environments where barricaded work areas have become regular obstacles for drivers. Despite their ubiquity, work zones present a novel and unexpected occurrence embedded within the normal and sometimes mundane driving task (Dewar & Hanscom, 2002). Given unexpected scenarios can decrease driver response time by up to 33%, it is important to understand the human factors associated with driver behavior as people encounter and navigate designated work areas (Olson, 1996).

The nature of infrequent events occurring within an otherwise largely stable system augments accident probability. Consequently, accidents translate into considerable capital costs for society. These costs occur both in terms of equipment damage and lost productivity, but also include those costs associated with human injury and death (Hargroves, 1981; Reason, 1990). In 2005, 949 fatal crashes resulting in 2,722 deaths were reported nationwide, with Florida accounting for approximately 15% (141 total) of all fatal crashes and 15% (400 total) of all fatalities (Fatal Accident Reporting System; FARS, 2007). While a fatality instance could refer to the driver, a passenger, or work zone personnel, it is clear that without the protection of an automobile's body, its restraints, and its safety systems, work zone personnel are placed at considerable risk.

The highway construction worker has one of the most dangerous jobs in the United States. Work zone employees are twice as likely to be killed by a motor-vehicle than the average non-roadway worker (Ore & Fosbroke, 1997). The category of workers struck by motorist results in about 50% of the vehicle related fatalities among highway workers (Pratt et al. 2001), although drivers and passengers comprise over 80% of highway work zone fatalities (Ohio Department of Transportation, 2005). FARS estimates that about 700 fatalities occur in work zones each year across the U.S. There are also about 24,000 non-fatal injury crashes and 52,000 property damage only crashes each year (Council et al., 2000). Florida accounted for the largest number of fatalities in motor vehicle traffic accidents in work zones by state totaling 162, according to the National Work Zone Safety Information Clearinghouse (2005).

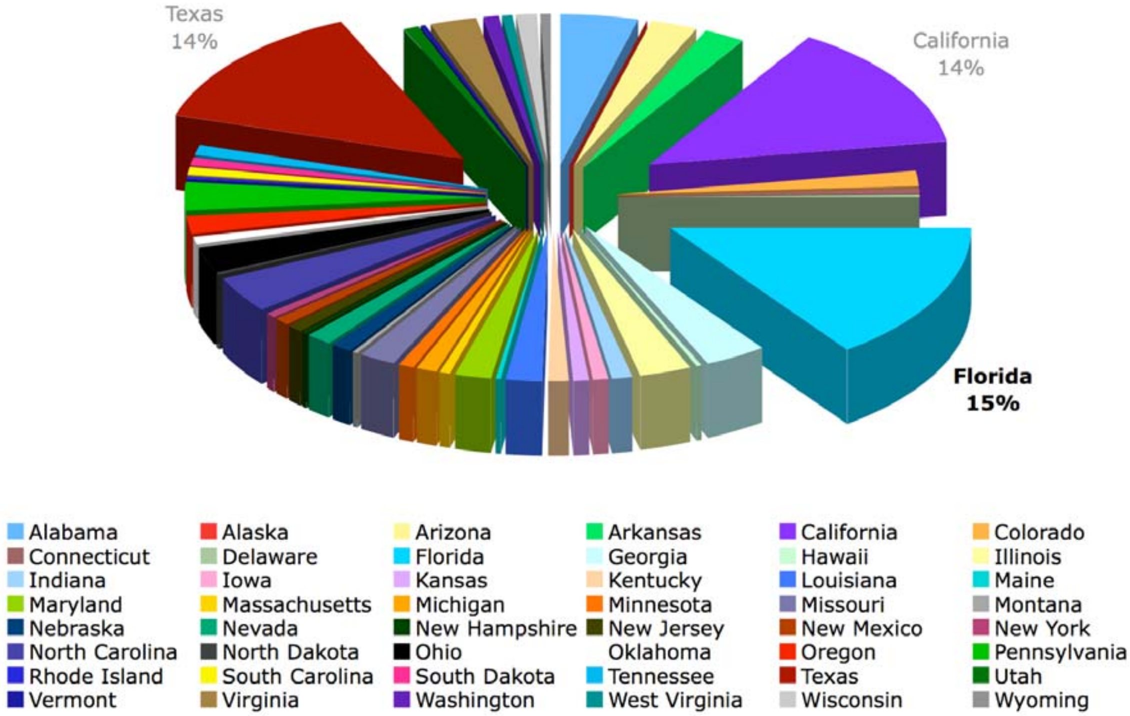

Figure 1. ***In 2005, Florida represented 15% of the total fatal crashes occurring in work zones, maintenance and utility zones (FARS, 2007). As is evident, even adjusting for population and roadway miles, Florida represents a disproportionate number of work zone accidents***

In respect of these concerns, and as part of the present report, a review of the literature regarding work zones, work zone safety, and the impacts of human and technology features on safety was conducted. Four major areas were identified as contributors to safety while traveling through work zones: (1) the structure of the work zone, (2) the visual features of the work zone, (3) the potential distracters in competition for driver attention, and (4) the personality traits of the driver. These findings are summarized and discussed.

4.1 Work Zone Structure

The extant literature has mostly examined highway and freeway work zone configurations. Thus, most of the literature discussed in this review is based on previous data not specifically germane to work zones in urban environments. Nevertheless, it is important to acknowledge this limitation and recognize the need for further inquiry.

Driving through a work zone elevates one's risk for an accident. Council et al. (2000) found that once inside the work zone total crash rate was 21.5% higher than the pre-work zone period. When crash frequencies were considered, Council and colleagues noted that duration and work zone length contributed to the increase. Moreover, other researchers have reported similar trends. For example, Liste et al. (1976) reported an increase of 119% in crash rate during the work zone period. Rouphail et al., (1988) reported an 88% increase in crash rate relative to a pre-work zone period for one long-term work area, while a comparable short-term work area saw only a constant rate of 0.8 crashes per mile per day. Taken together, the evidence suggests that work zone length plays an important role in the number of accidents observed for a given work site.

Because vehicle speed is an important factor contributing to work zone-related accidents, some researchers have focused on developing strategies for reducing speed in and prior to work zone entry. Rouphail and Tiwari (1985), for instance, found that although speed generally decreases through work zones as intensity of construction or maintenance activities increases, that controlling speed at these areas reduces accident frequency (also see Rouphail et al., 1988). Richard and Dudek (1986) have provided guidelines for implementing speed control to increase work zone safety. They recommend that work zones consist of properly attired and trained flag bearers placed off of the lane of travel, use of law enforcement, employment of changeable message signs, and implement slight reductions in lane width. All of these manipulations were found to successfully reduce driver speed within work zones.

The following five traffic accident types were identified in an analysis of the New York State Department of Transportation construction projects from 1999 to 2001: (a) work space intrusion, (b) worker struck by vehicle inside work zone, (c) flag bearer stuck by a vehicle, (d) worker struck by vehicle entering/exiting work space, and (e) construction equipment struck by vehicle inside work space. Together, these accidents types accounted for almost 86% of fatal injuries and 70% of hospitalizations for other minor injuries (Mohan & Zech, 2005). Bryden and Andrew (2000) found intrusion accidents accounted for 10% of all traffic accidents and 8% of all serious injuries. Collisions with flag bearing personnel accounted for 50% of pedestrian accidents (Ore & Fosbroke, 1997).

Another issue of concern is driver lane behavior. In a study examining driver expectancy in work zones, Pietrucha (1995) noted that drivers who traverse a long section of road within a work zone without encountering any signs, construction, or lane closure are unlikely to enter the directed lane until such an obstacle is encountered. This may potentially create a situation where lane changing is occurring at a late, and thus more risky time. Pietrucha (1995) concluded that appropriate and clear marking are essential for safe work zone travel.

4.2 Visual Performance in Driving

There are two major subsystems of the human visual system, which are the fovea and the periphery (Horry & Wickens, 2004). The fovea visual system is the central visual area and responsible for the majority of information fed to the visual cortex of the human brain. The primary functions of this focal visual system are visual search, object orientation, and other tasks that require high visual acuity, including reading text. Although, focal vision can extend beyond the fovea, its strengths are best at that location. The periphery ambient visual system feeds much less information to the visual cortex of the brain, but does contribute to change detection and the detection of motion on the outer edges of the visual field.

Since the 1970's, researchers have studied how drivers utilize peripheral vision during driving (Mourant & Rockwell, 1972). Its relevance to driving has been noted for critical sub-tasks such as hazard detection and lane position maintenance (Crundall, Underwood, & Chapman, 2002). The major responsibilities of the peripheral ambient visual system include spatial orientation and postural control in locomotion (Horrey, Wickens, & Consalus, 2006). Studies have shown that ambient vision can support only certain elements of driving task. Summala, Nieminen, and Punto (1996) used a technique known as *the forced-peripheral* technique to require drivers to perform a lane-keeping task relying only ambient vision. Drivers were asked to remain fixed on different in-vehicle locations and to avoid look upward to the outside of the car. Results showed that experienced drivers could use only ambient visual resources to maintain vehicle control. However, in a follow up study, Summala, Lamble, and Laakso (1998) showed that ambient vision did not effectively support the more crucial driving task of hazard detection. Drivers were engaged in the same forced-peripheral technique when asked to detect and brake in response to the slowing of a lead vehicle. Response times of the driver significantly increased, suggesting that timely hazard detection requires some degree of focal visual resources.

Spotlight Theory (Eriksen & Eriksen, 1974) contends that human visual attention can be regarded as a 'beam of attention', where objects within this beam receive attentional focus. However, Spotlight Theory has undergone some theoretical modifications since its inception. A slight modification to the basic theory allows the previously fixed-width spotlight to vary in diameter based on the amount of attention one wishes to invest (Eriksen & Murphy, 1987). This modification is known as the Zoom Lens theory of attention. A major issue for Zoom Lens theorists, however, has come from the ‘Object-Based Attention’ hypothesis. This notion posits that the human visual system does not attend to an area of space but rather attend to objects (Crundall et al., 2002). Recent research has showed that object-based attention only works within a spatial spotlight (Lavie & Driver, 1996), and when this spotlight contracts in response to a peripheral cue, object effects are removed. The Zoom Lens Theory is highly relevant to driving studies, as the majority of research in the field refer to the narrowing of attention, implying that the field of view of attention adjusting itself to larger or smaller field according to process demand at the point of fixation (Miura, 1990).

It is well established that young drivers collectively represent one of the highest accident groups (Maycock, Lockwood & Lester, 1991). Crundall et al (2002) cites many factors that might influence this observation. For example, smoking, drinking, fatigue, or simply driver experience each represent an underlying cause for the elevated accident rate for younger drivers. To reduce accident liability, many researchers have attempted to identify the changes that occur in drivers as experience increases. One major area of focus is on visual information acquisition during driving. Some researchers have reported substantial differences between driver groups of varying experience in their eye movements while perform driving task in simulation and on real roads. Crundall and Underwood (1998), for example, found experienced drivers producing more varied horizontal scanning on a divided highway when compared with inexperienced drivers (people who just received their driver’s license).

In attempt to identify the reasons for experiential differences in visual search during driving, Crundall et al. (1999) conducted an experiment to test the hypothesis that experience in the task domain releases attentional resources from the foveal point. It was found that experienced drivers spotted more peripheral cues than non-drivers, and the performance of a group of novice drivers falling midway between the other two groups. The implication of this study was that driving experience had created an improvement in peripheral target detection.

Richards and Dudek (1982) examined driver sight distances in work zones and reached a number of conclusions. Primarily, drivers tend to get trapped at the end of a work zone taper if sight distances are sub-optimal. This timeline was determined to be approximately 15 seconds of travel on the highway. However, durations longer than this may lead to drivers believing no work zone is imminent and returning to the soon-to-be closed lane.

4.3 Driving Distractions

Even though driver inattention and human errors are often linked with vehicle accidents, the real scope of the problem remains unclear. By the end of 20th century, distraction had been linked to as much as 50% of the motor-vehicle accidents on US highways (US Department of Transportation, 1998).

There is no doubt that the developments of in-vehicle technologies, such as cellular phones, navigation displays, and entertainment systems, offer drivers tremendous benefits. However, driving is a complex, and safety-critical task. When drivers decide to concurrently perform one or more tasks while driving, there is an associated increase in accident risk (Stevens & Minton, 2001).

Early studies on cell phones and accidents suggested that using cell phone while driving affects perceptual and motor skills (Violanti, 1997). A case-control study in New York State found a 34% increased risk of collision among those with cell phones in their vehicle (Redelmeier & Tibshirani, 1997). People who used cell phones more than a median time of fifty minutes per month had a 5.5-fold increased risk of a traffic accident (Violanti & Marshall, 1996). Studies examining the process of interacting with an in-car touch screen found that participants using the touch screen during a critical driving maneuver had approximately 25% smaller field of safe travel around their vehicle during the critical maneuver (Hancock, Simmons, Hashemi, Howarth, & Ranney, 1999). Clearly there are effects of using distracting technologies in the vehicle; although there is an expected negative impact of these technologies on the safe passage through a work zone, the exact magnitude of the impact remains unquantified in general.

One well-accepted theory to explain the incapability of attention mentioned above is Baddeley's working memory model (Baddeley, 1996). To quote a recent source, "Working memory models a system that is responsible for the processing and maintenance for short durations" (Jamson & Merat, 2005). The system has three major components. The central executive performs a supervisory function that oversees two slave systems, the phonological loop and the visuospatial sketchpad. The phonological loop response to linguistic information and the visuospatial sketchpad serves visual and spatial information. When dual tasks are performed, the working memory suggests that if those two tasks share the same working memory resource, performance in one or both deteriorates when tasks are performed concurrently as opposed to independently. Working memory model provides the basis to explain the driver's limited ability interacting with in-vehicle technologies while driving.

4.4 Personality and Gender

Personality factors have been studied to find connection between driver traits and frequency of aggressive and risky driving. In turn, aggressive and risky driving has been studied to find a relationship to accident occurrence. The Five Factor Model research supports the traits of extraversion, neuroticism, and conscientiousness in predicting driving behavior (Dahlen &

White, 2006). Extraversion has been associated with motor vehicle accidents (Eysenck, 1970; Fine, 1963; Lajunen. 2001; Renner & Anderle, 2000; Smith & Kirkham, 1981; Martin & Boomsma, 1989; Matthews, Dorn, & Glendon, 1991). Neuroticism has been found to be related to vehicular accidents, fatalities, aggression while driving, and dislike of driving (Kirkcaldy & Furnham 2000). Conscientiousness is inversely related to at-fault crashes and total crashes (Arthur & Doverspike, 2001). The other two factors, agreeableness and openness have not been unequivocally demonstrated to affect driving behavior.

Sensation seeking has also been found to support predictions of driver behavior. Sensation seeking and habitual alcohol use have each been linked to risky driving behaviors (Dobson et al., 1999; Iversen & Rundmo, 2002; Jonah, 1997). High sensation seekers seem to get in more traffic accidents and are involved in many other unsafe driving practices (Arnett, 1990; Arnett, Offer, & Fine, 1997; Donovan, Queisser, Salzberg, & Umlauf, 1985; Jonah, 1997; Jonah, Thiessen, & Au-Yeung, 2001; Trimpop & Kirkcaldy, 1997).

