A Literature Review of Inattentional and Change Blindness in Transportation

U.S. Department
of Transportation
Office of the
Secretary of
Transportation

DTOS5908X99094
DOT-VNTSC-OST-10-01

Final Report
December 2009

Notice

Notice

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*LEAVE BLANK*)	2. REPORT DATE December 2009	3. REPORT TYPE AND DATES COVERED Final Report August 2008 – December 2009

4. TITLE AND SUBTITLE A Literature Review of Inattentional and Change Blindness in Transportation	5. FUNDING NUMBERS OP3CA1 FG278
6. AUTHOR(S) Daniel J. Hannon	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142	8. PERFORMING ORGANIZATION DOT-VNTSC-OST-10-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1200 New Jersey Ave, SE Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DTOS5908X99094
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, VA 22161	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Inattentional blindness refers to situations in which a person is unaware of a change that is occurring because attention is not currently focused on what is changing. Change blindness occurs when a change takes place during an eye movement or blink that is not noticed. These phenomena pose a serious hazard in transportation, particularly when unexpected changes occur, such as a child running out into the road from between parked cars, or if an air traffic controller fails to detect an aircraft deviating from the assigned clearance. Failure to detect unexpected changes can have devastating consequences. The literature in these fields over the last 10 years is reviewed with a particular focus on transportation issues. Laboratory and field-based studies are viewed, including research on theoretical issues, underlying mechanisms, biological bases, as well as mitigation approaches. The emerging view is that these phenomena are in part driven by prior experience and expectations for what is likely to happen next. Research on mitigation of inattentional and change blindness show promise for developing systems that help human operators to overcome the dangers posed. Recommendations are provided for further research in this area.

14. SUBJECT TERMS Inattentional blindness, change blindness, transportation, operator performance	15. NUMBER OF PAGES 60 16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20 LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

Acknowledgments:

The author wishes to express his appreciation to Mrs. Raquel Calderon from the U.S. Department of Transportation, Volpe Center, for her assistance in the research for this manuscript. Thanks are also extended to Marilyn Gross and Susan Dresley from the Volpe Technical Reference Center for their assistance in identifying and compiling the articles for this report. Valuable editorial comments were received from Dr. Stephen Popkin and Mr. Arnold Konheim.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC / METRIC TO ENGLISH

LENGTH (APPROXIMATE)

English to Metric		Metric to English	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)

AREA (APPROXIMATE)

English to Metric		Metric to English	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		

MASS - WEIGHT (APPROXIMATE)

English to Metric		Metric to English	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg)
			= 1.1 short tons

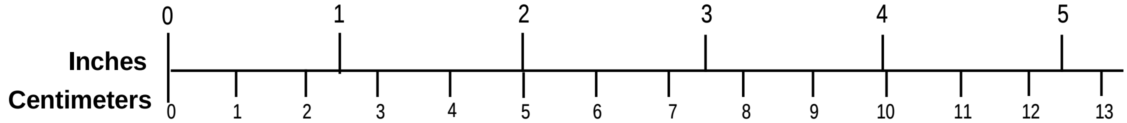
VOLUME (APPROXIMATE)

English to Metric		Metric to English	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

English to Metric		Metric to English	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

□F	-40□	-22□	-4□	14□	32□	50□	68□	86□	104□	122□	140□	158□	176□	194□	212□
□C	-40□	-30□	-20□	-10□	0□	10□	20□	30□	40□	50□	60□	70□	80□	90□	100□

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Table of Contents:

Executive Summary

Inattentional and change blindness are terms that describe when a person is unaware of significant changes in the environment, despite the salience of what has changed. More specifically, inattentional blindness refers to situations in which a person is unaware of a change that is occurring because attention is not currently focused on what is changing. Change blindness, on the other hand, occurs when a change takes place during an eye movement or blink. These phenomena pose a serious hazard in transportation, particularly when unexpected changes occur, such as a child running out into the road from between parked cars, or if an air traffic controller fails to detect an aircraft deviating from the assigned clearance. Failure to detect unexpected changes can have devastating consequences.

This report provide a review of the literature on inattentional and change blindness, with the particular goal of highlighting potential mitigation strategies and areas for further research and development. The information is organized into several sections, including: a demonstration of the basic phenomena, a review of research methods, a consideration of different theoretical and empirical studies, a look at biological bases for inattentional and change blindness, and a review of field studies on driving. The report concludes with a section regarding the research on the mitigation of inattentional and change blindness and a summary and recommendations section.

Inattentional and change blindness have been implicated in many transportation errors. An analysis of a runway incursion in 2009 revealed that the driver of a vehicle was unaware of the cues in the environment that would have told him that he was not in a safe place, as well as the absence of the cues that should have been available had he been following the correct procedure for that day. Recent accidents on the public transportation system in Boston have been attributed to the use of cell phones by the operators. It is also the case that vehicle operators of any kind, as well as the people who dispatch and control traffic are all susceptible to inattentional and change blindness.

Simons and Chabris (1999) conducted a widely cited study on inattentional and change blindness in which a video was created of people playing a type of basketball pass game. Unbeknownst to the viewer, while they were instructed to watch and count the number of completed bases by one of the teams, a person in a gorilla suit walked into the middle of the game, thumped his chest, and walked out. A large number of viewers were unaware of the presence of the gorilla. In a related study on change blindness, Simons and Levin (1998) found that people often were not aware of the appearance of the actual person they were talking with when the other person was a complete stranger. Together, these studies demonstrate the phenomenon of inattentional and change blindness by showing that the demands of a particular task can determine to what information people typically attend.

A variety of experimental techniques have been developed for evaluating inattentional and change blindness. Laboratory exercises, such as rapidly alternating between two images, or a mud splash technique that embeds changes in the stimulus image with random changes that resemble mud spatter, allow for basic research. Studies conducted in simulators and out in the field allow for the transfer of information from the research lab.

One of the prominent theories used to explain inattentional and change blindness is representation theory, which posits that internal mechanisms in the brain represent views of the world before and after a change has occurred. The inability to detect a change, then, becomes a property of these representations and the mechanisms that generate them. Additional research has shown that inattentional and change blindness are related to where in the visual field a change has taken place, the nature of the signal of the changing object (easy to see or not), the instructional set, and the time required for changes to occur. A relatively clearly defined set of studies found that inattentional and change blindness increases when the task demands increase, and when the expectations of what will change do not match what actually does change.

Inattentional and change blindness have been demonstrated in auditory and tactile processing as well as in vision. Change detection and a lack of change detection have also been demonstrated cross modally, with information presented visually, for example, interfering with the perception of a tactile pattern. Studies of brain mechanisms have shown that some parts of the brain appear to be responding to stimuli even when the person is not able to detect them. Other parts of the brain, however, appear to be turned on and off depending on the instructions a person is following. Together these results suggest that the brain is able to dynamically generate filters for what will be detected and what will not.

A review of the literature on development revealed that by the age of 12, most children have developed change detection skills that are equivalent to an adult. However, this ability declines with advancing age. Older people tend to have less change detection skill, greater uncertainty in decision-making, and slower overall response times.

Field studies looking at inattentional and change blindness with respect to driving-related tasks, both in the laboratory and in the field, show that these phenomena have a big impact on driving performance. Making decisions, such as deciding to make a left turn at an intersection is hampered during change detection. The use of cell phones while driving increases the chances that significant changes in the environment will be missed. The problems are significantly worse for older drivers. The demands of the driving task and the inherent slowing in processing that takes place in older drivers increases the potential for lack of change detection.

Several authors have reported results from studies attempting to mitigate inattentional and change blindness. In some cases, providing additional capability through the use of speech interfaces was found to decrease performance. Others have attempted to develop intelligent alerting mechanisms to help operators become more aware of their surroundings. Alerting mechanisms have been found to be most helpful for novice users. Research on display-related tasks has found a reduction in change detection errors when a change history is provided on the screen. It has also been demonstrated that having additional team members improves overall change detection, particularly if the team members are encouraged to communicate with one another. Learning what changes to look for and practicing the change detection has yielded mixed results. However, instructing people to pay attention to potential changes in unexpected places was shown to improve overall performance.

The results of the literature review have led to a list of suggestions for further research and development in this area. These include:

1. Research is needed into the identification of the types of changes that may occur in different types of transportation applications. This information can then be used to develop improved training programs.