Gender has been used in order to differentiate risky and angry drivers. Due to increases in risky driving, accidents and fatalities among males, the research focus on female drivers is lacking in scope (Donovan, Lonczak, & Neighbors, 2006) Among American drivers in 2002, males were three times more likely than females to be involved in a fatal automobile accident (NHSTA, 2003). In a NHSTA (1998) telephone survey questioning 21 types of risky driving, males were more likely to commit each one. Although males tend to be involved in more risky driving behaviors, there seems to be no different in driving anger between both sexes (Hennessy & Wiesenthal, 2001; Lajunen et al., 1998; Lawton & Nutter, 2002). Deffenbacher et al. (2000) found no gender differences in frequency or intensity of anger in day-to-day driving, anger intensity, anger stimulus, or trait anger. In contrast to suspicion, female drivers were found to have greater impatience, frustration, and anger (Brewer, 2000). It seems that angry driving responses to impeded progress, inconsiderate driving and impatient driving were more common in male drivers (Parker et al., 2002).

4.5 Summary

Although a major factor in the maintenance of the nation's roads, and especially a part of Florida's roadway systems as the state continues to see exponential growth in terms of population and demand for road use, the topic of work zones remain relatively unstudied in the peer reviewed literature. This is despite the fact that highway work zone accidents contribute to the total number of accidents taking place in both the state and the nation. These accidents are costly to motorists, and often deadly for construction workers.

Three main components tend to be identified in the research on work zone safety: the number of work zones, the duration of the work zone, and length of the work zone. Properly setting up, spacing, and equipping the work zone was identified as a major contributor to the overall safety in terms of motorist speed reduction and reduction of accidents.

After the physical structure of the work zone, visual performance of the driver is perhaps most related to the immediate safety of work zones. Here, we define visual performance as the ability of the driver to adequately detect and monitor work zones before the need for action occurs. Findings in the literature indicate a need for drivers to have adequate sight distances and notification by signs and channeling devices well ahead of the work zone. This also serves to better control traffic flow within the work zone, which is a contributor to traffic safety in these circumstances.

The continual invasion of in-vehicle technologies within the driver's environment poses serious questions regarding driver distraction. The majority of findings concur that in-vehicle technologies such as mobile telephones and in-dash displays have a detrimental effect on driver performance and lead to an increase in accidents. By using the driver's cognitive resources for these communications and entertainment systems, less mental facilities are available for the safe navigation within work zones. Mitigating driver distraction requires a training solution (increased driver training and awareness of the hazard such devices present), a legislative solution, or the production of devices that reduce the possibilities for driver distraction.

Personality factors of the driver also influence the safety of the work zone. Of the commonly used “Big Five” personality factors, extroversion, neuroticism, and conscientiousness have all been identified as linked to accidents. The understanding of driver personality and the interdependence of driver personality and driver training will most likely have a major impact upon the safety of highway work zones.

Many factors seem to be of primary importance in determining the safety of highway work zones. Our review of these factors has highlighted many possible areas that need the attention of the scientific community for further study. However, the implementation of many of the findings already in the body of literature should have a profound effect upon the number and severity of work zone accidents within the State of Florida.

Table 3. Summary of Findings: Lessons Learned

	Lesson Learned
Work Zone Structure	• Crash rate within the work zone period appears to be higher than the pre-work zone period • Duration and length of a work zone appears to be factors of accidents • Length of work zone appears to increase user cost delays due to speed decreases at work sites • Controlling speed at work zones plays an important role in reducing accidents • Appropriate and clear marking are essential to safe transit through work zones
Visual Performance	• Focal visual system performs tasks such as visual search, object orientation, and tasks that require high visual acuity

	• Peripheral visual system contributes to change detection and the detection of motion on the outer edge of the visual field • Peripheral vision has noted for hazard detection and lane position maintenance • Experienced drivers may spot more peripheral cues than no-drivers • Drivers tend to get trapped at the end of a work zone if sight distance are sub-optimal
Distraction	• When drivers perform one or more tasks while driving, there is an associated increase in accident risk • Using cell phone while driving may affect perceptual and motor skills • People who use cell phones more than a median time of fifty minutes per month may have a 5.5-fold increased risk of a traffic accident (57)
Personality	• Extraversion personality has been associated with motor vehicle accidents • Neuroticism has been found to be related to vehicular accidents, fatalities, aggression while driving and dislike of driving • Conscientiousness is inversely related to at-fault crashes • High sensation seekers seem to get in more traffic accidents and are involved in many other unsafe driving practices
Gender	• Male drivers may be more likely than female drivers to be involved in a fatal automobile accident • No different in driving anger between sexes was found • No gender difference was found in frequency or intensity of anger in day-to-day driving • Female drivers may have greater impatience, frustration, and anger • It seems that angry driving response to impeded progress, inconsiderate driving and impatient driving are more common among male drivers

Table 4. Work zone Best Practices

	Best Practices for Reduction of Accidents
Work Zone Structure	• Control speed while driving through work zones • Properly attired and trained flaggers • Presence of law enforcement at work zones • Variable message signs • Slight reduction in lane width
Visual Performance	• Adequate sight distances of the work zones • Accurate sign notification • Optimally placed channeling devices before approaching work zones
Distraction	• Educate drivers regarding the risk of using in-vehicle devices while driving • Promote new technologies which reduce driver's distraction • Examine possible legislative solutions
Personality	• Driver training associated with driver personality and the interdependence of driver personality

5.0 Experiment 1

5.1 Method

5.1.1 Participants

Participants were 13 females and 8 males from the University of Central Florida who were recruited from psychology courses in exchange for a small amount of extra course credit. The mean age for participants was 21.14 years (*SD* = 2.29). Participants were all licensed drivers in the State of Florida and had normal or corrected to normal vision. Of the 21 participants, 3 reported that they consumed alcohol in the past 24 hours, 5 participants reported feeling ill in the past week, 20 participants reported that they were currently in their usual state of fitness, 4 individuals reported taking prescription medication in the past 24 hours, and 17 people reported having sufficient sleep the night prior to the experiment. On a pre-experimental scale of general discomfort, 14 participants reported feeling no discomfort, 5 participants reported slight discomfort, and 2 individuals reported moderate discomfort. On a pre-experimental scale of fatigue, 13 participants reported no fatigue, 6 people reported moderate fatigue, and 2 individuals reported feeling moderately fatigued.

5.1.2 Apparatus

Driving Simulator. A fixed-base, medium fidelity, I-SIM driving simulator (GE, Version 4.0.86) was interfaced with a custom stimulus presentation and control software application written in LabVIEW (8.2, National Instruments). Data generated by the simulators control computer was monitored for network transmissions of simulator state at 60 Hz (i.e., 16.67 ms time slice). Data was logged for offline analyses and was subsequently parsed for vehicle and environmental information.

Figure 2. ***Screenshot of simulated driver view when following the lead-vehicle.***

Figure 3. ***Screenshots of city setting.***

General driver performance metrics are discussed in a later section. This section specifically addresses those dependent variables possessing the greatest explanatory power for the current experimental manipulation. While a collision with the lead-vehicle or with a work zone channelizing device is an obvious and useful performance metric, collision frequency has limited explanatory power. One's frequency of collisions, for example, does not include the "close-calls" or heightened risk that may be indicative of poor driver performance, dangerous road conditions, or an interaction of the two. While not necessarily inaccurate, inferences drawn from collision frequency alone are incomplete at best. Because the current factors under investigation (i.e., presence of a lead vehicle, visual distraction) may heighten the risk of a possible mishap, but may not manifest in a collision, it is critical to identify specific metrics that identify risk on a ratio not nominal scale. Figure 4 illustrates possible quantitative dependent variables that can be evaluated to explicate driver performance changes in response to experimental manipulation.

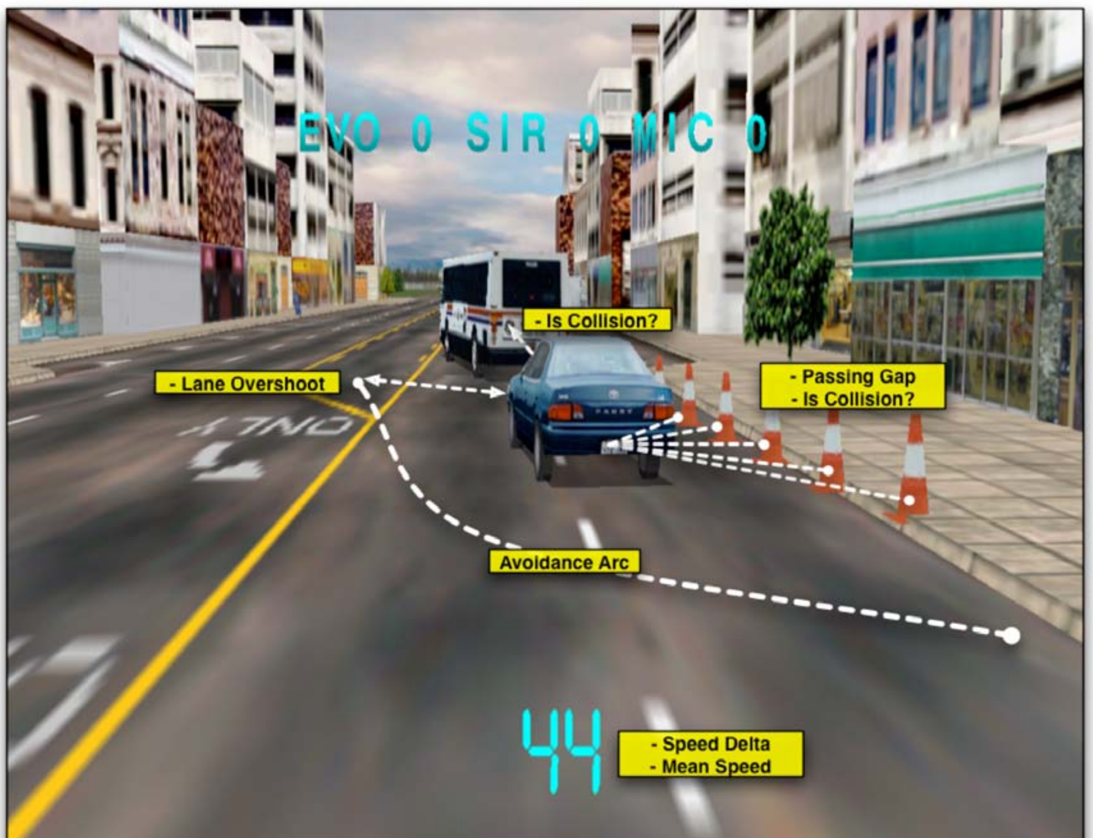

Figure 4. ***Simulated reduced taper work zone with lead vehicle following and associated measures.***

Each of these metrics requires certain data be collected during vehicle operation. That is, for each frame or instance in time (60 Hz) we need to know driver speed, position, steering, braking, lane position, in addition to the lead-vehicle and channelizing device position. Figure 5 shows pilot data collected from a participant during a lead-vehicle / reduced taper condition. This screenshot represents a subset of the actual data collected, but shows a drive in its entirety. The names of each channel are presented on the left of the Figure. Starting from the top: Acceleration, Braking, Lead Vehicle Follow Distance, Lane Position, Steering, Speed are shown. At the top of the Figure, the different numbers correspond to specific points during the drive which are explained below:

Table 5. Explanation of data waypoints in Figure 5.

Waypoint	**Indicator**
The scenario begins. The driver starts the car and waits for the experimenter to signal to begin.	Speed = 0 Δ (x, y) = 0
The brake is released and the driver accelerates to approach the lead vehicle.	Brake = 0 Acceleration ↑
The driver turns left behind the lead-vehicle and closes to follow-distance.	Speed ↑ Lane Position ↺ Follow Distance ↓
The driver maintains speed and continues to follow the lead vehicle.	Δ Speed ≈ 0 Δ Follow Distance ≈ 0
The lead vehicle crosses an intersection and makes a small adjustment in lane position in preparation for the upcoming work zone.	Lane Position ↑
The bus evades the work zone channelizing devices and the driver makes an evasive maneuver to avoid hitting cones or the lead vehicle.	Speed ↓ Brake ↑ Steering ↑↓ Lane Position ↓
The driver comes to a stop shortly after the conclusion of the work zone and the scenario ends.	Speed = 0 Brake ↑

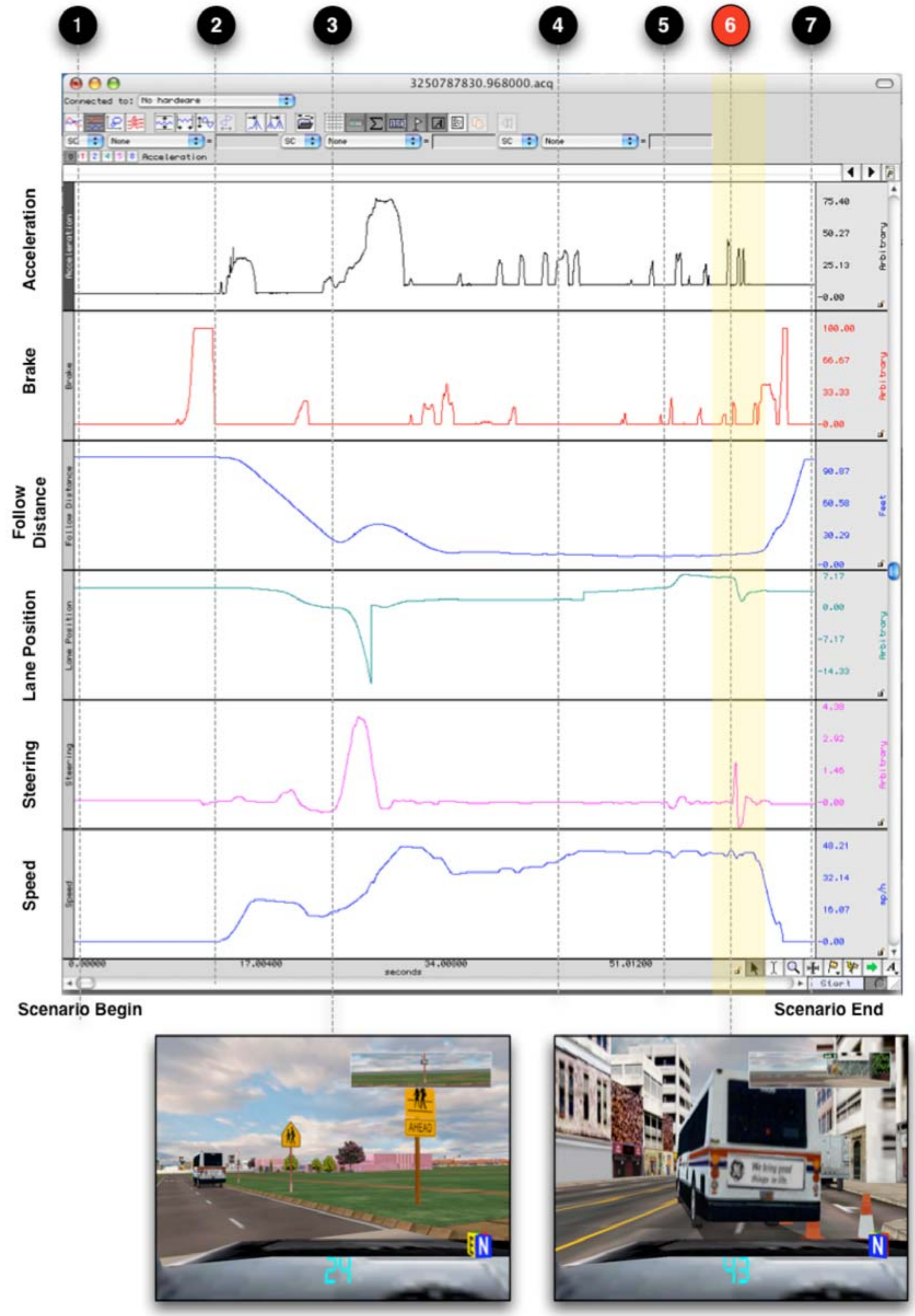

Figure 5. ***Screenshot of a single participant's pilot data for the Reduced Taper/ Lead Vehicle condition. Please refer to Table 4.2 for an explanation of the various segments listed at the top of the figure.***

5.1.3 Questionnaires

Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, et al., 1992) – Simulators have the potential to induce physical symptoms of nausea and dizziness which is variably present in the general population. The SSQ is a multifaceted scale of simulator sickness frequently used in simulator-based studies. The scale uses a 26-symptom checklist with a 4-point scale for all items to calculate scores in three factors: nausea, oculomotor, and disorientation. A total score may be calculated as well, which was the primary metric used from this questionnaire. The SSQ was administered before participation for a baseline measure and following the last trial for comparison.