2. Research on optimal team performance for the mitigation of inattentional and change blindness will lead to more effective teams. Additionally, research on the use of artificial intelligence agents as virtual team members may provide the benefits of team mitigation on inattentional and change blindness to individuals.

3. The integration of the various approaches to display mitigation of inattentional and change blindness may lead to the development of guidelines for their implementation, including:
    a. clutter reduction for the highlighting of salient changes;
    b. displaying a change history to help orient the viewer to significant developments in the environment;
    c. defining minimum processing times for change detection to allow the brain sufficient time to complete the task;
    d. the use of spatially relevant tactile and auditory feedback to help orient a person to significant changes in the environment; and
    e. the use of sounds and animations to help highlight both static and dynamic information.

4. Greater research on eye movement patterns may yield a strategy for detecting the potential for inattentional and change blindness to occur.

5. Research is needed in order to understand what makes tasks compatible for minimizing inattentional and change blindness.

6. Research has shown that most people do not believe they are susceptible to the problem inattentional and change blindness. Mass-media demonstrations and education may be effective at getting people to realize they need to develop good change detection skills.

7. Practice with change detection, particularly with software tools or simulations, has been shown to promote better change awareness. Research and development efforts are needed to determine what types of practice and what types of devices provide the best mitigation and positive transfer of training to specific transportation applications.

8. Change detection education could be included in all aspects of transportation, capitalizing on many of the research and development efforts listed above. Additionally, the design of instructions for operators should include information on change detection. The development of checklists to assess compliance may be helpful for this purpose as well.

9. Inattentional and change blindness mitigation research is needed at all levels, from simple laboratory studies, to simulator projects, to field studies with actual vehicles. Laboratory studies, including the use of simulators, will allow for safe evaluation environments. Field research, however, allows for the transfer of the research from laboratory settings to actual operations. A research program in inattentional and change blindness needs to consider the value of all levels of research.

Introduction

Inattentional and change blindness are terms used to describe situations in which a person is unaware of a significant modification in his or her environment, despite the salience of the change. While these are naturally occurring phenomena, they pose a serious safety concern for people in high hazard potential situations in which the safety of individuals depends on the ability of another person to detect changes in the environment. For example, the safety of pedestrians in crosswalks on a busy street is dependent on the ability of drivers to become aware of the presence of a person in the crosswalk and slow down. Understanding the causes of inattentional and change blindness, and determining strategies to mitigate their effects, therefore, will ultimately lead to improvements in safety.

The reason for the two terms, inattentional blindness and change blindness, stems from the finding that these situations appear to happen under different types of circumstances. Noe (2007) suggests that there are two basic types. In one type, a person may be paying attention to the completion of a task and not be aware that a change has taken place right in front of them because his or her attention is not focused on the change. This is a case of inattentional blindness. In the second type, the change takes place during a moment when the changing elements in the world are masked, such as during an eye blink, or the changing elements are modified so slowly that a person is unaware of the change. Not detecting changes in the environment under these situations would be labeled change blindness. Although these terms are used interchangeably at times, their difference points out that the problem of not being aware of changes in the environment has multiple sources and will likely be amenable to multiple solutions.

The goal of the present document is to provide a review of the research literature on inattentional and change blindness in the context of the impact on transportation safety. Current research in both topics will be reviewed with respect to theories that account for these phenomena, the range of parameters that have been studied, and biological perspectives. Applied research studies also will be reviewed to gain a better understanding of how inattentional and change blindness affect human performance in a range of real-world transportation-related settings. Ultimately, studies that have attempted to mitigate the effects of these phenomena will be reviewed to identify which techniques show promise, with further development, for reducing inattentional and change blindness throughout the transportation industry.

The document is organized into the following sections. First, background is provided on the phenomena of inattentional and change blindness. This will include some case examples, as well as a description of some research in the area that illustrates the concepts. It will also include a brief description of some related topics and a review of some of the basic approaches to conducting research in these areas. The next section considers some theoretical issues underlying these phenomena. This is followed by a review of specific parameters that have been studied and their implications for understanding the underlying mechanisms. Following a review of different biological issues pertaining to inattentional and change blindness, information from applied research studies in transportation is then presented. A section on studies addressing mitigation strategies is presented next, followed by a summary section with concluding thoughts and recommendations.

2. Background on Inattentional and Change Blindness

Although these concepts have been studied for many years, interest in these topics was increased tremendously by the thorough treatments of the phenomena of inattentional and change blindness provided by Mack and Rock (1998). Since then, several hundred research articles have been published in an attempt to account for a wide range of theoretical concerns and experimental conditions. Before delving into the research, however, it is worth considering these phenomena in the context of real-world events.

2.1 Case Studies

In the domain of aviation, runway safety is a critical aspect of overall system safety. Protecting aircraft moving at high rates of speed from colliding with one another and from colliding with other vehicles moving on the surface is considered safety critical at all airports. The Federal Aviation Administration (FAA) imposes rules for surface operation at airports that minimize the chance that an aircraft or vehicle will inadvertently taxi onto an active runway and interfere with a high-speed operation, such as another airplane during landing or takeoff. When this type of error does occur, it is classified as a runway incursion.

Studies of runway incursions have revealed a surprising result in that the pilot or vehicle operator committing the error frequently reports having acknowledged instructions from the air traffic control tower, but then does not follow them (Cardosi, 2009, personal communication). In many cases, the pilot or driver has continued to drive completely across an active runway, with a landing or departing airplane moving toward them down the runway at a high rate of speed, and without ever noticing the impending collision. In the aftermath, an investigator is likely to ask how the pilot or driver failed to see the large aircraft moving toward them, and the pilot or driver most of the time is at loss to explain what happened.

In a relatively recent incursion that occurred at a large airport, a construction vehicle on its way to a construction site on the airport surface was seen crossing in front of a departing B737, narrowly avoiding a collision that would likely have killed hundreds of people. Debriefing the driver indicated that he had been unaware of several salient cues that would have informed him that he was not where he should have been, including a change in the signs and markings in front of him, and the absence of other highly salient indicators that would typically have marked a safe route for him to follow. However, it also was clear that for the previous few weeks, the driver had safely followed this same route, appropriately and without incident. This account of the runway incursion, an example of inattentional blindness, points out how repetitive behavior and focused attention (i.e., the driver was on his way to work), can focus one's attention to the point that other aspects of the environment are not noticed, even potentially at one's own peril.

Real world examples of change blindness are also evident in transportation accidents. A recent accident on the mass transit system in Boston, MA, has been attributed to inappropriate use of a cell phone by the train operator (Boston Globe, 2009). One of the primary jobs of any vehicle operator is to monitor the path ahead of the vehicle to avoid collisions and other hazards. In this situation, the operator was distracted from this task by attending to the cell phone. Taking his eyes off of the track in front of him, even though it was only for a moment, allowed for a change in the status of the situation in front of him that he did not detect. The collision with the stationary train on the track ahead of him resulted in several injuries and tremendous physical damage.

These two examples are somewhat dramatic illustrations of the magnitude of inattentional and change blindness in transportation settings. However, there are more subtle situations that also can prove quite dangerous. Psymouli et. al. (2005) point out that inspecting aircraft composite materials for defects is a challenging visual task. It isn't always possible to know what visual features indicate a potential defect. This condition is compounded by environmental conditions such as dirt and debris on the surface. Inattentional blindness during inspection, resulting from looking for specific types of visual cues, for example, could result in missing other potential problems, and ultimately result in a material failure in the future.

Inattentional and change blindness are potential hazards in any situation in which unexpected changes can occur that require an immediate response. For example, failure by an air traffic controller to detect an aircraft on a radar screen that has changed course without clearance, or failure to detect the movement of unauthorized marine vessels by a Coast Guard watch stander, are also possible results of inattentional and change blindness that could lead to serious outcomes. Although the majority of the research that has been conducted on these topics has focused on laboratory studies or automobile driving applications, it is important to keep in mind the broader effects of these phenomena.