Driver Stress Inventory and Driver Coping Questionnaire (DSI and DCQ, respectively; Matthews et al., 1997) are two questionnaires which measure driver personality traits which have proven to accurately reflect on driver decisions and behavior. The DSI consists of 48 questions marked on a 10 point Likert-type scale, and produces five factors when scored: Aggression, Dislike of Driving, Hazard Monitoring, Thrill Seeking, and Fatigue Proneness. The Driver Coping Questionnaire consists of 35 questions marked on an 5 point Likert-type scale, and produces six factors: Confrontive, Coping, Task-Focus, Emotion-Focus, Reappraisal, and Avoidance coping dimensions. A driver demographics section asking the participant to recall date of license, annual miles driven, typical driving environment, and any driving infractions precedes the two questionnaires. Both questionnaires were administered to participants prior to participation in the driving scenarios.

5.1.4 Procedure

Following the administration of the DSI, DCQ, and SSQ questionnaires, the driver was familiarized with the driving simulator controls. The driver then completed a route containing a

2.5 minute segment of traveling between safety orange arrow signs in the environment and then another 2.5 minute segment of following a lead vehicle. During this training scenario, participants were given feedback as to how closely to follow the lead vehicle and instructed to drive in the right hand lane whenever possible and keep their speed as close to 45 mph (72 kph) as possible. After the training scenario, participants began the experimental trials. There were five possible routes the participants experienced. Four routes contained work zones, one route did not contain any work zone or other critical event. Two manipulations of each route were given: one in which there was a *lead vehicle* to follow and one in which the participant followed signs to navigate. Two manipulations of work zone *taper length* were also presented: one for the standard taper (540 ft) and one with the reduced taper (100 ft). Both configurations had an 8 ft shoulder. Each participant experienced 20 total trials, 10 with a lead vehicle and 10 with no lead vehicle. A city transit bus served as the lead vehicle for all trials, as pilot data had revealed the bus to be the most visually occluding vehicle to use in the driving task. In the no lead vehicle trials, participants navigated between work zone arrow signs directing their turns that were placed above each intersection. Participants drove until they reached a parked vehicle that served as the stop indicator for all trials. The order of presentation (lead vehicle, no lead vehicle, no work zone) was counterbalanced across participants.

5.1.5 Analysis

Separate general linear models were used to evaluate a number of driver performance variables using a 2 x 2 Analysis of Variance. Independent variables included Lead Vehicle (Present, Absent) and Taper Length (Standard, Reduced). The following dependent variables were included in the analysis: Collisions, Braking, Acceleration, Pre-Work zone Speed, Post-Work zone Speed, Cone Area, Vehicle Speed.

5.2 Results

Results for Experiment 1 are presented below. Questionnaire data is presented first followed by a statistical summary of the data. For the questionnaire data, means and standard deviation data from both the Driver Stress Inventory and the Drive Coping Questionnaire question have been provided.

5.3 Driver Stress Inventory

Table 6. Driver Stress Inventory Summary Tables

Year obtained driving license.	2001.43 (2.58)

How often do you drive nowadays?	**Everyday**	**2-3 Days per week**	**Once per week**	**Less Often**
	85.7%	9.5%	4.8%	0%

Miles driven in past year.	**< 5,000**	**5,000 – 10,000**	**10,000 – 15,000**	**15,000 – 20,000**	**>20,000**
	9.5%	28.6%	28.6%	23.8%	9.5%

Drive to and from work?	**Everyday**	**Most days**	**Occasionally**	**Never**
	42.9%	28.6%	14.3%	14.3%

Types of roads frequently used. (Multiple selection)	**Freeways**	**Other main roads**	**Urban Roads**	**Country Roads**
	52.4%	85.7%	57.1%	0%

Number minor accidents.	**0**	**1**	**2**	**3>**
	57.1%	28.6%	4.8%	9.5%

Number major accidents.	**0**	**1**	**2**	**3>**
	66.7%	28.6%	4.8%	0%

During last 3 years, have you ever been convicted for:	**Yes**	**No**
Convictions for speeding.	38.1%	61.9%
Careless or dangerous driving.	4.8%	95.2%
Driving under the influence.	0%	100%
Other moving violations.	19%	81%

Question	**Anchors (Values ranged 1-10)**	**Mean (SD)**
Does it worry you to drive in bad weather	Very much → Not at all	4.70 (2.65)
I am disturbed by thoughts of having an accident or the car breaking down	Very rarely → Very often	4.15 (2.86)
Do you lose your temper when another driver does something silly?	Not at all → Very much	4.58 (2.31)
Do you think you have enough experience and training to deal with risky situations on the road safely?	Not at all → Very much	5.94 (2.30)
I find myself worrying about my mistakes and the things I do badly when driving	Very rarely → Very often	3.53 (2.14)
I would like to risk my life as a racing driver	Not at all → Very much	1.58 (3.20)
My driving would be worse than usual in an unfamiliar rental car	Not at all → Very much	4.03 (2.55)
I sometimes like to frighten myself a little while driving	Very much → Not at all	6.93 (3.74)
I get a real thrill out of driving fast.	Very much → Not at all	5.18 (3.32)
I make a point of carefully checking every side road I pass for emerging vehicles	Very much → Not at all	3.38 (2.79)
Driving brings out the worst in people.	Not at all → Very much	4.83 (2.74)
Do you think it is worthwhile taking risks on the road?	Very much → Not at all	7.48 (2.96)
At times, I feel like I really dislike other drivers who cause problems for me	Very much → Not at all	4.13 (2.32)

Advice on driving from a passenger is generally	Useful → Unnecessary	5.93 (2.73)
I like to raise my adrenaline levels while driving	Not at all → Very much	1.78 (1.90)
It's important to show other drivers that they can't take advantage of you	Not at all → Very much	3.23 (2.33)
Do you feel confident in your ability to avoid an accident?	Not at all → Very much	6.73 (2.06)
Do you usually make an effort to look for potential hazards when driving?	Not at all → Very much	7.18 (2.06)
Other drivers are generally to blame for any difficulties I have on the road	Not at all → Very much	4.68 (2.34)
I would enjoy driving a sports car on a road with no speed-limit	Very much → Not at all	4.23 (3.51)
Do you find it difficult to control your temper when driving?	Very much → Not at all	6.38 (3.03)
When driving on an unfamiliar road do you become more tense than usual?	Very much → Not at all	4.48 (2.78)
I make a special effort to be alert even on roads I know well	Very much → Not at all	3.83 (2.28)
I enjoy the sensation of accelerating rapidly	Not at all → Very much	4.53 (2.86)
If I make a minor mistake when driving, I feel it's something I should be concerned about	Very much → Not at all	5.83 (2.83)
I always keep an eye on parked cars in case somebody gets out of them, or there are pedestrians behind them	Not at all → Very much	7.08 (2.36)
I feel more anxious than usual when I have a passenger in the car	Not at all → Very much	5.03 (2.72)
I become annoyed if another car follows very close behind mine for some distance	Very much → Not at all	2.43 (2.17)
I make an effort to see what's happening on the road a long way ahead of me	Not at all → Very much	7.43 (1.74)
I try very hard to look out for hazards even when it's not strictly necessary	Not at all → Very much	6.28 (2.00)
Are you usually patient during the rush hour?	Very much → Not at all	4.78 (2.26)
When you pass another vehicle do you feel in command of the situation?	Not at all → Very much	4.875 (1.97)
When you pass another vehicle do you feel tense or	Not at all → Very much	3.68 (2.46)

nervous?		
Does it annoy you to drive behind a slow moving vehicle?	Very much → Not at all	2.33 (2.28)
When you're in a hurry, other drivers usually get in your way	Not at all → Very much	5.88 (2.10)
When I come to negotiate a difficult stretch of road, I am on the alert	Very much → Not at all	2.93 (2.26)
Do you feel more anxious than usual when driving in heavy traffic?	Not at all → Very Much	6.03 (2.04)
I enjoy cornering at high speed	Not at all → Very much	2.33 (2.46)
Are you annoyed when the traffic lights change to red when you approach them?	Very much → Not at all	4.73 (2.73)
Does driving usually make you feel aggressive?	Very Much → Not at all	6.98 (2.26)

5.3.1 Driver Coping Questionnaire

Question (Anchors: Not at all [0] – Very much [5])	**Mean (SD)**
Relieved my feelings by taking risks or driving fast	1.25 (1.29)
Cheered myself up by thinking about things unrelated to the drive	3.20 (1.15)
Stayed detached or distanced from the situation	2.30 (1.34)
Tried to make other drivers more aware of me by driving close behind them	1.20 (1.54)
Wished that I was a more confident and forceful driver	1.40 (1.39)
Ignored my feelings about the drive	2.10 (1.37)
Made sure I avoided reckless or impulsive actions	4.15 (1.04)
Showed other drivers what I thought of them	1.00 (1.34)
Drove assertively or aggressively	1.85 (1.50)
Tried to gain something worthwhile from the drive	1.90 (1.55)
Showed other drivers I was in control of the situation	1.15 (0.99)
Made an extra effort to drive safely	3.55 (1.40)
Felt that I was becoming a more experienced driver	3.35 (1.14)
Made an effort to stay calm and relaxed	3.40 (1.27)
Swore at other drivers (aloud or silently)	2.40 (1.70)
Thought about good times I've had	2.80 (1.47)

Wished that I found driving more enjoyable	2.05 (1.61)
Made sure I kept a safe distance from the car in front	3.55 (1.32)
Went on as if nothing had happened	2.30 (1.17)
Refused to believe that anything unpleasant had happened	1.60 (1.19)
Told myself there wasn't really any problem	2.20 (1.28)
Let other drivers know they were at fault	1.40 (1.23)
Criticized myself for not driving better	2.35 (1.66)
Thought about the consequences of having an accident	4.00 (0.92)
Flashed the car lights or used the horn in anger	1.90 (1.55)
Felt I was learning how to cope with stress	1.85 (1.31)
Deliberately slowed down when I met a difficult traffic situation or bad weather	4.00 (1.03)
Made a special effort to look out for hazards	3.55 (1.32)
Blamed myself for getting too emotional or upset	1.35 (0.99)
Concentrated hard on what I had to do next	3.10 (0.79)
Worried about what I was going to do next	2.50 (1.32)
Looked on the drive as a useful experience	2.60 (1.60)
Worried about my shortcomings as a driver	2.30 (1.66)
Thought about the benefits I would get from making the journey	2.90 (1.33)
Learnt from my mistakes	3.60 (1.05)

5.4 Statistical Analyses

5.4.1 Collisions

The omnibus interaction for Lead Vehicle x Taper Length for Total Collisions emerged as significant, F (1, 19) = 7.03, p = .016. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 6 shows the mean total number of collisions for each level within the Taper Length by Lead Interval interaction (also see Table 7). Significantly more collisions were observed when the lead vehicle was present for the reduced taper work zone (M = 0.13, SE =

0.12) as compared to conditions where the lead vehicle was absent regardless of work zone taper (M = 0, SE = 0.43).

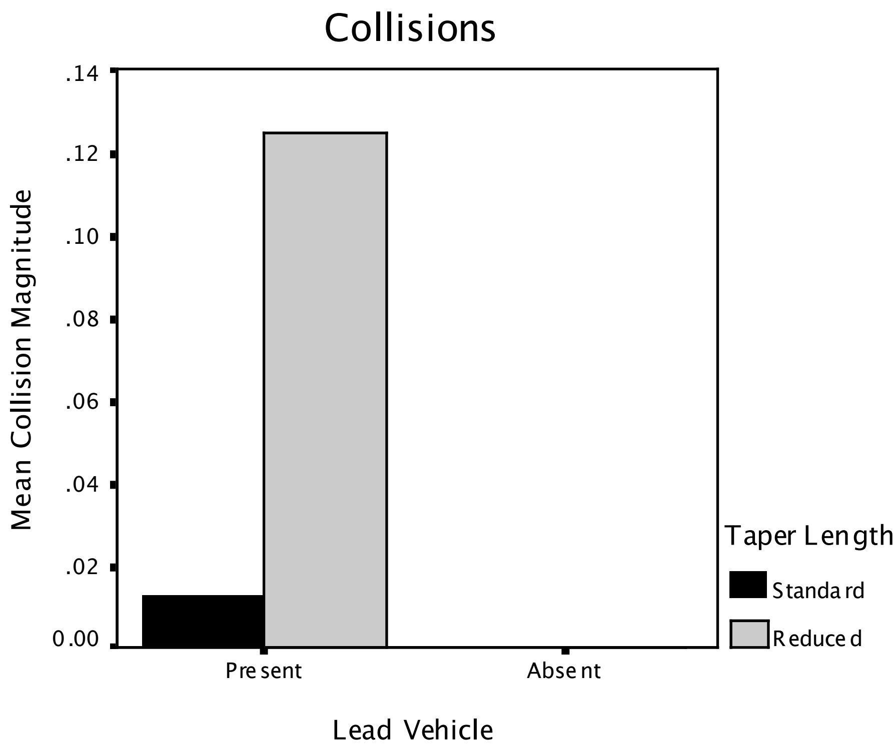

Figure 6. ***While collisions were by in large not a frequent occurrence for Experiment 1, those collisions that did occur happened exclusively when the Lead Vehicle was Present. Interestingly, for those collisions that did occur when the lead vehicle was present, significantly more were observed for the reduced taper as compared to the standard taper configuration.***

Follow-up analyses also revealed a marginally significant difference for the number of collisions when the lead vehicle was present, with more collisions occurring for the reduced taper condition compared to the existing work zone standard. Main effects for both Lead Vehicle and Taper Length were also significant, F (1, 19) = 8.786, p = .008 and F (1, 19) = 7.027, p = .016, respectively. Because only two levels exist for either main effect, no follow-up analyses were conducted. The significant main for Lead Vehicle indicates that when collapsed across Taper Length, more collisions were observed when a lead vehicle was present compared to conditions when the lead vehicle was absent. These results are consistent with the prediction that visual occlusion by the lead vehicle compromised one's ability to assess work zone entry. Moreover, the main effect for Taper Length indicates that when collapsed across Lead Vehicle, that more collisions occurred for the reduced taper configuration compared to the standard taper configuration.

Table 7. Means and standard errors for object collisions.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	0.013 (0.12)	0 (0)
	Reduced	0.125 (0.43)	0 (0)

5.4.2 Braking

The omnibus interaction for Lead Vehicle x Taper Length for Peak Braking was not significant, F (1, 19) = 0.198, $p > .05$. Figure 7 contains the data observed for each condition. Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions (also see Table 8). The main effect test for Taper Length was also not significant, F (1, 19) = 3.507, p = .077. However, the main effect for Lead did emerge as significant, F (1, 19) = 7.750, p = .012. That is, when collapsed across Taper Length, greater peak braking was observed when the vehicle was present (M = 1.640, SE = 0.526) compared to conditions where the vehicle was absent (M = 0.241, SE = 0.113).

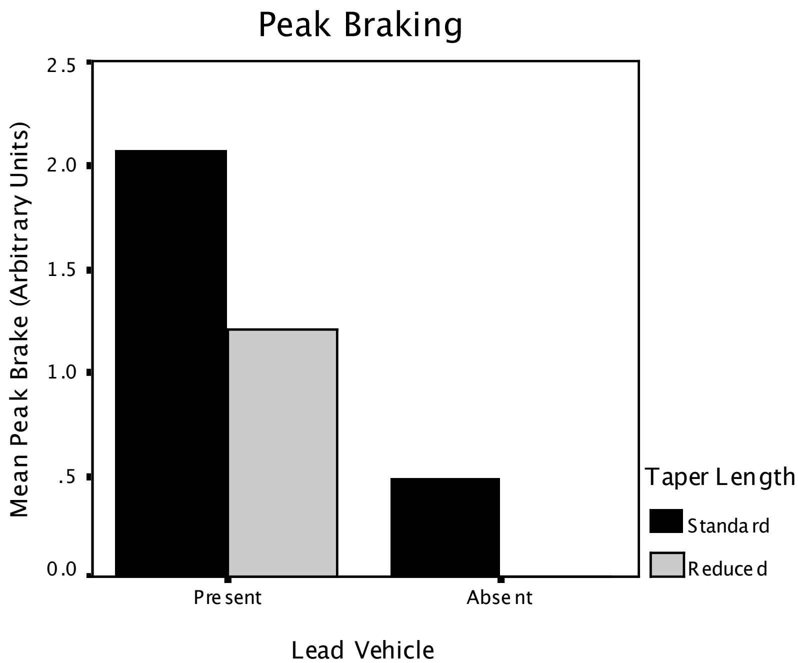

Figure 7. ***Peak brake depressed 500 ms prior to the entering the work zone to 500 ms after entering the work zone.***

Table 8. ***Means and standard errors for peak brake.***

Taper Length	Lead Vehicle: Present	Lead Vehicle: Absent
Standard	2.071 (0.672)	0.483 (0.226)
Reduced	1.209 (0.622)	0 (0)

5.4.3 Acceleration

The omnibus interaction for Lead Vehicle x Taper Length for Acceleration was not significant, F (1, 19) = 2.948, p = .102. Figure 8 contains the data observed for each condition (also see Table 9). Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions.

The main effect test for Taper Length was significant, F (1, 19) = 6.942, p = .016. When collapsed across Lead Vehicle, greater peak acceleration was observed when for the reduced taper work zone (M = 10.991, SE = 0.818) compared to the standard taper work zone (M = 9.455, SE = 0.528). The main effect for Lead Vehicle was not significant, F (1, 19) = 0.001, p > .05.

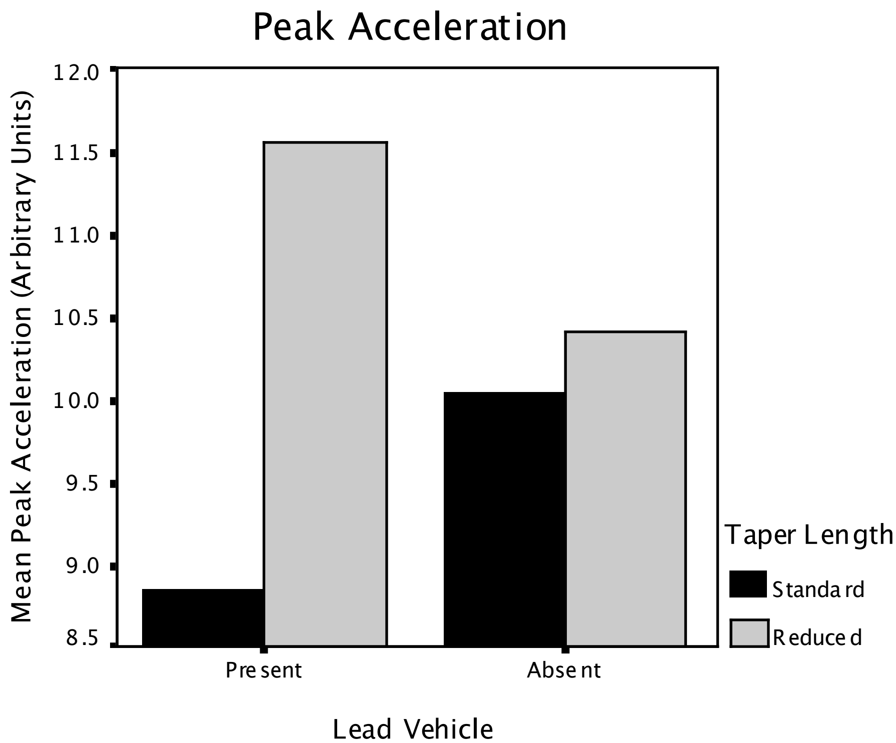

Figure 8. ***Shows the peak acceleration inside a work zone.***

Table 9. ***Means and standard errors for peak acceleration.***

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	8.857 (0.809)	10.053 (0.664)
	Reduced	11.564 (1.173)	10.418 (0.905)

5.4.4 Pre-Work Zone Speed

The omnibus interaction for Lead Vehicle x Taper Length for Pre-Work zone Speed was not significant, *F* (1, 19) = 3.573, *p* = .74. Figure 9 contains the data observed for each condition (also see Table 10). Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions. However, both the main effect for Lead Vehicle and Taper Length were significant, *F* (1, 19) = 11.382, *p* = .003 and *F* (1, 19) = 11.588, *p* = .003, respectively. Participants drove significantly faster prior to entering the work zone when the lead vehicle was not present (*M* = 49.717, *ES* = 1.174) compared to when the lead vehicle was present (*M* = 45.618, *SE* = 0.322). Further, when collapsed across Lead Vehicle, participants drove significantly faster prior to entering the standard taper work zone (*M* = 48.481, *SE* = 0.719) compared to the reduced taper work zone (*M* = 46.921, *SE* = 0.583).

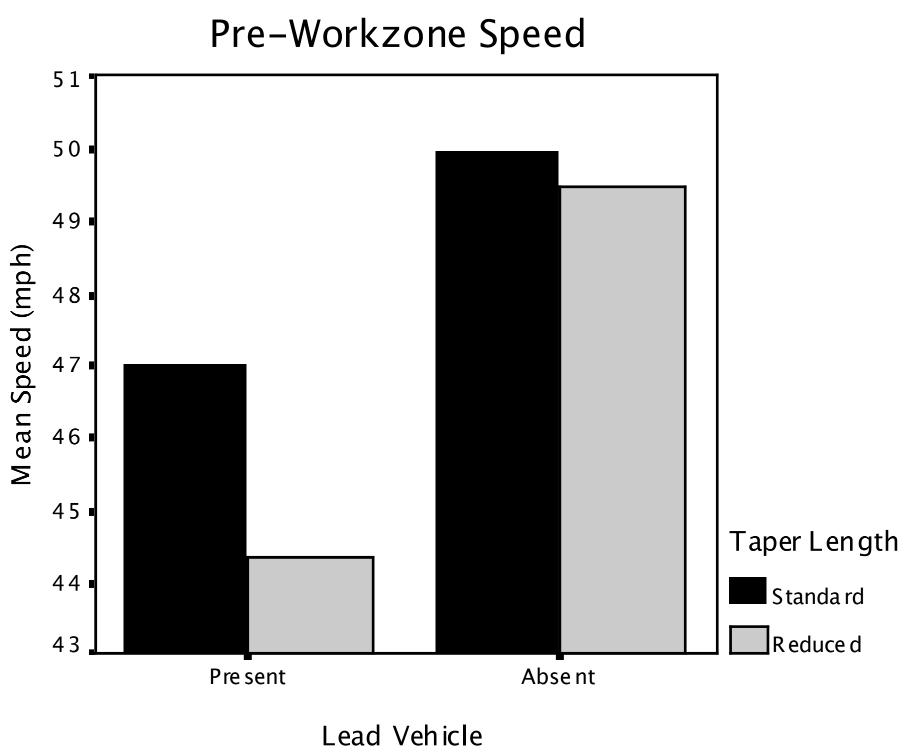

Figure 9. ***Vehicle speed 60 ms prior to entering work zone.***

Table 10. Means and standard errors for vehicle speed 60 ms prior to work zone entry.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	47.004 (0.549)	49.959 (1.366)
	Reduced	44.366 (0.194)	49.476 (1.123)

5.4.5 Post-Work Zone Speed

The omnibus interaction for Lead Vehicle x Taper Length for Post-Work zone Speed was not significant, F (1, 19) = 1.173, $p > .05$. Figure 8 contains the data observed for each condition (also see Table 11). Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions. The main effect for Lead Vehicle was significant, F (1, 19) = 12.353, p = .002. When collapsed across Taper Length, participants drove significantly slower after when exiting the work zone with a lead vehicle present (M = 48.399, SE = 0.727) compared to conditions where the lead vehicle was absent (M = 47.101, SE = 0.647). The main effect for Taper Length was also significant, F (1, 19) = 7.125, p = .015. Participants drove significantly slower exiting the standard work zone (M = 45.618, SE = 0.322) compared the reduced taper work zone (M = 49.882, SE = 1.215).

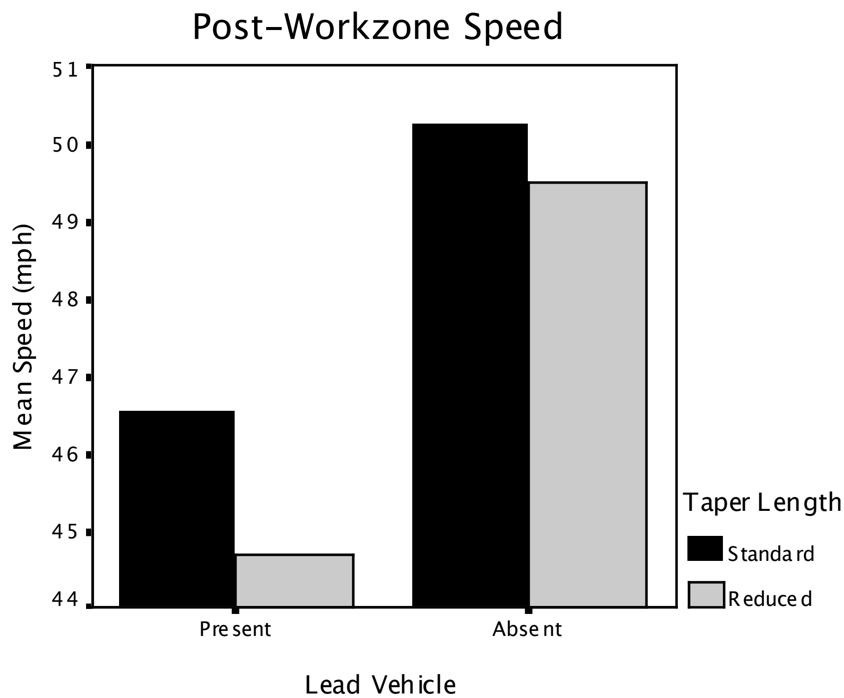

Figure 10. Vehicle speed at 60 ms following work zone exit.

Table 11. Means and standard errors for vehicle speed at 60 ms following work zone exit.

Taper Length		Lead Vehicle: Present	Lead Vehicle: Absent
	Standard	46.548 (0.599)	50.249 (1.368)
	Reduced	44.688 (0.287)	49.514 (1.182)

5.4.6 Cone Area: First Cone

The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the first cone was significant, F (1, 19) = 13.339, p = .002. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 11 shows the mean total area for each level within the Taper Length by Lead

Interval interaction. While the comparison between Lead Vehicle Present/Standard Taper and Lead Vehicle Absent/Reduced Taper was not significant, all other factor levels were significantly different from each other. The vehicle-to-cone area was significantly smaller when a lead vehicle was *present* versus *absent* for both the *standard* (*M* = 8.292, *SE* = 0.293 versus *M* = 10.326, *SE* = 0.367) and *reduced* (*M* = 5.115, *SE* = 0.285 versus *M* = 8.010, *SE* = 0.187) work zones, respectively. Notably, the largest difference occurred for conditions where the lead vehicle was absent in a standard work zone (*M* = 10.326, *SE* = 0.367) and conditions where the lead vehicle was present in the reduced work zone configuration (*M* = 5.115, *SE* = 0.285).