2.2 Illustrative Research Examples and Related Topics

Simons and Chabris's (1999) now classic study on inattentional blindness is one of the most widely used examples to demonstrate the phenomenon (see http://www.youtube.com/watch?v=hwCzasHBXNc for a television commercial that uses the same demonstration method). In their work, a video was created in which two teams were seen passing basketballs between them. One team was dressed in white shirts and the other in black. Each team had a ball and all six players weaved among each other as they passed the ball to their fellow teammates. In this situation, an observer was given an instruction such as to count the number of completed passes made by one of the teams. When the video was complete, most observers were able to report the number of completed passes. However, what they are often were not aware of was that during the middle of the video, another actor dressed in a gorilla suit had walked into the middle of the scene, faced the camera, thumped his chest, and then walked out of the field of view. When the video was reviewed with this fact revealed, most observers could not believe they missed something as salient as a person in a gorilla suit.

Upon further reflection, it is possible to dissect this situation a little to get a better understanding of what was going on. In the video, the team members continue to move around the gorilla as if nothing were different. Therefore, nothing about what the observer is focusing on, namely the counting of the passes, changes. If an observer is able to ignore aspects of the video that are irrelevant, such as the other team, then it may be the case that any other person, or figure resembling a person, would be ignored as well. The fact that the team being watched does not change their basic behavior reinforces the tendency to ignore other aspects of the scene.

Simons and Levin (1998) conducted a study of change blindness that has also become relatively well known. In this work, an actor, posing as a person who is lost, stops passersby to ask for directions. The actor has a map and provides it to the person who stops to help and they engage in a brief conversation about how to get to some nearby location. While this interaction takes place, two more actors carrying a large, opaque door, pass between the two having the conversation. The door is held up high blocking the view of each other for the two in the conversation. During this event, the original actor takes hold of the door and becomes one of the door carriers. One of the actors carrying the door then stands in the place of the original actor and continues the conversation with the passerby once the door has been carried off. Videotapes of these events produced by the authors reveal remarkably that several of the passersby continue in the conversation and provide the new actor with directions without any indication that the person they were talking to has actually changed.

One way to interpret these results is that the passersby who are not able to detect the change had not completely encoded in their minds the visual identity of the person with whom they were talking. The presence of a person for the passers by to talk to, after the door was removed, was sufficient for them to continue their task of providing directions. Essentially, what they were doing was providing directions to a person, the specific person had not really mattered up to that point. It is worth noting as well that not all passersby were fooled by this event, suggesting that inattentional and change blindness are not all-or-nothing events. Different people, in different circumstances, under different conditions may or may not experience these phenomena. Therefore, it is important to understand that inattentional and change blindness must be considered with respect to the probability of their occurrence and not as events that are certain to happen.

Research in other areas supports the finding that people can be unaware of large changes in the visual world. Henderson and Smith (2008) note that most moviegoers are insensitive to changes in the camera perspective in scenes. In fact, cinematographers and movie editors are well aware of how to combine changes in camera angle with changes in action in the scene so that the viewer is unaware that their point of view has changed. For example, during a conversation between two people, the camera may change to face each person as they speak, giving the viewer the perspective of being the listener to both sides of the dialog. At other times, a large arm or hand gesture by an actor in a given direction may be accompanied by a change to view the scene in the newly gestured direction. These authors suggest that what makes this work for the viewer is that the changes in camera perspective follow the narrative of the story being told. If the viewer is following the storyline, then the changes in perspective are congruent with the narrative and become undetected as the story unfolds.

Mantyla and Sundstrom (2004) found that when the basic activity in a scene was changed following a cut in the movie, viewers often did not notice the change in the activity, and accepted the newly presented activity as what the movie was about. Levin and Varakin (2004) found that brief disruptions of video images on the order of 200 – 600 ms were not noticed if the viewers were instructed to pay close attention to the activity in the scene. Hollingworth and Henderson (2004) found inattentional blindness to changes in orientation when the global point of view of a scene was changed in 1-degree increments on each subsequent presentation. Angelone et. al. (2003) found that despite whether an observer recognized a deliberate change in a motion picture, they were still able to recognize the changing object, indicating that both the pre-change and post-change information had some impact on the viewer. Together, these studies suggest that the compelling story that unfolds in a video, whether through dramatic effect or simply through the continuity of the images, is sufficient to induce the viewer to be insensitive to rather large changes in what is presented. Martinez-Conde and Macknik (2008) liken the effectiveness of magic tricks to a similar phenomenon in which the viewer is induced to believe something is true and then becomes insensitive to other changes that are occurring in front of his or her eyes.

Before turning to a review of the basic techniques for studying inattentional and change blindness, some additional phenomena are worth mentioning. Johansson et. al. (2006) presents results on a concept known as choice blindness. In this situation, a person is presented with multiple-choice options that are then accompanied by matched outcomes. In specific change trials, the outcome is switched from what the research participant was expecting. Nevertheless, the participant continues on with the outcome as if it were what they had intended. Analysis of subjective introspections about the changed outcomes reveals that the participant is unaware that the outcome has changed. Like the study by Simon and Levin (1998) above, it may be the case that the particular outcome had not been associated with the specific inputs, so that an outcome was all that was really expected, and not a specific outcome.

The review of the classic studies by Simon and Chabris (1999) and Simon and Levin (1998), and the related research, particularly with respect to motion pictures, illustrate on the one hand the extreme changes that can be overlooked by observers, and the ubiquity of the phenomena on the other. To some degree, the appreciation of movies, television, and related media would not be possible if it were not for the occurrence of inattentional and change blindness as naturally occurring human experiences.

Although this report is primarily about inattention, the role of attention should also be discussed. A simple definition of attention is the ability to utilize mental resources to accomplish different tasks. Researchers have looked at attention in various ways, with two notable categories being selective attention and divided attention. As the terms imply, selective attention refers to the ability to focus on one input to the exclusion of others. Divided attention refers to the ability to distribute mental resources across multiple tasks simultaneously. In contrast to these phenomena, inattention and therefore inattentional blindness refer to situations in which changes in the environment are not detected despite the fact that mental resources are being used by a person to pay attention to the world around him or herself.

One of the major research findings in the field of attention has been the distinction between parallel and serial processing in visual search tasks. Triesman and Gelade (1980) for example, found that some types of visual targets can be attended to quickly, regardless of the number of distracting objects in the scene, provided that the visual target differed from the distracters on a salient dimension such as color, shape, or orientation. In these situations, the target appears to "pop out" at the observer. In other situations, where the target is defined by the unique conjunction of two different dimensions, such as shape and color, and when the distracters contain a variety of similarly shaped or similarly colored objects, the time required to attend to the target is a function of the number of distracters. These two results were dubbed "parallel" and "serial" search describing what is thought to be the underlying mechanisms. In the first case, parallel processing suggests that all objects in the scene are processed at the same time, or "in-parallel", resulting in the same response time regardless of the number of distracters. In the second case, serial search implies that each item in the scene is processed independently, one-at-a-time. The time required to complete a serial search is directly related to the number of items that must be searched.

Parallel processing is thought be supported by relatively low-level perceptual mechanisms that process the visual world somewhat automatically. Serial search requires more effort at higher processing levels in the brain. Failures of low-level mechanisms to detect changes in the world, or failures in the serial search process could also result in inattentional and change blindness.

Another phenomenon that may be related to inattention is complacency. After repeated exposure to the same circumstances without a change in the outcome, a person often becomes complacent. In these situations response time is increased, and errors in detection can occur. Similarly, chronic exposure to the same stimulus may result in habituation, in which case the stimulus no longer elicits a response from the person. Both complacency and habituation share similar properties with inattentional and change blindness in that a significant event in the environment may take place but still go unnoticed. In all of these cases, expectations about what is happening around a person lead to predictions about what will happen next. The major distinction, however, is that complacency and habituation come about as a result of prolonged exposure. Inattentional and change blindness can be demonstrated in single events, such as in the video by Simon and Chabris (1999).

One of the potential culprits in many transportation accidents is the increased use of automation. When tasks for operators are simplified, operators can become complacent and reduce the resources they are using to monitor the task at hand. In some situations, however, the spare capacity for the operator that results from automation is filled by secondary tasks, such as communication or record keeping. At some point, when a person's spare capacity has been filled or exceeded by secondary tasks, there is no longer any processing ability left to handle conflicts that emerge with the primary task. Consider, for example, how automatic transmissions have increased the spare capacity for drivers, reducing the need to focus on shifting gears and freeing a hand to use for other tasks. Once that spare capacity is used for talking and the hand is engaged in pushing buttons on a phone, however, there is no longer any spare capacity to be used to respond to a sudden emergency on the road. The amount of spare capacity a person has in a given situation may be inversely related to the potential for inattentional and change blindness.