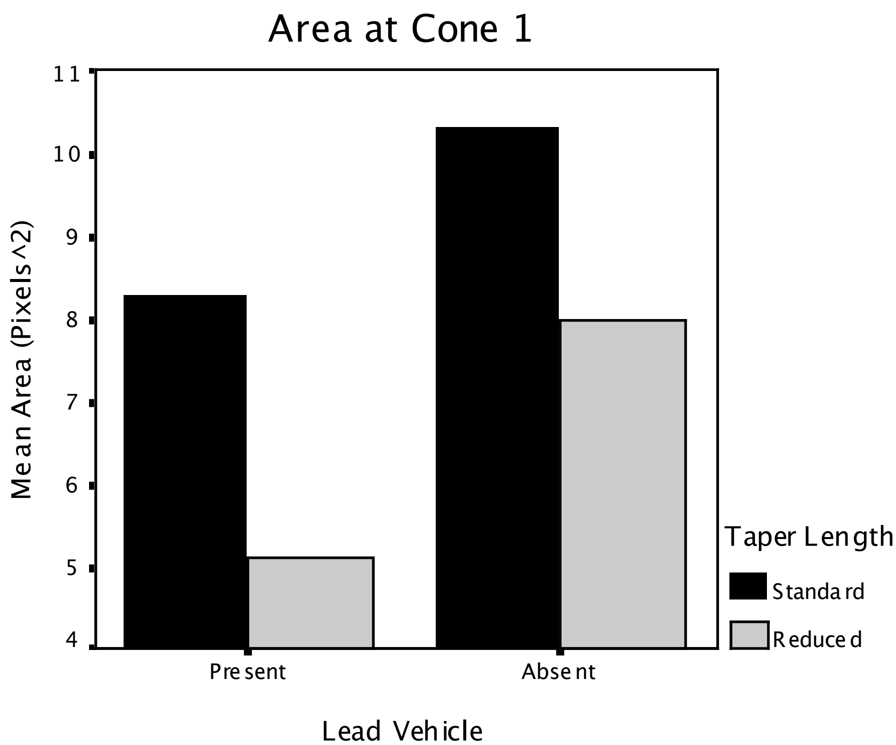

Figure 11. ***Depicts the total area between the driver's vehicle and the third cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.***

The main effects for both Lead Vehicle and Taper Length were also significant, *F* (1, 19) = 86.809, *p* < .001 and *F* (1, 19) = 165.853, *p* < .001, respectively. When collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present

(*M* = 6.703, *SE* = 0.260) compared to when the lead vehicle was absent (*M* = 9.168, *SE* = 0.267). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (*M* = 6.562, *SE* = 0.203) compared to the standard work zone configuration (*M* = 9.309, *SE* = 0.291).

Table 12. Means and standard errors for vehicle-to-cone area at cone 1.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	8.292 (0.293)	10.326 (0.367)
	Reduced	5.115 (0.285)	8.010 (0.187)

5.4.7 Cone Area: Second Cone

Total vehicle-to-cone area for the second cone showed a similar pattern to observations at the first cone. The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the second cone was significant, *F* (1, 19) = 9.850, *p* = .005. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 12 shows the mean total area for each level within the Taper Length by Lead Interval interaction. Again, the comparison between Lead Vehicle Present/Standard Taper and Lead Vehicle Absent/Reduced Taper was not significant, however, all other factor levels were significantly different from each other. The vehicle-to-cone area was significantly smaller when a lead vehicle was *present* versus *absent* for both the *standard* (*M* = 8.023, *SE* = 0.312 versus *M* = 9.973, *SE* = 0.367) and *reduced* (*M* = 5.109, *SE* = 0.296 versus *M* = 7.904, *SE* = 0.191) work zones, respectively. The largest difference was again observed for conditions where the lead vehicle was absent in a standard work zone (*M* = 9.973, *SE* = 0.299) and conditions where the lead vehicle was present in the reduced work zone configuration (*M* = 5.109, *SE* = 0.296).

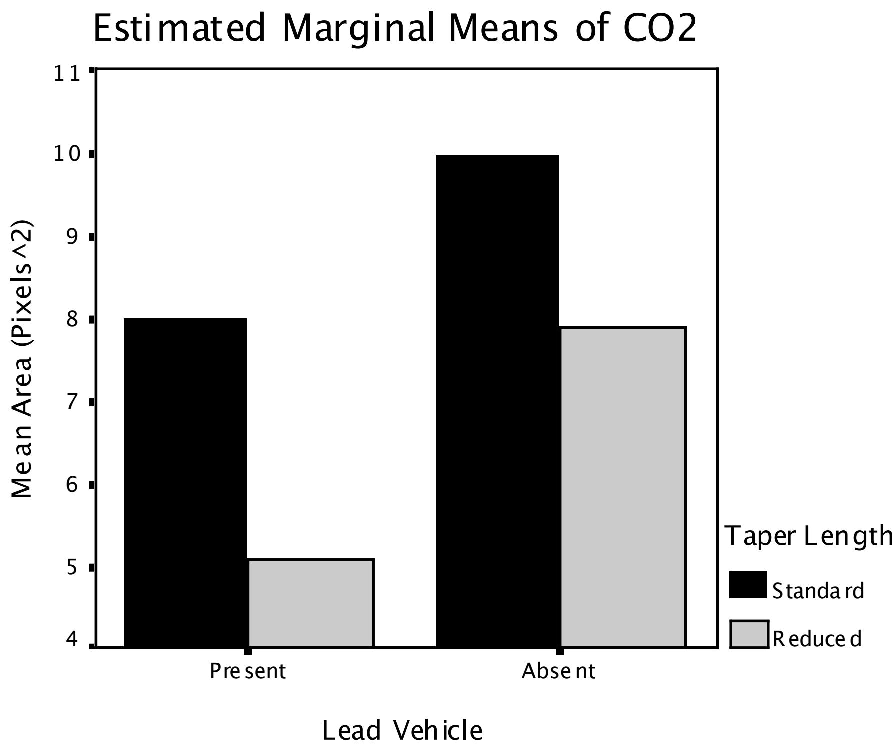

Figure 12. ***Depicts the total area between the driver's vehicle and the second cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.***

The main effects for both Lead Vehicle and Taper Length were also significant for the vehicle-to-cone area at cone 2, F (1, 19) = 95.073, $p < .001$ and F (1, 19) = 162.259, $p < .001$, respectively. Similarly to Cone 1, when collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present (*M* = 6.566, *SE* = 0.272) compared to when the lead vehicle was absent (*M* = 8.938, *SE* = 0.231). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (*M* = 6.506, *SE* = 0.214) compared to the standard work zone configuration (*M* = 8.998, *SE* = 0.266).

Table 13. Means and standard errors vehicle-to-cone area at cone 2.

Taper Length		Lead Vehicle: Present	Lead Vehicle: Absent
	Standard	8.023 (0.312)	9.973 (0.299)
	Reduced	5.109 (0.296)	7.904 (0.191)

5.4.8 Cone Area: Third Cone

The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the third cone was not significant, F (1, 19) = 3.491, $p > .05$. Figure 13 contains the data observed for each condition. Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions. However, the main effects for both Lead Vehicle and Taper Length were significant for the vehicle-to-cone area at cone 3, F (1, 19) = 69.035, $p < .001$ and F (1, 19) = 161.458, $p < .001$, respectively.

Similarly to cones 1 and 2, when collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present (M = 6.505, SE = 0.267) compared to when the lead vehicle was absent (M = 8.548, SE = 0.252). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (M = 6.340, SE = 0.224) compared to the standard work zone configuration (M = 8.714, SE = 0.268).

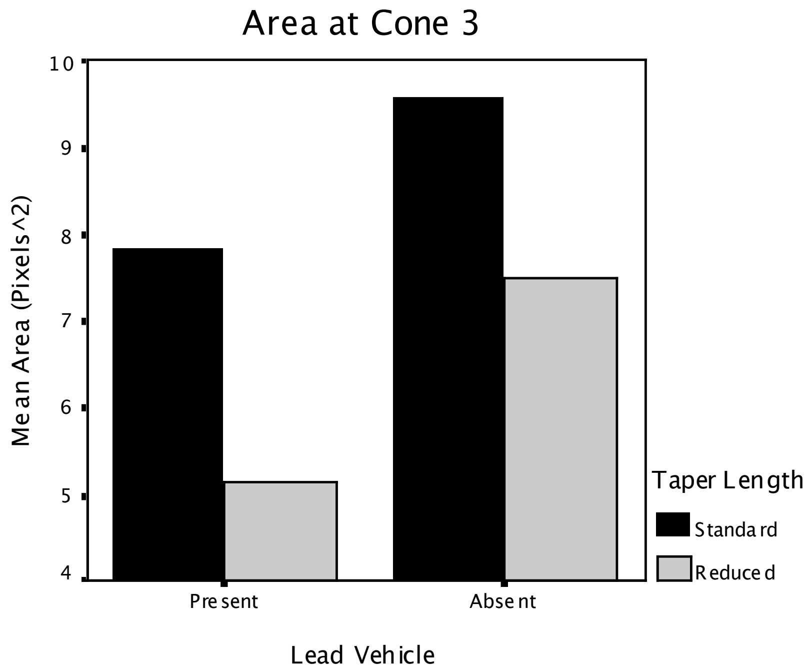

Figure 13. Depicts the total area between the driver's vehicle and the third cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.

Table 14. Means and standard errors vehicle-to-cone area at cone 3.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	7.846 (0.286)	9.973 (0.299)
	Reduced	5.165 (0.308)	7.904 (.191)

5.4.9 Vehicle Speed

The omnibus interaction for Lead Vehicle x Taper Length for work zone speed approached significance, F (1, 19) = 4.271, p = .053. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 11 shows the mean total area for each level within the Taper Length by Lead Interval interaction.

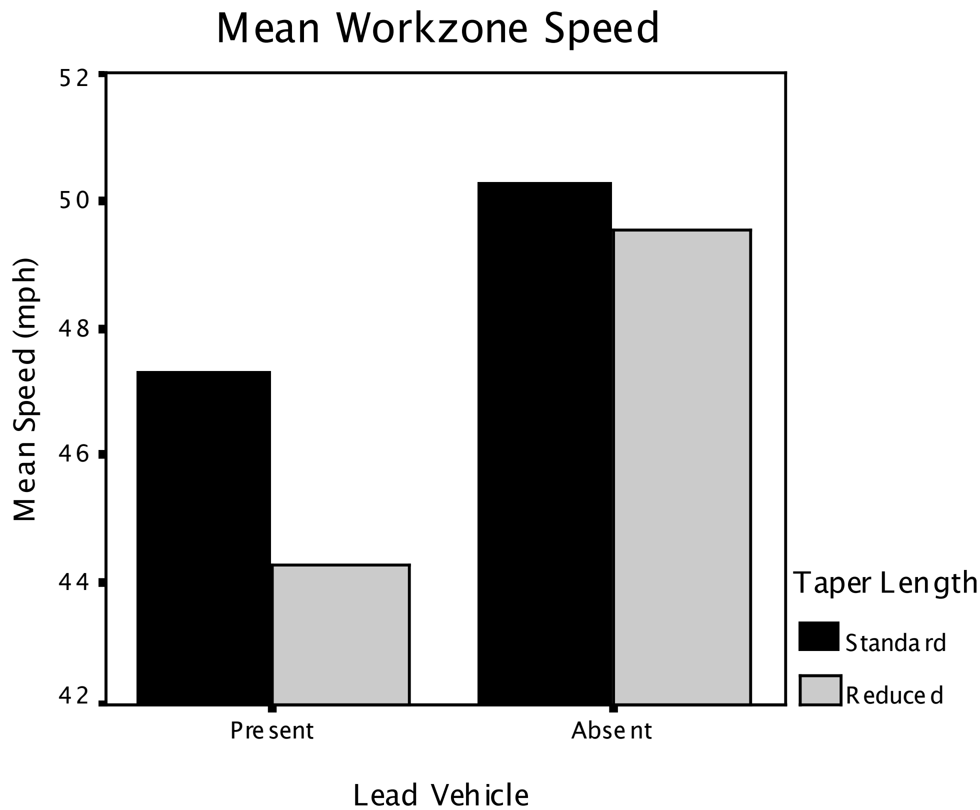

Figure 14. ***Vehicle speed inside work zone.***

The main effect for Lead Vehicle was significant, *F* (1, 19) = 11.561, *p* = .003. When collapsed across Taper Length, participants drove significantly slower when the lead vehicle was present when within the work zone (*M* = 45.800, *SE* = 0.310) compared to when the lead vehicle was absent (*M* = 49.923, *SE* = 1.191). When collapsed across Lead Vehicle, participants drove significantly faster through the standard taper work zone (*M* = 48.811, *SE* = 0.720) compared to the reduced taper work zone (*M* = 466.911, *SE* = 0.613).

Table 15. ***Means and standard errors for vehicle speed inside the work zone.***

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	47.326 (0.574)	50.297 (1.361)
	Reduced	44.274 (0.211)	49.549 (1.159)

6.0 Experiment 2

6.1 Method

6.1.1 Participants

Participants were 13 females and 8 males from the University of Central Florida who were recruited from psychology courses in exchange for a small amount of extra course credit. The mean age for participants was 21.14 years (*SD* = 2.29). Participants were all licensed drivers in the State of Florida and had normal or corrected to normal vision. Of the 21 participants, 3 reported that they consumed alcohol in the past 24 hours, 5 participants reported feeling ill in the past week, 20 participants reported that they were currently in their usual state of fitness, 4 individuals reported taking prescription medication in the past 24 hours, and 17 people reported having sufficient sleep the night prior to the experiment. On a pre-experimental scale of general discomfort 14 participants reported feeling no discomfort, 5 participants reported slight discomfort, and 2 individuals reported moderate discomfort. On a pre-experimental scale of fatigue, 13 participants reported no fatigue, 6 people reported moderate fatigue, and 2 individuals reported feeling moderately fatigued.

6.1.2 Apparatus

See experiment 1.

6.1.3 Analysis

Separate general linear models were used to evaluate a number of driver performance variables using a 2 x 2 Analysis of Variance. Independent variables included Lead Vehicle (Present, Absent) and Taper Length (Standard, Reduced). The following dependent variables were included in the analysis: Collisions, Braking, Acceleration, Pre-Work zone Speed, Post-Work zone Speed, Cone Area, Vehicle Speed.

6.1.4 Procedure

The second experiment used the exact same conditions and protocol as Experiment 1, with the addition of additional roadway traffic in the driving environment. This additional roadway traffic served to “box in” the driver and increase the operator demand in the work zone-driving task. Three additional vehicles served as the additional roadway traffic; these were programmed to follow directly alongside the vehicle's driver's side door, directly behind the driver's vehicle, and to the driver's side rear of the vehicle. The type and appearance of the vehicles were varied between each scenario and all vehicles used were either foreign or domestic cars and light trucks. Just prior to work zone entry, all vehicles entered the non-closed lane, forcing the driver to make a smooth transition as well, or experience a collision.

6.2 Results

Results for Experiment 2 are presented below. Questionnaire data is presented first followed by a statistical summary of the data. For the questionnaire data, means and standard deviation data from both the Driver Stress Inventory and the Drive Coping Questionnaire question have been provided.