The preceding discussion has been intended to point out that inattentional and change blindness does not occur in isolation during everyday life. Therefore, as the remaining research results are reviewed, it is important to keep in mind that these phenomena are part of a complex set of human responses.

2.3 Experimental Techniques Used in Inattentional and Change Blindness Research

Research on inattentional and change blindness has been conducted using a variety of techniques. Each technique is designed to isolate different aspects of these phenomena and allow for analysis of specific elements of human information processing. Since it is not possible to provide a thorough catalog of all of the research methods that have been used, discussions of the more common approaches will be presented in an effort to further illustrate what is going on for observers when changes in a scene are not detected.

The work of Simon and Chabris (1999) and Simon and Levin (1998) are examples of single trial studies in which specific situations are set up for a person to experience. Whether viewing videotape or interacting with other people, once the participant has been through the trial the experiment is complete. Typically, in these examples, the subject becomes aware of the plot of the study during a debriefing period and would no longer be susceptible to further trials. In the case of Simon and Levin, people randomly selected on the street became unwitting participants in the research. Levin and Simons (2002) conducted a more controlled study in which a conversation partner was switched while students were in the process of signing up to participate in a research study. In all of these cases, however, only one observation can be collected per participant.

In order to collect multiple data points from the same observer, other techniques have been developed that allow for repeated experimental trials. A flicker task, such as employed by Shore and Klein (2000), presents two (or more) images to the observer in rapid succession. On change trials, the aspects of the second image are modified. The rate of flicker, the time delay between image presentation, the location of the changed item in the image, and the orientation of the images are among some of the parameters that are manipulated using this technique. By inserting a blank between two images, it is possible to mask the visual transient (i.e., the abrupt visual difference that is noticed when something changes) that occurs when a change is made in the second image. With these modifications it is possible to study the time course for detecting change, the impact of various types of image changes (e.g., colors, high and low levels of contrast), the effect of image continuity and meaning, and the difference between centrally fixated and peripheral changes, among others.

O’Regan, Rensink and Clark (1999) developed another technique in which an initial image is switched with a second. The view of the second is accompanied by sparsely positioned, irregular shapes, resembling ‘mud splashes’ on a windshield. On non-change trials the second image is identical to the first and only the mud splashes are new. On change trials, both the second image is different along with the randomly placed mud splashes. In these trials, two different change signals are potentially occurring at the same time, namely the change in the second image (if any) and the random mud splashes. This situation makes it difficult for the viewer to detect a change based only on global sensitivity to scene changes. They must be able to attend to the original image and what has changed in it for change detection to be successful. This technique is considered particularly useful for assessing the influence of higher order mental processes, such as the influence of expectation on change detection.

Slow changes between views have been employed as a means for inducing change blindness (e.g., Simons & Franconcerni, 2000). Natural scenes can be particularly effective for this purpose, with slow change occurring between two plausible instances of the same scene (e.g., a picture of a house with and without a mailbox). The use of natural scenes also lends themselves to studying the influence of meaningful relationships between the positions of various elements in the scene.

A number of tasks resembling real-world activities have also been used for studying inattentional and change blindness. Images and videos are used to display scenes while driving a car and participants are asked to identify changing conditions in the road. Driving simulators have been developed to present participants with expected and unexpected situations to determine if these types of changes are detected. In some cases, people have been studied while actually driving. Within this context, one area that has received a great deal of attention of late has been the influence of the use of cell phones on driving performance (e.g., Streyer et. al., 2003).

Given the variety of approaches that have been developed for studying inattentional and change blindness it becomes necessary to consider the technique used in the interpretation of the results. Weins (2007) cautions about what is being measured by various techniques. It is possible to over-generalize the results of any one study, using any one of the research methods that have been developed. It also will be the case that different experiments using different techniques will reach different and conflicting results. Since convergence from multiple studies using different research paradigms is needed before reasonable conclusions can be achieved, it will become clear that more work is needed in this field.

3. <u>Review of Research on Inattentional and Change Blindness</u>

There are many different ways of looking at the literature on inattentional and change blindness. One way to organize the information is around theoretical accounts. Another is to address the different parameters of change detection that have been studied. In this section a theoretical account based on internal representations is first presented to motivate a greater understanding of these phenomena. A review of research into the various parameters of change detection is then presented. This leads to a specific look at two variables that have garnered a lot of attention in the field, specifically the influence of the task demand and the influence of expectation on the detection of change. The section is concluded with a look at specific biological issues, particularly the presence of inattentional and change blindness in different sensory domains, evidence for inattentional and change blindness in studies of the brain, and evidence for differences in change detection across the life span.

3.1 A Representational Theory of Inattentional and Change Blindness

One of the main underlying assumptions in theories on visual information processing is the idea of internal representations of external stimuli. At least since the work of Sperling (1960) in which the amount of information available in a single fixation was measured following the termination of the visual stimulus, various studies and theories have been put forward demonstrating or at least postulating various forms of internal representations. In the most general terms, low-level representations are considered to be rather veridical replicas of the external world, with higher-level representations becoming more abstract as greater amounts of processing impose meaning onto the external world. With this as a backdrop, it is possible to consider mechanisms that can account for inattentional and change blindness in terms of internal representations.

Simons (1997) considers the general problem of lack of change detection as suggesting there is little information preserved in representations from one view to the next. This view is supported, for example, by the findings of Levin and Simon (2002) when people are insensitive to changes in conversation partners. In this study, a participant was instructed to approach the person behind a counter in order to sign up to participate in a research study. The person behind the counter excused him or herself briefly from the participants view and a different person returned in the original person's place. The subjects were later questioned to determine whether they had noticed the change. As with other related studies, the participants who were unaware of the change may not have made a complete initial internal representation of the first person they encountered, or even of the second, so that it was not possible to notice the change. Varakin and Levin (2007) extend this idea further by noting that in addition to the possibility that the representations of the pre- and post- change scenes were incomplete, it is also possible that the failure to detect the change was due to a failure to do an adequate comparison between the representations.

One of the values of considering internal representations is that once an internal representation is generated it may be possible to access it in different ways. Yeh and Yang (2008), for example, found that whether or not a change was detected had an influence on whether the pre-change image was recognized in a subsequent test after the initial experiment. Good recognition of pre-change images occurred in post tests if a change was detected during the initial trials without having to identify where in the images the changes took place. This effect was diminished if the location of changes was also required. Recognition for pre-change images in post tests was better if the changes were detected than if the changes were not detected (i.e., change blindness). These results are interpreted to mean that representations of pre and post change images can vary in their effectiveness from event to event. When a change is detected between images, the representations appear to be relatively robust. However, when a higher level of processing is required, such as determining the location of a change, the representation of the pre-change image may have insufficient information resulting in a reduction in subsequent recognition during a post test. When changes are not noticed, perhaps the pre-change representation lacks sufficient information to allow a comparison.

The results of Yeh and Yang point out another interesting aspect of change detection, that of the disassociation of the detection of what has changed, as measured by recognition, from the identification of where in the scene the change has occurred. Their results show that people continue to know something about what was shown to them well after the stimulus is removed, even though they were not able to detect that something changed. Mitroff and Simons (2002) found a similar result for the difference between detecting a change and detecting the location of the change. These results point out that the brain appears to process change detection using different mechanisms at the same time. The mechanisms responsible for identification of target objects on a global scale work differently than the mechanisms that identify the location of objects. Therefore, human performance will vary to the extent that these different mechanisms have been successful at detecting changes. These differences may account for both intra and inter-individual variations in performance. Galfano and Mazza (2008) interpret related results for detecting the location of a change as due to a shift in focal attention to the location of the change. That is, when a global change is detected, it may trigger an internal shift of attention to the location of the changed object. The representations provided by the 'what' and 'where' mechanisms, however, must provide sufficient information to allow shifts in attention to occur. If the change is not well represented by the location mechanism, for example, then the observer may be aware that something has changed, but may be unaware of where the change has taken place.

Further evidence in support of internal representations is provided in a study by Hollingworth (2005), in which delays between the presentation of the pre and post change images of up to 24 hours still produced above chance levels of change detection. This author interpreted these results as suggesting that the internal representation generated by the pre-change image was maintained by the participant for subsequent comparison. This interpretation is supported by results from Tatler and Gilchrist (2003) who found that different levels of information are abstracted from an image at different rates. Within a few seconds, relatively rich abstract representations of images have been created that can be used for later processing. Becker and Pashler (2000) found that information in briefly presented pre and post change images could be retrieved, but not from both simultaneously. Together, these results suggest that to some degree, inattentional and change blindness are in part artifacts of the time parameters for the display of information. When information is briefly presented, prior to a change, the probability of a richly encoded representation is reduced. Further, if the location of the change was not currently the focus of attention, the shift of attention can further deteriorate the effectiveness of the original representation, or generate a condition in which adequate comparison between the pre and post change representations is not feasible. Under some circumstances, a weak initial internal representation may result in no change detection at all.

The influence of unattended information (e.g., change blindness) has been demonstrated in a number of situations, providing further support for the idea of internal representations. Bridgeman and Lathrop (2007) found that frame information presented preattentively, can bias a person's perception of orientation. Silverman and Mack (2006) found that pre and post change can influence later recognition, but unlike Yeh & Yang, recognition of pre-change information after the fact was lost if a change was detected. Merikle and Smith (2005) found evidence that the influence of unattended information can last for days in subsequent memory tests. Based on similar results, Mack (2002) suggested that rather than calling the phenomenon change blindness, perhaps it is best to think of it as amnesia. Under conditions in which changes need to be detected, some information, at times, is suppressed, but the influence is not totally forgotten.

In contrast to these studies, Levin and Simons (2002), in their study of changing conversation partners, found poor recognition for pictures of the original person behind the counter when participants were tested at the end of the trial. An important difference between this study and the others is the use of a natural setting and a single trial method. It is possible that some of the results found in studies using simpler stimuli and repeated trials are due to the method, which, among other things, may bias participants with respect to what information is retained. In more complex situations, such as that used by Levin and Simons, what the participant needs to attend to may be less certain. Therefore, evidence in support of representation theories of visual information processing may be more a product of how the data were collected than of the actual underlying mechanism.

Further results calling representation theory interpretations of change detection into question come from studies of eye movements. Pappas et. al. (2005) found that changing objects that were clearly under fixation by the eye were not always detected as having changed. Additionally, changing objects that were not being fixated at the time of change could be detected. Koivisto et. al. (2004) found that when explicit instructions were given to ignore certain objects, these objects were not detected when they changed, even if they were being fixated at the time. Together, these results challenge the notion of veridical "snap shots" of the visual world taken by the eye on each subsequent fixation. The mechanism for how representations are generated, therefore, is unclear.

In summary, representation theories help to frame the understanding of inattentional and change blindness within the context of information processing theory. The results from several research studies, particularly those conducted using brief presentations and repeated trials have been interpreted in support of representation theory. Additionally, lack of change detection can be considered as resulting from either inadequate representations or failures to properly compare representations. More research is needed to help tease apart these two possibilities. It is also the case, however, that lack of change detection can be accounted for without resorting to theories of internal representations. Additional research is considered next that ultimately points in new interpretations of why people fail to detect change.

Before concluding this section, it is worth pointing out that although this type of basic research has yielded somewhat ambiguous results, in a larger view these results indicate that there are limits to the capacity of the brain for detecting change under certain circumstances. Once these limits are fully identified through further investigation, it may be possible to develop system display enhancements that will minimize the potential for inattentional and change blindness to occur. For example, if an air traffic control display system is able to detect that a change has taken place and is also aware that the circumstances surrounding the change may have occurred without the controllers awareness, (e.g., the controller may have been resolving a conflict in the lower right corner of the screen and the new change has occurred in the upper left) then the system can point out the change to the controller.

3.2 Parametric Research on Inattentional and Change Blindness

Research over the past decade has focused on a number of different parameters of inattentional and change blindness. Subsequent theories accounting for these phenomena will have to take into account these results.

Chen (2008), and Chen and Triesman (2008) document an effect of eccentricity of the changing target from the focal point of attention. The more removed the changing target is from the center of attention the greater the likelihood of inattentional blindness. Newby and Rock (1998) also found effects of eccentricity, even for unexpected change targets. When the subject in a study is aware of what changes may take place it is assumed he or she is utilizing stored information about what to expect. This is considered a top-down strategy. However, when an unexpected target change is detected, this is a bottom-up process since the change alone must capture attention. Change blindness, under these conditions, is often higher for unexpected changes than for expected changes. That change blindness increases with eccentricity for both expected and unexpected targets suggests that there is an interaction between the perceptual mechanisms that support bottom-up processing and those that support top-down processing. In a related finding, Gallace et. al. (2007) found that inattentional blindness increases as the number of potential change locations increases, suggesting an internal processing limit.

Arrington et. al. (2006) found that visual transients between images representing color or luminance changes (i.e., brightness) were not well detected compared to other changes. In these cases, the change did not indicate the appearance or disappearance of an object in a natural scene. These results suggest that change alone, even an abrupt visual change, may not be sufficient to capture attention. Cole and Liversedge (2006), however, found that the onset of a visual change associated with the appearance of an object was more likely to be detected as a change than objects that appeared to be moving toward the viewer. Objects looming toward the viewer, however, were more resistant to change blindness than receding objects. These authors interpreted their results to suggest that the visual system may be somewhat hardwired to detect specific types of changes. Similar results were found by Cole et. al. (2003), and Cole et. al. (2004) were able to show an advantage for onsets that indicated new objects in the scene in comparison to onset changes accompanying existing objects.

Rodriguez et. al. (2005) also found support for a special status of object onsets. However, their results found that onsets are detected more quickly, but not necessarily more accurately. Ludwig and Gilchrist (2002) found that distracter onsets, that is the appearance of non-target objects intended to distract the viewer from detecting a primary target, interfered with target detection in relation to the similarity between the distracters and the target. Distracter offsets had a more complex pattern. Together, the results of these studies point toward a complex internal mechanism that may favor specific types of changes, particularly the appearance of new objects in the environment. This mechanism is not simply a change detector, but is able to discriminate objects, and in particular, objects with which the viewer may have to interact (e.g., things moving toward the viewer).

Inherent in the description of change detection is the notion that a change is detected among things that are not changing. Theeuwes (2004), however, has shown that it is possible for people to detect something that is not changing amidst objects that are changing. Gradual changes, however, have been shown by Simons and Franconeri (2000) to be susceptible to change blindness. Along with the results above on object onsets in the visual scene, these results suggest that sufficient conditions for change blindness include events in which visual transients (i.e., abrupt changes in visual information from one view to the next) are suppressed are modulated gradually so as not to capture attention.

Shore and Klein (2000) explored different testing methods and found that different methods can produce somewhat contradictory results. For example, when images were compared side-by-side, change blindness was worse when the images were inverted than when they were right side up. This result was interpreted as favoring a somewhat top-down advantage for interpreting images that correspond with our view of the world. That is, prior knowledge of the world leads to expecting certain relationships to exist in an image. However, when the images were flickered successively, there were no differences in performance between the inverted and right-side-up images. These authors interpreted these findings as suggesting that results from flicker studies are based primarily on bottom-up processing, since low-level perceptual mechanisms would be particularly sensitive to visual transients that would be visible with the images in either orientation. Bottom-up in this case refers to image processing that is built up from low-level sensory and perceptual mechanisms without bias from prior knowledge. In related research, Varakin and Levin (2008) compared performance between jumbled images and intact images of natural scenes. Change detection was worst for jumbled scenes than for intact images and inverted views of intact images. Clearly, the way information is presented to the viewer, whether simultaneously, successively, inverted or jumbled has an influence on whether change is detected and what mechanisms will be able to detect the changes (i.e., higher level or lower level mechanisms).

A handful of researchers have explicitly explored time as a parameter in change detection. Horstmann (2006) measured the time course for attentional capture of unexpected targets and expected targets. While performance for expected targets was unaffected by the asynchrony between a cue and a target, performance for unexpected targets did vary with cue and target asynchrony. These results are suggestive of a mechanism that requires additional time for unexpected events to capture attention since they are not consistent with what is expected. Consistent with this interpretation are the results of Schwartz and Kuhn (2008) in which it was found that increasing the availability of information improves target identification, and the results of Ariga and Yokosawa (2008) in which it was found that target detection improves the later it comes in a sequence of images. Detection of unexpected changes may still require an abrupt change, however, since as David et. al. (2006) found, when slow changes are introduced in an image change blindness is increased.