6.2.1 Driver Stress Inventory

Year obtained driving license. (Median)	2002.47 (2.86)

How often do you drive nowadays?	**Everyday**	**2-3 Days per week**	**Once per week**	**Less Often**
	85%	5%	5%	5%

Miles driven in past year.	**< 5,000**	**5,000 – 10,000**	**10,000 – 15,000**	**15,000 – 20,000**	**>20,000**
	5%	45%	10%	20%	20%

Drive to and from work?	**Everyday**	**Most days**	**Occasionally**	**Never**
	45%	30%	10%	15%

Types of roads frequently used. (Participants make multiple selections so totals not equal to 100%)	**Freeways**	**Other main roads**	**Urban Roads**	**Country Roads**
	90%	60%	70%	10%

Number minor accidents.	**0**	**1**	**2**	**3>**
	65%	25%	5%	5%

Number major accidents.	**0**	**1**	**2**	**3>**
	70%	20%	10%	0%

During last 3 years, have you ever been convicted for:	**Yes**	**No**
Convictions for speeding.	45%	55%
Careless or dangerous driving.	15%	85%
Driving under the influence.	5%	95%

Other moving violations.	5%	95%

Question	Anchors (Values ranged 1-10)	Mean (SD)
Does it worry you to drive in bad weather	Very much → Not at all	5.92 (2.46)
I am disturbed by thoughts of having an accident or the car breaking down	Very rarely → Very often	3.03 (2.18)
Do you lose your temper when another driver does something silly?	Not at all → Very much	4.35 (2.94)
Do you think you have enough experience and training to deal with risky situations on the road safely?	Not at all → Very much	7.91 (1.13)
I find myself worrying about my mistakes and the things I do badly when driving	Very rarely → Very often	3.19 (2.35)
I would like to risk my life as a racing driver	Not at all → Very much	2.40 (3.19)
My driving would be worse than usual in an unfamiliar rental car	Not at all → Very much	3.53 (2.27)
I sometimes like to frighten myself a little while driving	Very much → Not at all	6.85 (3.72)
I get a real thrill out of driving fast.	Very much → Not at all	4.15 (2.52)
I make a point of carefully checking every side road I pass for emerging vehicles	Very much → Not at all	4.19 (2.53)
Driving brings out the worst in people.	Not at all → Very much	4.90 (2.53)
Do you think it is worthwhile taking risks on the road?	Very much → Not at all	7.75 (2.34)
At times, I feel like I really dislike other drivers who cause problems for me	Very much → Not at all	4.05 (2.41)
Advice on driving from a passenger is generally	Useful → Unnecessary	6.04 (2.08)
I like to raise my adrenaline levels while driving	Not at all → Very much	2.95 (2.19)
It's important to show other drivers that they can't take advantage of you	Not at all → Very much	4.25 (2.27)
Do you feel confident in your ability to avoid an accident?	Not at all → Very much	8.33 (1.28)
Do you usually make an effort to look for potential hazards when driving?	Not at all → Very much	8.68 (0.89)
Other drivers are generally to blame for any	Not at all → Very much	5.75 (2.15)

difficulties I have on the road		
I would enjoy driving a sports car on a road with no speed-limit	Very much → Not at all	1.82 (2.77)
Do you find it difficult to control your temper when driving?	Very much → Not at all	7.25 (2.71)
When driving on an unfamiliar road do you become more tense than usual?	Very much → Not at all	5.40 (2.33)
I make a special effort to be alert even on roads I know well	Very much → Not at all	3.90 (1.55)
I enjoy the sensation of accelerating rapidly	Not at all → Very much	6.35 (2.87)
If I make a minor mistake when driving, I feel it's something I should be concerned about	Very much → Not at all	6.40 (2.70)
I always keep an eye on parked cars in case somebody gets out of them, or there are pedestrians behind them	Not at all → Very much	7.24 (1.65)
I feel more anxious than usual when I have a passenger in the car	Not at all → Very much	4.35 (2.98)
I become annoyed if another car follows very close behind mine for some distance	Very much → Not at all	2.05 (1.88)
I make an effort to see what's happening on the road a long way ahead of me	Not at all → Very much	7.55 (1.60)
I try very hard to look out for hazards even when it's not strictly necessary	Not at all → Very much	6.70 (1.75)
Are you usually patient during the rush hour?	Very much → Not at all	5.40 (2.92)
When you pass another vehicle do you feel in command of the situation?	Not at all → Very much	6.75 (1.48)
When you pass another vehicle do you feel tense or nervous?	Not at all → Very much	2.85 (2.13)
Does it annoy you to drive behind a slow moving vehicle?	Very much → Not at all	2.20 (2.19)
When you're in a hurry, other drivers usually get in your way	Not at all → Very much	5.75 (2.05)
When I come to negotiate a difficult stretch of road, I am on the alert	Very much → Not at all	2.25 (1.89)
Do you feel more anxious than usual when driving in heavy traffic?	Not at all → Very Much	4.60 (2.33)

I enjoy cornering at high speed	Not at all → Very much	4.20 (3.11)
Are you annoyed when the traffic lights change to red when you approach them?	Very much → Not at all	4.23 (3.05)
Does driving usually make you feel aggressive?	Very Much → Not at all	6.60 (2.56)

6.2.2 Driver Coping Questionnaire

Question (Anchors: Not at all [0] – Very much [5])	**Mean (SD)**
Relieved my feelings by taking risks or driving fast	1.40 (1.10)
Cheered myself up by thinking about things unrelated to the drive	3.80 (0.89)
Stayed detached or distanced from the situation	2.55 (1.28)
Tried to make other drivers more aware of me by driving close behind them	1.05 (1.05)
Wished that I was a more confident and forceful driver	0.85 (1.04)
Ignored my feelings about the drive	2.30 (1.03)
Made sure I avoided reckless or impulsive actions	3.75 (1.12)
Showed other drivers what I thought of them	1.05 (0.83)
Drove assertively or aggressively	2.05 (1.50)
Tried to gain something worthwhile from the drive	2.20 (1.28)
Showed other drivers I was in control of the situation	1.90 (1.17)
Made an extra effort to drive safely	3.45 (1.15)
Felt that I was becoming a more experienced driver	3.30 (0.98)
Made an effort to stay calm and relaxed	3.70 (0.66)
Swore at other drivers (aloud or silently)	2.25 (1.62)
Thought about good times I've had	2.80 (1.47)
Wished that I found driving more enjoyable	1.75 (1.48)
Made sure I kept a safe distance from the car in front	3.70 (0.80)
Went on as if nothing had happened	2.85 (1.18)
Refused to believe that anything unpleasant had happened	1.70 (1.34)
Told myself there wasn't really any problem	2.10 (1.29)
Let other drivers know they were at fault	1.20 (1.11)
Criticized myself for not driving better	1.50 (1.70)

Thought about the consequences of having an accident	2.30 (1.38)
Flashed the car lights or used the horn in anger	1.70 (1.34)
Felt I was learning how to cope with stress	1.85 (1.14)
Deliberately slowed down when I met a difficult traffic situation or bad weather	4.05 (0.76)
Made a special effort to look out for hazards	3.70 (0.87)
Blamed myself for getting too emotional or upset	0.95 (0.95)
Concentrated hard on what I had to do next	3.35 (0.99)
Worried about what I was going to do next	2.05 (1.23)
Looked on the drive as a useful experience	2.15 (1.27)
Worried about my shortcomings as a driver	1.35 (1.50)
Thought about the benefits I would get from making the journey	2.35 (1.27)
Learnt from my mistakes	4.00 (0.86)

6.3 Statistical Analyses

6.3.1 Collisions

The omnibus interaction for Lead Vehicle x Taper Length for Total Collisions was not significant, F (1, 17) = 0.279, $p > .05$. Figure 15 contains the data observed for each condition (also see Table 16). Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions.

A significant main effect for Lead Vehicle was also observed, F (1, 17) = 30.600, $p < .001$. When collapsed across Taper Length significantly more collisions occurred when the lead vehicle was present (M = 0.194, SE = 0.032) compared to when the lead vehicle was absent (M = 0.007, SE = 0.007). The main effect for Taper Length was not significant, F (1, 19) = 0.702, $p > .05$.

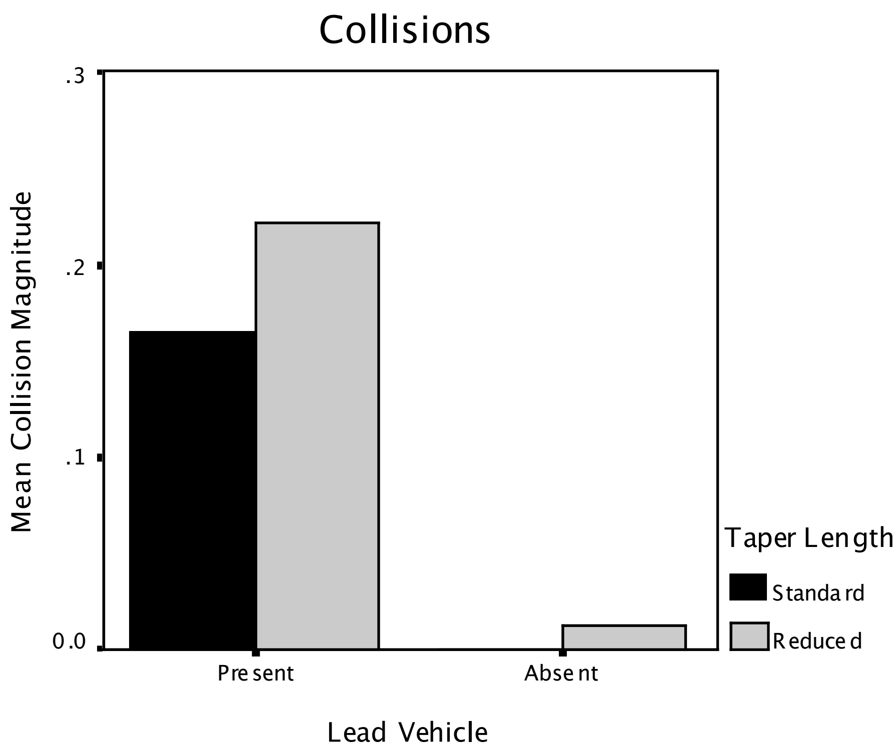

Figure 15. ***Significantly more collisions occurred when the lead vehicle was present compared to when the lead vehicle was absent when collision data was collapsed across Taper Length (i.e., mean number of collisions for both the standard and reduced work zones). In Experiment 1, the number of collisions observed was found to vary as a function of both Taper Length and Lead Vehicle. However, this interaction was not observed in Experiment 2..***

Table 16. ***Means and standard errors for object collisions.***

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	0.167 (0.045)	0 (0)
	Reduced	0.222 (0.057)	0.014 (.014)

6.3.2 Braking

The omnibus interaction for Lead Vehicle x Taper Length for Peak Braking was not significant, F (1, 17) = 0.006, $p > .05$. Figure 7 contains the data observed for each condition. Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions. The main effect for Lead Vehicle for peak braking was significant, F (1, 19) = 36.106, $p < .001$. Collapsed across Taper Length significantly greater peak braking was observed when the lead vehicle was present (M = 16.914, SE = 2.632) compared to conditions where the lead vehicle was absent (M = 1.136, SE = 0.615). The main effect for Taper Length was not significant, F (1, 19) = 0, p > .05

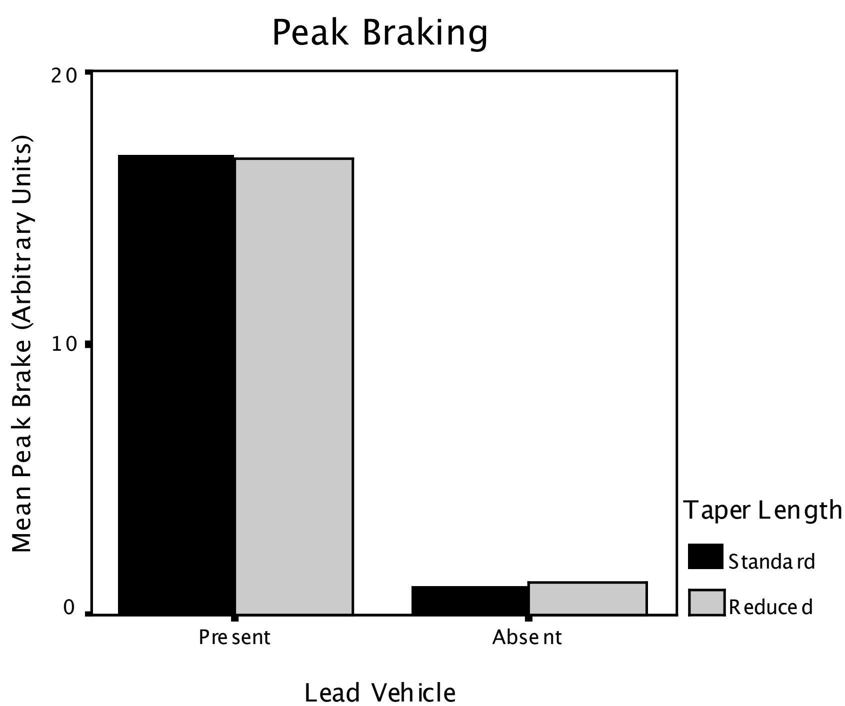

Figure 16. ***Peak brake depressed 500 ms prior to the entering the work zone to 500 ms after entering the work zone. Peak Brake was not significantly different across Lead Vehicle or Taper Length for Experiment 2.***

Table 17. Means and standard errors for peak brake.

Taper Length	Lead Vehicle: Present	Lead Vehicle: Absent
Standard	16.990 (3.529)	1.044 (0.740)
Reduced	16.837 (3.327)	1.227 (0.586)

6.3.3 Acceleration

The omnibus interaction for Lead Vehicle x Taper Length for Acceleration was not significant, F (1, 19) = 0.875, $p > .05$. Figure 17 contains the data observed for each condition. Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions.

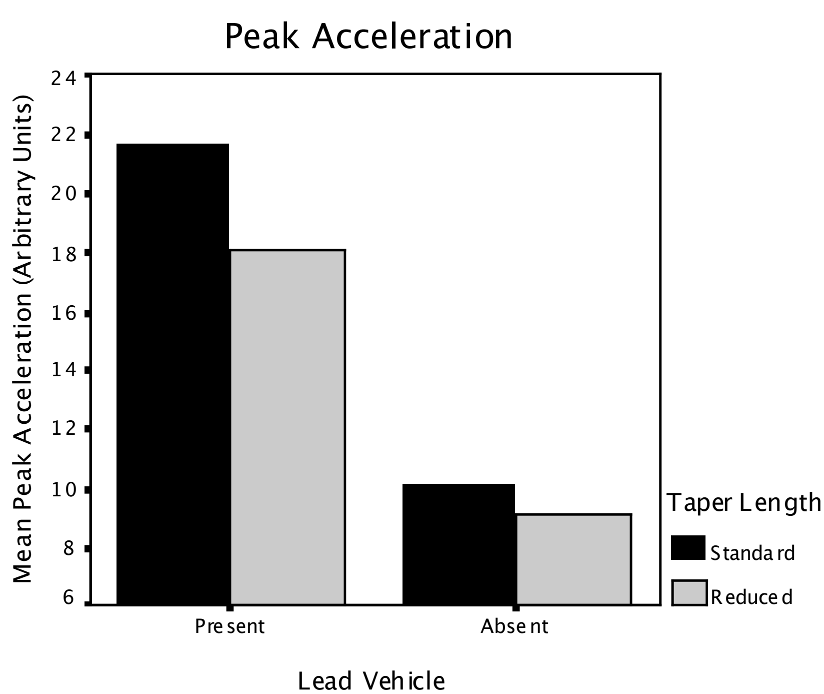

Figure 17. Shows the peak acceleration inside a work zone.