The instructions given to study participants can have an effect on change detection, as well as the similarity between targets, unexpected targets and distracters. In a study of team sports, Memmert and Furley (2007) postulate that tactical instructions increase inattentional blindness among team members since their focus will be narrowed. Wayland and Levin (2005) found that instructing participants to focus their attention on a specific task while viewing a video resulted in many of the viewers being unaware of a person entering the scene and scratching her fingernails on a blackboard. Similar to the work of Simons and Chabris (1999), instructions to pay attention to something can lead a person to become unaware of other elements in their environment. Koivisto and Revonsuo (2008) found that manipulations of the similarity between expected targets and unexpected targets produced different amounts of change blindness. However, manipulations of the similarity between unexpected targets and distracters had no effect. These authors suggest that a top-down mechanism that focuses on objects that match the expected target to various degrees can account for the results without resorting to the consideration of a mechanism that actively suppresses unwanted information.

Several investigators have explored various aspects of the meaningfulness of information in the images when inattentional and change blindness occurs. Mazza and Turato (2005) conducted a change detection study in which target objects were either embedded in the foreground or background. Their results showed that without explicit instruction, participants were biased to look for changes in foreground objects, showing inattentional blindness toward objects deemed part of the background. Landman et. al. (2004) also found that objects in the foreground and background appear to naturally be segregated by attentional mechanisms. In their study, large amounts of change blindness were found when detecting change required re-segregating an object from the background. Attentional capture, therefore, appears to function in part by separating out significant objects in the visual world from those that can more readily be ignored.

How objects are chosen for inclusion in the foreground is not entirely clear. Jingling and Yeh (2007), found that the addition of new objects into a display do not capture attention if they were not critical to the task. Ariga and Yokosawa (2008b) found that distracters could capture attention when they shared a semantic feature with the target. Stirk and Underwood (2007) found that change blindness was greatest for changes made to congruent objects in natural scenes (i.e., objects that are supposed to be there) as compared to incongruent objects in the scenes (i.e., objects not expected in the scene). The salience of the change, however, had no effect. These results suggest that visual processing is able to abstract various degrees of coherence from scenes in accordance with their resemblance to real world views. As the degree of coherence increases, some objects make sense as belonging together. The higher the degree of coherence in the image, the more elaborate the attentional capture mechanism can become, allowing for scanning at semantic levels if sufficient information exists.

3.3 The Influence of Task Demands and Expectations on Inattentional and Change Blindness

The difficulty of the task that someone is doing can have an impact on his or her performance, particularly if the demands of the task force internal processing mechanisms to function at their highest capacity. For example, working memory is presumed to have a capacity limit of approximately seven items. Having someone perform a task that requires working with seven or more items at one time will utilize all of the person's capacity unless the person finds a way of reducing the memory load through organization of the information or the use of a memory aid (e.g., writing something on paper). Under these circumstances, the chances for error increases due the potential for new information to interfere with what is currently stored in memory, due to the potential for information loss resulting from the decay of information from memory if new tasks do not allow for the constant processing of stored information, or alternatively due to the limited spare capacity a person has because he or she is using a lot of mental resources to maintain the original set of information in memory. Research into task demands in the domain of inattentional and change blindness also finds that change detection is a function, to some degree, of task demand. It is also the case, however, that tasks can be simplified, at times, by utilizing expectation and probabilities to limit possible choices. Research into the role of expectations in change detection reveals a strong connection between what a person is expecting to see and how well changes are detected. Both of these concepts are reviewed here.

Smilek and Eastwood (2008) review findings from several studies regarding the relationship between scene complexity and the level of effort needed to successfully monitor for change detection. These authors conclude that most people are at least intuitively aware of the direct relationship between the two. MacDonald and Lavie (2008) directly manipulated perceptual load in a letter search task. Awareness of a task irrelevant shape was used as a measure of sensitivity. High perceptual load showed reductions in sensitivity to the irrelevant shape. Modifications of the load on working memory, however, had no effect. Simons and Jensen (2009) and Cartwright-Finch and Lavie (2007), also found that perceptual load directly affected inattentional blindness.

The effects of task demand are not limited to perceptual phenomena. Foungie and Marois (2007) found inattentional blindness during tasks that required higher order cognitive executive function, such as information organization, classification, computation, or decision making. In this work, participants were asked to perform one of two tasks. In the first task they were asked to maintain a list of items in working memory. In the second, they were asked to arrange the list in alphabetical order. This second task is thought to require higher executive function since it requires mental rearrangement of information into a specific order. During both tasks, an unexpected visual stimulus was presented to the participants. The results revealed that the stimulus was more likely to be missed when presented during the second task than during the first. The authors interpreted these results as indicating that inattentional blindness can result from an increase in the executive function load.

Tasks requiring rapid responses also are considered to have a negative effect on performance. Shalgi et. al. (2007) found that having subjects respond at the onset of a signal increased their error rate when compared to responding when the signal was turned off. However, the participants were more aware of their errors when responding rapidly to the stimulus onset than they were when responding the stimulus offset. Therefore, although the demands of the task appear to have increased due to the increase in errors, the awareness of the errors did not decrease. Rather, less awareness was seen in the slower responding situation, which occurred when the stimulus was turned off. As reviewed above, stimulus offsets are not as powerful as stimulus onsets for capturing attention. Increases in errors due to task demands do not necessarily result in reductions in change detection.

Rodway et. al. (2006) found a reduction in change detection errors with prolonged exposure to images. Saiki (2002) found that increasing image motion reduced the number of objects that can be tracked from four down to two. Olsson and Poon (2005) developed estimates of visual working memory suggesting that the capacity may be as low as one object at a time. The low capacity limits estimated for visual working memory, therefore, are consistent with the finding that longer exposure to stimuli reduces change detection error. The longer time a person has to evaluate a scene, the more information can be processed for longer-term storage, so that it is no longer subject to the limited capacity of visual working memory.

Tripathy and Barrett (2004) found that the difficulty of tracking multiple moving targets increases as the size of the deviation decreases. In this case reducing the set size is helpful, as well as providing a visual cue as to which objects are moving in what direction. Larger motions make tracking somewhat easier, but there still is a relatively small upper limit on the number of independently moving objects that can be simultaneously tracked. Wright et. al. (2002) found that more targets are missed as a function of set size when a focal attention task is required. Also, Wolfe et. al. (2002) found that target searches in novel scenes were as effective as searches in familiar scene, prompting a conclusion that similar attention mechanisms are at work. Taken together, these results point out that task demands interact with different processing mechanisms. When the capacity of a mechanism has been reached by the demands of the task, performance appears to deteriorate.

Turning now to the role of expectation and probability in inattentional and change blindness, a somewhat different approach is taken with less of an emphasis on underlying mechanisms. Expectations are to some degree derived from the instructions a person has been given or by the demands of the task that is being completed. Part of understanding expectations involves thinking about he congruency of the presence of specific objects in the environment. Following this line of thinking, change blindness may be due at times to a particular change in the environment not being expected and therefore, the changed object is not detected. For example, a deer crossing a road is potentially expected along a highway winding through the country, but would be highly unlikely in an urban setting. Not detecting a deer standing along a city street is understandable given that none of a person's experiences up to that point would ever have made this event seem probable.

Expectations, therefore, are in part about the demands of a task, in part about any explicit instructions a person has been given when figuring out how to complete a task, and in part about the sum of a person's experiences to that point in time. At a smaller scale, expectations are linked to semantic relationships and can be derived from what makes sense in a scene based on the context. Even if a person has never experienced a specific scene before, some aspects of the image seem to go together and compel a specific interpretation. For example, a person carrying a picnic basket would seem appropriate in a scene depicting a park in the summer, but would seem out of place in an image of a glacier. Every scene has a story, and people appear to be good at understanding the story. The review of research on motion pictures earlier supports this idea as well.

Researchers have begun to understand how the manipulation of expectations can influence change detection. Horstmann (2005), for example, found that targets of unexpected color are able to capture attention to the degree that they differ from expectations about the possible colors of distracter objects in the environment. Most et. al. (2005) argue that the attentional goals of an observer (i.e., derived from the task they are trying to complete) influence both attentional capture and change detection. Most et. al. (2001) found that the likelihood that an unexpected object will be detected depends on the degree of similarity to the attended objects in the scene and the specific attentional goals of the observer. Additionally, White and Davies (2008) found an interaction between expectation and perceptual load. As the load became greater, the observer's expectations for possible targets became more specific and therefore they were less likely to detect unexpected targets.

Studies of expert novice differences have shown that experts in various fields process scenes differently from novices, and therefore have different expectations. Werner and Thies (2000) found that experts in the game of football were more sensitive to semantic-related changes in images from the sport than were observers with little knowledge of the game. That is, changes made to an image from a football game that would affect the way someone who is knowledgeable about the game would interpret the image are more readily detected by these experts than by novices. Reingold and Charness (2001) measured the eye movements on expert and novice chess players in recognition of images of congruent and incongruent chessboards. Not only did the experts show superior memory for congruent chessboards, their eye scan patterns were different as well. These differences were not observed for the incongruent chessboards that depicted chess pieces in arrangements that were not possible in an actual chess match. These results support the understanding that experts have developed unique sets of expectations within their domain and will use these to process information differently and will likely have different types of inattentional and change blindness results than novices when viewing the same images.

One of the more intriguing notions regarding the role of expectations when it comes to changed detection involves a concept referred to as 'just-in-time' processing (Hayhoe, 2000; Triesche et. al., 2003). According to this concept, the internal representations that people have for the external world provide enough information to guide subsequent actions (Karn and Hayhoe, 2000). Although the representations may lack extensive detail, the information that is contained takes advantage of expectations in terms of the probability of the continuity of the world from one moment to the next so that only critical information for successful action needs to be represented.

Hayhoe et. al. (2003) studied the combination of eye movements and hand motions needed to complete the activity of making a sandwich. The analysis of the data suggests that only a limited amount of information is needed from any one fixation to successfully guide action from one moment to the next. This limited information set constitutes the basis for a 'just-in-time' representation. According to this concept, internal representations build up over a few fixations that store sufficient information in a spatial coordinate system so that subsequent actions can be planned and successfully executed. Planning for subsequent actions requires the use of expectations for the location of objects in the world at a future point in time so that action sequences can initiated.

Similar results were found by Aivar et. al. (2005), who extended this technique of monitoring eye movements and hand actions during a simple task by moving objects in the participants world every time the person looked away from the objects in front of them. Approximately 20% of eye movements returned to the location of the next item that was needed in the process, even if the item had been moved. These results lend further support to the idea that people retain internal representations of the spatial structure of the world to help guide subsequent actions.

These results help in understanding what is going on when inattentional and change blindness occur. In order to achieve success in completing moment-to-moment activities, actions must be planned based on where items are expected to be located. The ballistic nature of eye movements, for example, reveals that the eye moves from one location to the next without requiring feedback to reach the ultimate destination. Once the movement is executed, the eye arrives at the planned destination. The expectation of where an item is located in the world is established in the observer over repeated presentations of a stable visual environment. Additionally, what information specifically is being maintained for guiding action depends on the task being performed. It is likely that we maintain the information needed to complete the current or next task (i.e., just-in-time representations). In this context, inattentional or change blindness may be the result of a change in an object in the environment that was not critical to the completion of the task at hand and therefore, not being monitored for possible change.

Further evidence supporting these concepts has been provided by Droll et. al. (2007). In this study, eye movements were recorded while detecting objects undergoing changes. The likelihood of some objects changing was manipulated in the trials, and the results revealed that the participants distributed their fixations over various objects in relation to the probability that they would be changing. In other words, participants were able to learn the relative frequency with which some objects changed in their environment simply by having experience with them and then adjusted their behavior to match the resulting expectations for object change.

Droll and Hayhoe (2007) provide results that show a complex interplay between the use of 'just-in-time' representations that result from eye movements that scan the environment and working memory. In this study, participants are reported to have relied more on working memory when the task demands were relatively stable, but shifted to a strategy relying on eye scans when the task demands were less certain due to changes in the visual features of objects being manipulated and when the working memory load was high.

Evidence for the role of just-in-time representations along with working memory, particularly in the context of memory load, potentially allows for an integration of many of the different lines of investigation on inattentional and change blindness that have been presented so far. Several studies have been reported here that provide support for the idea that information is stored through some internal mechanism, and these results have been described with respect to internal representations. Whether in the form of an image, an abstract interpretation or visual coordinate system for guiding behavior, people do appear to hold onto information that can be accessed at a later time. Research on change detection also has shown that the likelihood of detection depends on many factors, including properties in the visual signal, time parameters, information content, instructions and the goals of the observer. Information on task demands reveals that detecting change gets harder when more perceptual and cognitive resources are engaged in the process, and the research on expectation points out that observers may be utilizing the probabilities about the relative stabilities in the world to reduce task difficulty.

O'Regan and Noe (2001) argue that the external world is its own representation and that there is no need to postulate internal representations to account for human behavior. However, the evidence reviewed so far at the least points out that unique properties of the human visual system as well as characteristics of individuals performing various tasks are manifest in human performance. The work of Droll and Hayhoe presented above, places the understanding of inattentional and change blindness in the context of people as active participants in their environments, able to adopt different strategies for meeting the demands of tasks, and shifting the strategies dynamically as task demands change. Inattentional and change blindness are the result of situations in which the present allocation of mental faculties (i.e., eye movement scans, working memory, etc.) by a person are tuned to the solution of a given problem or the execution of a task (e.g., driving), but are not particularly well suited for detecting a particular change in the environment (e.g., detecting a pedestrian crossing the street). Why a person is not able to detect a specific change is as much a function of what the person has been doing (i.e., establishes expectations) and is doing (i.e., allocation of current mental resources to meet task demands) as it is about the salience of the change itself (i.e., salience of the visual signal).

The information reviewed so far provides a useful backdrop for understanding the results of research on inattentional and change blindness in transportation applications. In this light, failures to detect changes in the world are seen within the complexity of factors that affect human performance. However, prior to moving to this topic, research exploring inattentional and change blindness with respect to different biological determinants should be considered. The inclusion of this information will provide a more complete understanding of the human behavior documented in the applied literature and will assist in the consideration of different approaches to improve transportation safety. The next section, therefore, reviews research on inattentional and change blindness in different sensory modalities, brain function and human development.

4. <u>Biological Components of Inattentional and Change Blindness</u>

In the consideration of human performance reviewed to this point, the focus has been on people's behavior when asked to detect various changes in the environment. As noted in the beginning of the document, it is difficult for some to understand how various changes are not detected, especially in the face of potentially dire consequences. Levin (2002) and Levin et. al. (2002) have studied when people believe they are susceptible to change blindness, and their results reveal that most people have a hard time believing that they would not be able to detect what appear to be obvious changes in their environment. These authors describe this result as change-blindness blindness. What people seem to be failing to realize is that inattentional and change blindness are a result of inherent mechanisms in human biology and not a matter of will power. In this section, three different biological components of inattentional and change blindness are considered. First, inattentional and change blindness are considered in different sensory modalities. Next, studies of brain function and change detection are reviewed. Last, inattentional and change blindness changes over the lifespan are considered.

4.1 Inattentional and Change Blindness in Different Sensory Modalities

The information reviewed to this point has focused almost exclusively on inattentional and change blindness as visual phenomenon. Indeed, most of the research on these topics has focused on visual processes. However, knowledge of sensory systems in general reveals that they share common features, such as thresholds, adaptation properties, and spatial sensitivity. Therefore, it makes sense to consider whether the equivalent of inattentional and change blindness can occur in the other senses. Given recent interest reported in the development of auditory and touch interfaces (e.g., Jones and Sarter, 2008 review of tactile interface design), understanding change detection in other sensory modalities beyond vision is essential. Research in the last few decades has also begun to focus on the effects between modalities, suggesting that inattentional and change blindness may occur across the senses. Information on change detection in auditory processing is presented next, along with research on the interaction between audition and vision. This is followed by a review of research on tactile information processing and research on the interaction of tactile and visual information processing.

In a task somewhat analogous to Simons and Chabris (1999), Vitevich (2003) found change deafness as a function of lexical complexity when the voice of the speaker was changed during a task in which participants were instructed to listen to and shadow a list of words presented on a recording. Roughly 40% of the participants failed to notice the change in the speaker's voice.