Significantly greater peak acceleration was observed as a main effect of Lead Vehicle, *F* (1, 19) = 19.928, $p < .001$, with greater peak acceleration observed when the lead vehicle was present (*M* = 19.879, *SE* = 2.768) compared to when it was absent (*M* = 9.654, *SE* = 1.207). The main effect for Taper Length was not significant, *F* (1, 19) = 1.632, $p > .05$.

Table 18. Means and standard errors for peak acceleration.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	21.685 (3.532)	10.194 (1.416)
	Reduced	18.073 (2.744)	9.114 (1.194)

6.3.4 Pre-Work zone Speed

The omnibus interaction for Lead Vehicle x Taper Length for Pre-Work zone Speed was not significant, *F* (1, 19) = 0.873, $p > .05$. Figure 18 contains the data observed for each condition. Because the omnibus interaction was not significant follow-up analyses were not conducted across conditions.

The main effect of Taper Length was not significant, *F* (1, 19) = 1.981, $p > .05$. However, the main effect for Lead Vehicle was significant, *F* (1, 19) = 71.945, $p < .001$. When collapsed across Taper Length, participants drove significantly faster when the lead vehicle was absent (*M* = 48.782, *SE* = 0.629) compared to when the lead vehicle was present (*M* = 42.259, *SE* = 0.311).

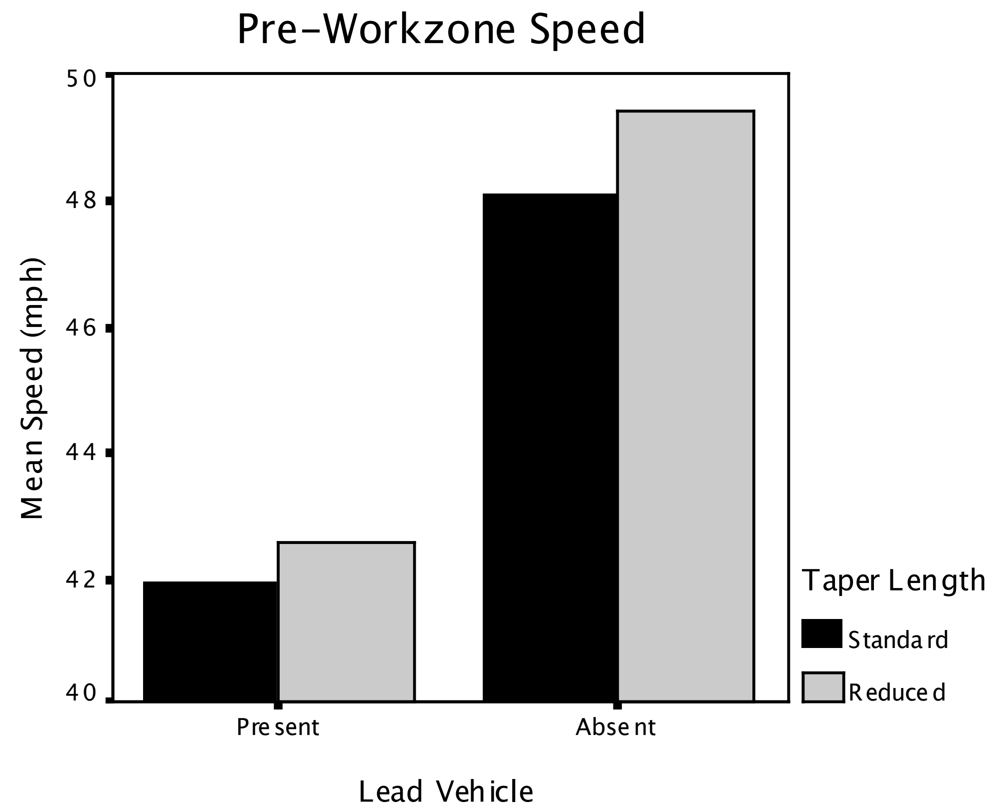

Figure 18. ***Vehicle speed 60 ms prior to entering work zone.***

Table 19. ***Means and standard errors for vehicle speed 60 ms prior to work zone entry.***

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	41.916 (0.454)	43.710 (0.612)
	Reduced	42.602 (0.527)	41.057 (0.907)

6.3.5 Post-Work zone Speed

The omnibus interaction for Lead Vehicle x Taper Length for Post-Work zone Speed was significant, F (1, 19) = 12.326, p = .003. Figure 19 contains the data observed for each condition.

Table 20. Means and standard errors for vehicle speed at 60 ms following work zone exit.

Taper Length	Lead Vehicle: Present	Lead Vehicle: Absent
Standard	43.710 (0.612)	48.011 (0.802)
Reduced	41.057 (0.907)	49.098 (0.773)

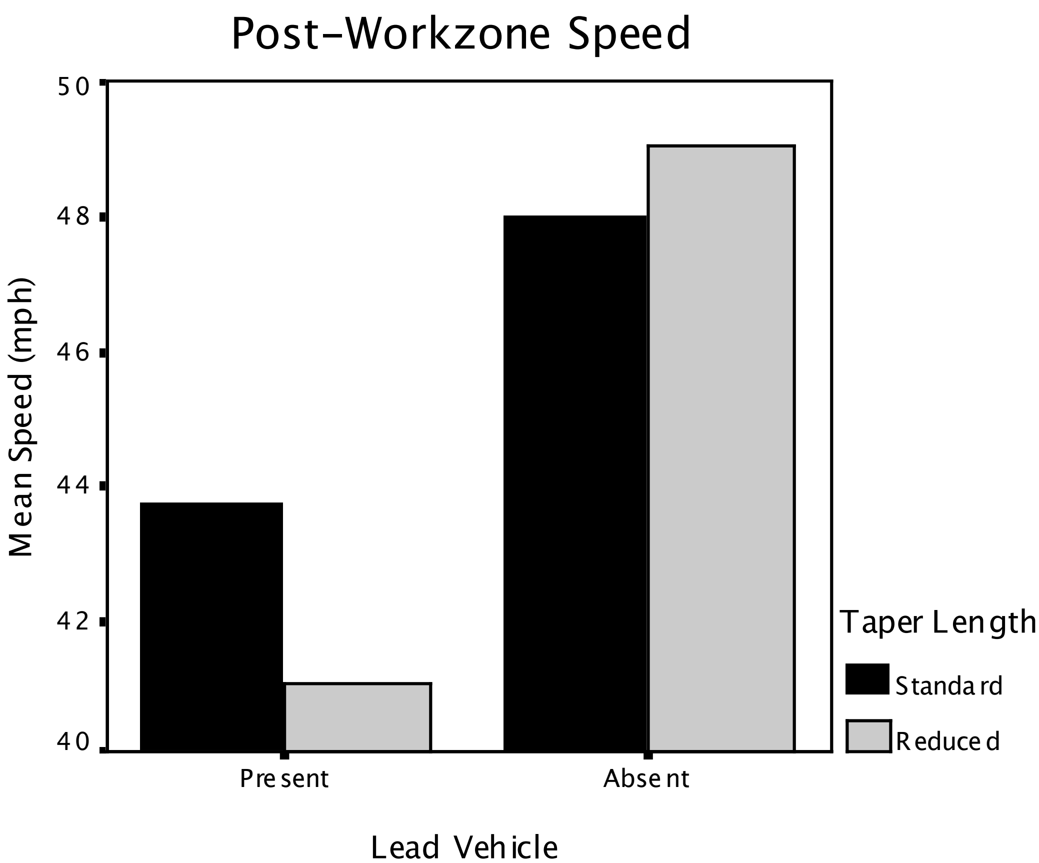

Figure 19. Vehicle speed at 60 ms following work zone exit.

6.3.6 Cone Area: First Cone

The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the first cone was significant, F (1, 17) = 16.238, p = .001. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 20 shows the mean total area for each level within the Taper Length by Lead Interval interaction. While the comparison between Lead Vehicle Present/Standard Taper and Lead Vehicle Absent/Reduced Taper was not significant, all other factor levels were significantly different from each other. The vehicle-to-cone area was significantly smaller when a lead vehicle was *present* versus *absent* for both the *standard* (M = 9.072, SE = 0.387 versus M = 11.074, SE = 0.152) and *reduced* (M = 4.691, SE = 0.443 versus M = 8.732, SE = 0.160) work zones, respectively. Notably, the largest difference occurred for conditions where the lead vehicle was absent in a standard work zone (M = 11.074, SE = 0.152) and conditions where the lead vehicle was present in the reduced work zone configuration (M = 4.691, SE = 0.443).

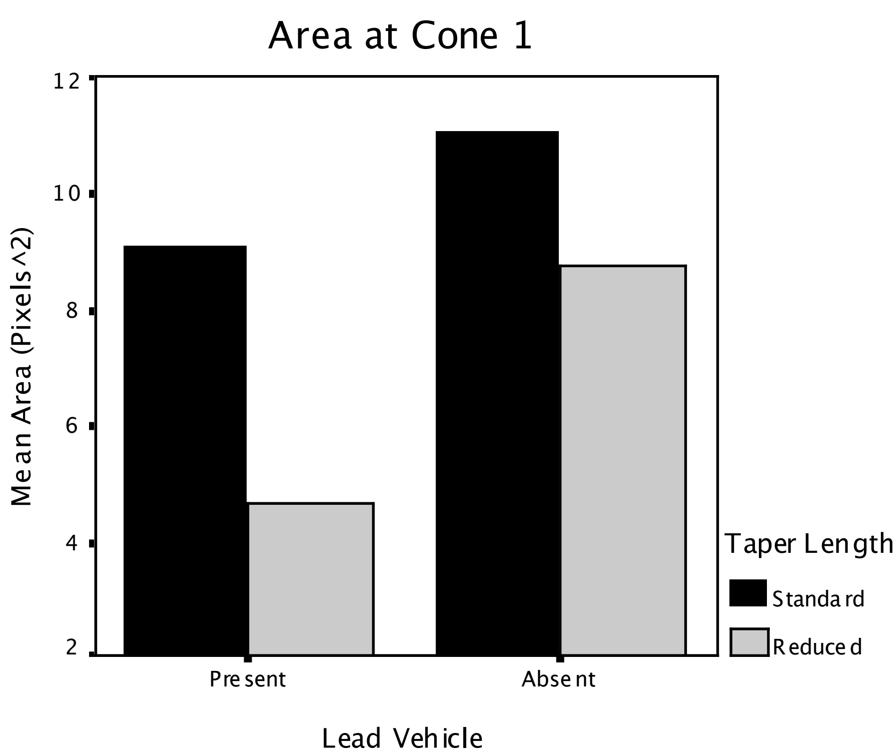

Figure 20. ***Depicts the total area between the driver's vehicle and the second cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.***

The main effects for both Lead Vehicle and Taper Length were also significant, F (1, 19) = 72.890, $p < .001$ and F (1, 19) = 135.435, $p < .001$, respectively. When collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present (*M* = 6.881, *SE* = 0.322) compared to when the lead vehicle was absent (*M* = 9.903, *SE* = 0.141). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (*M* = 6.711, *SE* = 0.251) compared to the standard work zone configuration (*M* = 10.073, *SE* = 0.199).

Table 21. Means and standard errors for vehicle-to-cone area at cone 1.

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	9.072 (0.387)	11.074 (0.152)
	Reduced	4.691 (0.443)	8.732 (0.160)

6.3.7 Cone Area: Second Cone

Total vehicle-to-cone area for the second cone showed a similar pattern to observations at the first cone. The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the second cone was significant, F (1, 17) = 8.619, $p = .009$. Follow-up post hoc analyses using Tukey’s HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 21 shows the mean total area for each level within the Taper Length by Lead Interval interaction. Again, the comparison between Lead Vehicle Present/Standard Taper and Lead Vehicle Absent/Reduced Taper was not significant, however, all other factor levels were significantly different from each other. The vehicle-to-cone area was significantly smaller when a lead vehicle was *present* versus *absent* for both the *standard* (*M* = 8.710, *SE* = 0.397 versus *M* = 10.718, *SE* = 0.141) and *reduced* (*M* = 4.281, *SE* = 0.412 versus *M* = 7.978, *SE* = 0.178) work zones, respectively.

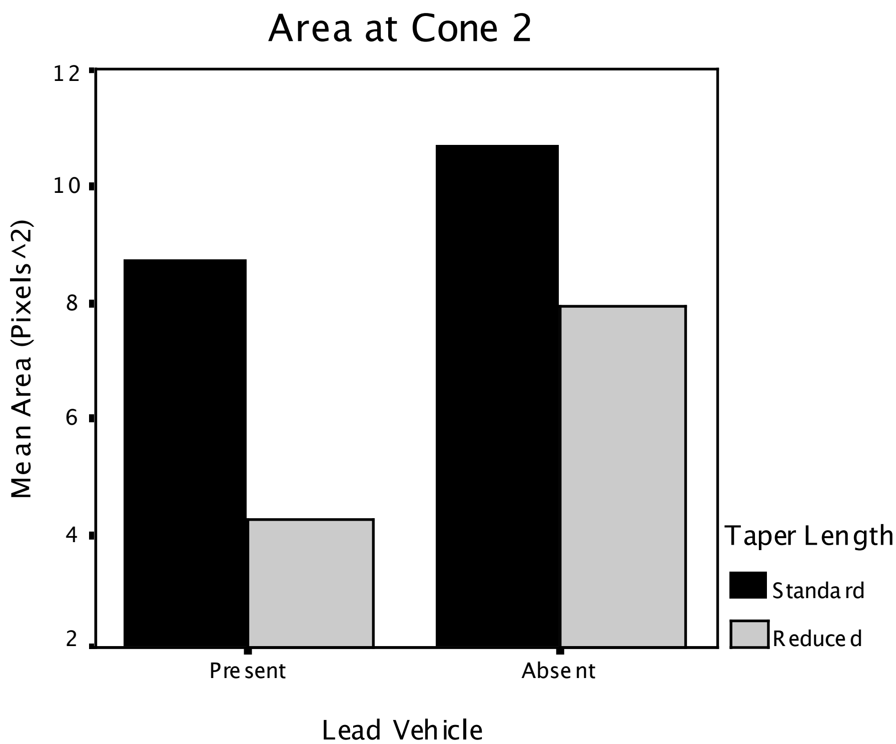

Figure 21. ***Depicts the total area between the driver's vehicle and the second cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.***

The main effects for both Lead Vehicle and Taper Length were also significant for the vehicle-to-cone area at cone 2, F (1, 19) = 95.073, $p < .001$ and F (1, 19) = 162.259, $p < .001$, respectively. Similarly to Cone 1, when collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present (*M* = 6.496, *SE* = 0.299) compared to when the lead vehicle was absent (*M* = 9.348, *SE* = 0.139). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (*M* = 6.129, *SE* = 0.224) compared to the standard work zone configuration (*M* = 9.714, *SE* = 0.198).

Table 22. Means and standard errors vehicle-to-cone area at cone 2.

Taper Length		Lead Vehicle: Present	Lead Vehicle: Absent
	Standard	8.710 (0.397)	10.718 (0.141)
	Reduced	4.281 (0.412)	7.978 (0.178)

6.3.8 Cone Area: Third Cone

The omnibus interaction for Lead Vehicle x Taper Length for Total Area at the third cone was also significant, *F* (1, 17) = 9.692, *p* = .006. Figure 22 contains the data observed for each condition. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Again, the comparison between Lead Vehicle Present/Standard Taper and Lead Vehicle Absent/Reduced Taper was not significant, however, all other factor levels were significantly different from each other. The vehicle-to-cone area was significantly smaller when a lead vehicle was *present* versus *absent* for both the *standard* (*M* = 8.512, *SE* = 0.381 versus *M* = 10.233, *SE* = 0.145) and *reduced* (*M* = 4.063, *SE* = 0.396 versus *M* = 7.355, *SE* = 0.156) work zones, respectively.

Similarly to cones 1, 2, and 3 when collapsed across Taper Length, participants had a much smaller vehicle-to-cone area when the lead vehicle was present (*M* = 6.288, *SE* = 0.301) compared to when the lead vehicle was absent (*M* = 8.794, *SE* = 0.132). When collapsed across Lead Vehicle, a much smaller vehicle-to-cone clearance was observed for the reduced taper work zone (M = 5.709, SE = 0.214) compared to the standard work zone configuration (M = 9.373, SE = 0.205).

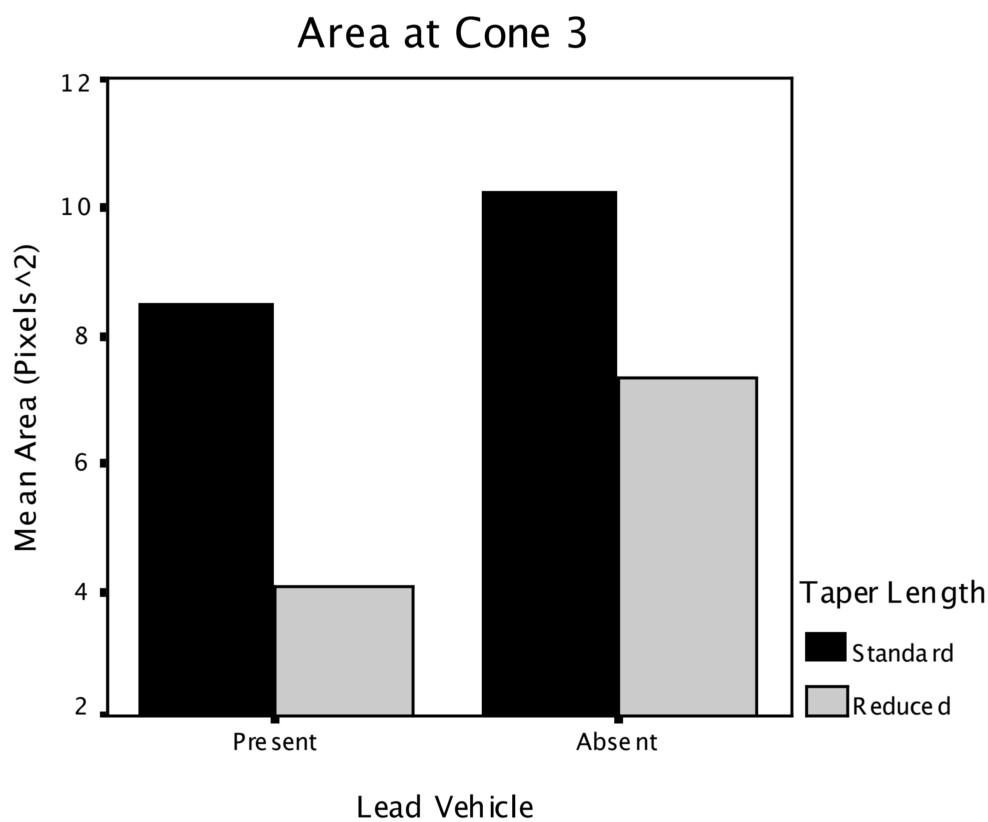

Figure 22. ***Depicts the total area between the driver's vehicle and the third cone in the work zone taper. Larger values reflect greater clearance between the driver and the work zone.***

Table 23. ***Means and standard errors vehicle-to-cone area at cone 3.***

		Lead Vehicle	
		Present	**Absent**
Taper Length	**Standard**	8.512 (0.381)	10.233 (0.145)
	Reduced	4.063 (0.396)	7.355 (0.156)

6.3.9 Vehicle Speed

The omnibus interaction for Lead Vehicle x Taper Length for work zone speed was significant, F (1, 17) = 6.072, p = .025. Follow-up post hoc analyses using Tukey's HSD procedure was subsequently considered to further isolate those conditions contributing to the interaction. Figure 11 shows the mean total area for each level within the Taper Length by Lead Interval interaction.

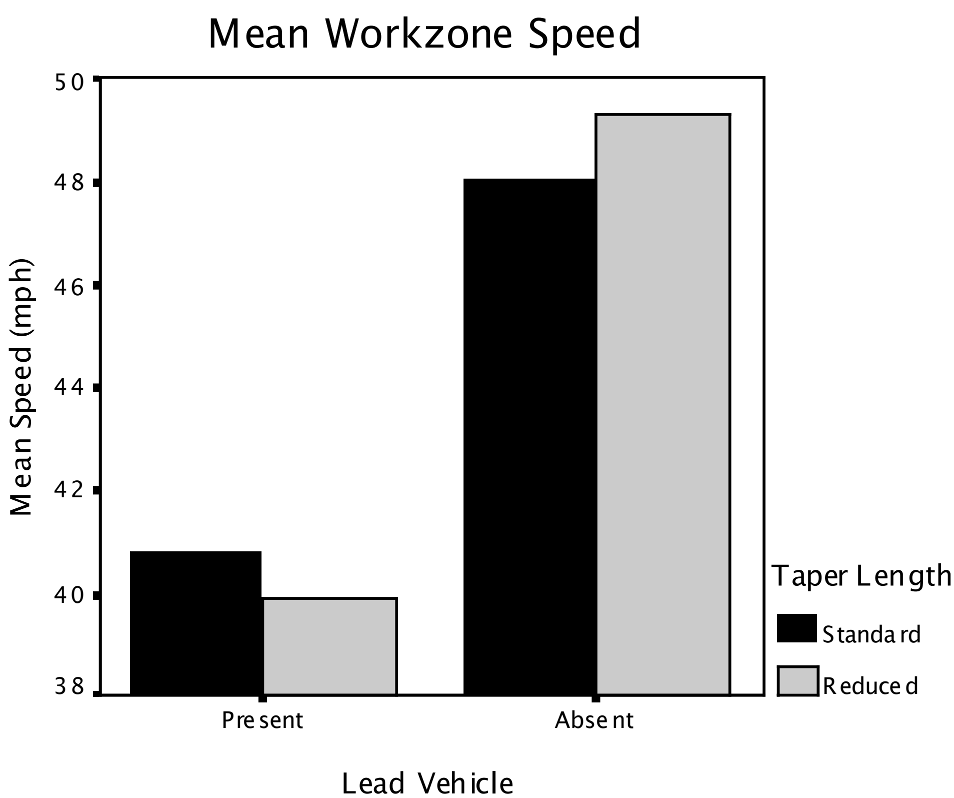

Figure 23. Vehicle speed inside work zone.

The main effect for Lead Vehicle was also significant, F (1, 19) = 77.879, $p < .001$. That is, when collapsed across Taper Length participants drove significantly faster when the lead vehicle was absent (M = 48.731, SE = 0.647) compared to conditions where the lead vehicle was present (M = 40.391, SE = 0.595). The main effect for Taper Length was not significant, F (1, 19) = 0.046, $p > .05$.

Table 24. Means and standard errors for vehicle speed inside the work zone.

Taper Length	Lead Vehicle: Present	Lead Vehicle: Absent
Standard	40.859 (0.609)	48.081 (0.752)
Reduced	39.922 (0.957)	49.382 (0.784)

7.0 Discussion

The purpose of this investigation was to determine whether reducing the standard taper length noted in Design Standard #613, Duration Note 2 increases accident likelihood. In addition to work zone taper length, the presence of a visually occluding lead vehicle was considered as a key-moderating factor that might influence work zone safety. Taken together, Taper Length and Lead Vehicle formed the two primary factors under consideration for Experiment 1. A second experiment replicated the experimental conditions of the first Experiment, with the major difference that additional vehicles were included in the simulation.

Generally speaking, results suggest that the proposed reduced taper work zone configuration increases accident likelihood, and that this likelihood is augmented when a lead vehicle occludes work zone entry. Because object collision frequency has limited explanatory power, this study used the vehicle-to-cone area to improve data collection fidelity to capture "close-calls" or heightened risk that may be indicative of poor driver performance. Vehicle-to-cone-area represents the distance from the participant's vehicle to the channelizing cones demarcating work zone entry. In both Experiment 1 and Experiment 2, the participant's vehicle-to-cone distance was significantly smaller when measured for conditions where the lead vehicle was present as compared to when absent for both the standard and reduced tapered work zones, respectively. When evaluated interactively, those conditions having the reduced taper work zone in combination with the lead vehicle present produced the smallest vehicle-to-cone distances. This, taken together with the collision data, where it was observed that significantly more collisions occurred when the lead vehicle was present for the reduced taper work zone as compared to conditions where the lead vehicle was absent regardless of work zone taper, strongly suggest that reduction of work zone taper paired with work zone occlusion increases accident risk.

In evaluating this finding for its relevance to work zone design configuration, one must consider a few important factors. First, given the area of the work zone remains constant, an increase in channelizing device slope is a natural consequence of a shortened work zone taper. Thus, the driver has less time to respond to the appearance of the work zone, particularly when little or no warning occurs to the physical work zone itself (e.g., because of a occluding lead vehicle). One can envision how this risk might be increased provided low-visibility due to fog, rain, or other environmental conditions for example. An increase in work zone taper slope also may increase the likelihood of vehicle spinouts because the distance one has to avoid a work zone breach is reduced, therefore producing the need for quicker and more pronounced driver corrective action.

While Experiment 1 and Experiment 2 produced had similar designs, Experiment 2 also evaluated driver behavior when evasive action to a parallel lane was not always a safe maneuver. In general, this manipulation produced a greater number of crashes mostly occurring with the principal work zone channelizing devices or from being rear-ended because of greater peak braking observed when the lead vehicle was present compared to conditions where the lead vehicle was absent.

Excluding the observations from this study, the topic of work zone design and taper configuration in urban terrain is an area that is poorly understood. Several key moderating factors need to be seriously considered to fully appreciate contemporary driver behavior in work zones. While such factors as day/night driving, weather, work zone length, traffic density, personality, and driver experience each need to be understood in the context of work zone operations, present-day competitors for driver attention should also be considered in the context of work zone design. New devices such as cell phones, navigational devices, and the like, may alter how urban work zones are planned and configured. We strongly suggest that future work in this area continue.

While this project has several unique strengths a number of limitations should also be acknowledged. The scope of this project did not present the opportunity to conduct field observations to corroborate evidence obtained from our driving simulation experimentation. While this approach is not always practical because of the need for experimental control of traffic conditions, cost, or safety, information obtained from field studies would add to the efficacy for the conclusions presented in this study. Another limitation of this investigation is the comprehensiveness for the myriad of factors that could influence driver performance for the imposed conditions. Such factors include simulating changes in weather, visibility, traffic density, different taper lengths, speed, warning and channelizing device variants, and the like.

Overall, the present results of this study yield information, which can assist in greater understanding of driver human factors in and around work zones. Vehicle distance from the initial channelizing devices demonstrates the importance of both enhancing work zone visibility and early warnings. By attempting to mitigate the impact of visual occlusion and eliminating uneven speed patterns, the safety and efficiency of roadway work zones may be greatly increased. Any increase in these two factors immediately result in benefits to society in terms of human life and capital.

8.0 References

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Appendix A

Conditions for Duration Note usage:

- Work zone in operation for less that or equal to 60 min.
- Operational speed limit of 45mph or lower.
- No sight obstructions for a distance equal to the buffer space and taper length combined. (280' for a 25 mph road, 380' for a 30 mph road, 495 for a 35 mph road, 625' for a 40 mph road, and 900' for a 45 mph road).
- Vehicles in the work zone have high-intensity, rotating, flashing, or strobe lights.
- The volume/complexity of the roadway is considered.

If the Conditions are Satisfied:

As the planned work is minor and the work zone satisfies the criteria stated in the Duration Note (Index 613), then the only physical Traffic Control Devices (TCDs) used to guide traffic from the closed lane to the available lane are the actual channelizing devices used for the lane taper.

The implications of this 'reduced' work zone design are as follows:

- No advanced warning TCDs are used (usually four warning signs would be utilized for this WZ design) to inform the driver of the impending required lane change.
- No advanced warning arrow panel used at the start of the lane taper to visually

reinforce the need to change lanes.

- No buffer space in the work zone (this is usually immediately after the lane taper and prior to the work area).
- No temporary white edge line (reflective pavement markings) that usually track the path of the WZ boundaries (i.e., along the lane taper, down the side of the work area, and along the post-work area).

The Appearance of the Work zone:

A 4-lane highway. In one direction of travel, one lane is closed for work in the right-hand lane. The first work zone-related physical items encountered by a driver in the right hand lane are the channelizing devices used to form the lane taper. The length of the taper depends on the cited speed limit of the road, and the distance of lateral transition. Given that the lateral transition to be used will be 12 feet, then the taper lengths options are as follows:

- Speed of 25 mph, then taper length of 125 feet.
- Speed of 30 mph, then taper length of 180 feet.
- Speed of 35 mph, then taper length of 245 feet.
- Speed of 40 mph, then taper length of 320 feet.
- Speed of 45 mph, then taper length of 540 feet.
-

At the point at which the taper stops, the work area begins. The channelizing devices follow on from the taper, down the outer perimeter (next to the open lane) of the work area. An additional TCD is located at the front of the work area, in the form of a Type 1, 2 or 3 barricade or a vertical panel or drum with a flashing light.

The channelizing devices that divide the open from the closed lane stop at the point at which the work area finishes. Whereas a white line will taper the end of the closed lane back into an open lane on longer duration work zones, for the present (shorter duration) design, the work zone ends at the end of the actual work area. Once the driver has passed this section, he or she is able to move back into the right hand lane.

Channelizing Devices

Index 600 gives details concerning the channelizing devices, and Table 1 in Index 613 provides maximum distances between each device, which is a function of the type of device used, the speed limit for that specific section of road, and the specific section of the work zone (be it the lane taper section, or the ‘tangent’ area parallel to the actual work area).

When the cited speed limit is 25 mph, the devices should be within 25 feet of each other in the taper section, and 50 feet in the tangent section, irrespective of the type of device used. However, the different types of device have differential regulations governing their spacing when the cited speed limit is 30-45 mph. Here, the devices should be within 25 feet of each other in the taper section and 50 feet in the tangent section if cones or tubular markers are used. If type I/II barricades, vertical panels or drums are used however, the devices should be within 30 feet of each other in the taper section and 50 feet in the tangent section.