More recently, Gregg and Samuel (2008) conducted several experiments on change deafness and found counterparts to properties found in the visual system on change blindness. Like the visual system, failures of change detection occurred for auditory stimuli despite the fact that the sounds were well encoded. That is, deafness for a change may occur even though the sound and sound-producing object may be well represented internally. Aspects of the sound source, including the fundamental frequency and periodicity of the sound played a role in change detection, similar to the advantages found for various properties of visual signals (e.g., looming targets). Harding and Cooke (2008) also argue for parallels with the visual system, noting that the gist of auditory content, like meaning in a visual scene, influences what information is selected for further processing.

Pavani and Turatto (2008) used more naturalistic stimuli and presented participants with a variety of auditory scenes composed of different animal calls in the wild. Changes between scenes were created by the addition or deletion of one animal. Unlike the results in visual tasks, the change deafness was not contingent on the presentation characteristics of the different scenes (e.g., time delay between them), but was a function of the capacity of auditory memory. These results highlight a significant distinction between auditory and visual processing, in that audition relies heavily on memory for comparisons, whereas visual stimuli in many cases can provide continual access to information. However, these results are consistent with previous results in the visual system regarding the role of task difficulty, and the relationship between the capacity of internal mechanisms and change detection.

Pizzighello and Bressan (2008) studied the influence of auditory processing on detection of unexpected visual targets. Their results showed that change detection while listening to an auditory presentation for comprehension was comparable during conditions in which visual attention was limited by instructions to track moving items. These results were interpreted to conclude that listening to the radio while driving, for example, imposes no greater risk for inattentional or change blindness that other typical visual tasks. In a more elaborate study, Sinnett et. al. (2006) found that inattentional blindness can result from focusing on auditory information and inattentional deafness can result from focusing on visual information, but that each of these effects is somewhat less than the extent of blindness or deafness that results within a given sensory mode.

Unfortunately, relatively little is know about change detection in the remaining sensory modes. Gallace and Tan (2006) provide results from one study of change detection in the tactile domain. Interestingly, as with auditory information processing, analogs to phenomena documented in the visual domain were found as well. In this study, spatially distributed vibrotactile patterns were presented in pairs to participants under varying conditions. In some cases the patterns were identical and in other cases they differed in one location. When no delay occurred between the delivery of the two patterns, change detection was best. Some change detection failure occurred when a delay was inserted between the patterns. The worst performance, however, occurred when a masking pattern was inserted between the two test patterns. As with vision, the masking pattern made the detection of the changing vibrotactile transients (i.e., the localized change that would be noted as one pattern ended and a second, different pattern began) more difficult.

Auvray et. al. (2007) looked at change detection within and across tactile and visual stimuli. Of particular interest in this work were the conditions in which vibrotactile stimuli and visual stimuli were paired, and change detection was measured across the senses. In these experimental trials, a spatially distributed vibration pattern was paired with a corresponding array of visual targets. Participants were able to note a change between the patterns (i.e., when a visual pattern did not correspond with a vibrotactile pattern, and vice versa), regardless of whether the vibrotactile or visual stimulus came first. Additionally, change detection deteriorated when either a vibrotactile or a visual mask pattern was inserted between the two stimuli. These authors also found, however, that less change blindness occurred within a mode (i.e., vision or touch) than between them, a finding at odds with the work of Sinnett et. al. (2006) when vision and auditory processing were compared.

In a follow-up study focused on the effects of inter-modal masking, Auvray et al (2008) looked at change detection in vibrotactile stimulation on the fingertips. Increasing the interval between presentations of vibrotactile stimulation to the fingers increased change blindness. Interposing both vibrotactile and visual masks between the stimuli also induced change blindness. However, auditory masks had no effect. Similar results for visual masks were found by Gallace et. al. (2006).

Interactions between vision and touch also have been looked at in terms of providing people with feedback in the environment. Jones and Gray (2008) located vibrotactile stimuli on the backs of participants to be used as cues to changing targets on a computer display. When the cues on their backs were correlated with the location of changing visual targets, performance with respect to change detection improved. When the vibrotactile cues were not correlated with changes on the visual display, participants had to make a conscious effort to override the tendency to automatically look in the location that was being cued on their backs. This result, therefore, demonstrates a tendency for the integration of information across the senses.

Lee and Spence (2008) also investigated the integration of information across the senses of vision and touch. In their work, active tactile feedback provided on a touch-screen computer display allowed users to more easily ignore irrelevant visual information than when only passive feedback was provided. They also found that visual feedback must precede active tactile feedback by 40 ms for the perception of the event to be experienced as simultaneous (i.e., the appearance on a screen of a button press must lead the tactile information by 40 msec in order for the person touching the display to integrate both sources of feedback as belonging to the action of pressing the button).

Although somewhat sparse in comparison to the available literature on vision and change detection, the studies on auditory and tactile inattentional and change blindness reveal both unique elements of these sensory systems, as well as similarities with the other senses. That inattentional and change blindness have been demonstrated in vision, audition and touch suggests that many of the mechanistic explanations developed based on research in vision may apply to all of the senses. This point is demonstrated more specifically by the research showing inter-modal inattentional and change blindness. These results further support the concepts put forward by Droll and Hayhoe (2007) regarding the dynamic allocation of internal resources to solving problems. People are able to integrate information, simultaneously from multiple sensory sources, allocate attention to one sense or between them, monitor the world for what is changing and what is not, and utilize working memory and other cognitive functions, all in the service of completing tasks and achieving their goals. The inherent limits in the internal mechanisms for information processing ultimately limit how much information can be processed at any moment, and expose everyone to the potential to experience inattentional and change blindness.

4.2 Brain Function Associated with Inattentional and Change Blindness

Advances in techniques for recording brain activity in relatively non-invasive procedures have allowed for the collection of data from participants during various activities, including while performing change detection tasks. These results provide evidence for a correspondence between activity in various brain structures when objects are presented and detected and the actual behavioral response from the person. They also prompt additional questions about the underlying mechanisms of inattentional and change blindness.

Event-related potentials (ERPs) are electrophysiological signals that can be recorded from electrodes placed on a person's scalp that correspond to brain activity during specific activities or 'events'. Schankin and Wascher (2008) monitored a component of the ERP signal, the Np2 signal, as a marker indicating detection of a change while participants were viewing targets on a display. Their results revealed that when changes occurred but the participant had not been informed about them, the Np2 signal was not measurable. When changes occurred and the participants had been told about them, the Np2 signal was present, even if the participant did not notice them. In related work, these authors found that differences in the Np2 signal strength corresponded with actual detection (Schankin and Wascher; 2007). These results show that brain mechanisms appear to underlie change detection, and that they are adjusted in accordance with the attentional goals of the person.

Kimura et. al. (2008) also monitored ERP signals, focusing on differences between conditions in which changes took place and were not detected (i.e., change blindness) and when no changes took place (i.e., person correctly identified that no change had occurred). Differences in the ERP signals between these two conditions were found. Using a different component of the ERP signal, Henderson and Orbach (2006) found similar results. Together with the previous studies, these results indicate that change blindness results in different brain activity than when subjects are aware of their environment (i.e., either that it is changing or that it is not).

A more intriguing result using ERP signals was reported by Pourtois et. al. (2006) who also reported distinct differences in neural activity between correct change detection, blindness and correct no change detection trials. Both types of correct trials showed some similarities in the ERP signals as compared to the blindness conditions. Additionally, detection of change showed unique patterns following presentation of the first image (i.e., pre-change) suggesting that the attentional state of the brain may be responsible for whether a change can be captured.

Todd et. al. (2005) noted activity suppression in the ERP signal associated with the temporo-parietal junction area of the brain as visual spatial memory load was increased.

This region of the brain is thought to be critical for visual spatial attention. They also noted that increased memory load increases change blindness. In a separate study, Niedeggen et. al. (2001) studied the time course in ERP signals during change detection. Significant brain activity was found up to 3 seconds prior to the actual recognition by the participant, potentially corresponding with activity in neural mechanisms involved in detecting the change and determining the location. Together, these finding support the conjecture that change detection and change blindness, as measured in human performance are the result of the activity of underlying neural mechanisms. Capacity limitations in these mechanisms ultimately determine how much information can be processed at one time.

Using different brain imaging techniques, Scholte et. al. (2006) showed data from different imaging sensors that were able to differentiate when the same and different spatial patterns were present, regardless of whether the participants were aware that differences would occur. Imaging signals from a separate part of the brain corresponded with actual change detection. These results suggest that automatic processing of the stimuli was occurring by various brain mechanisms, regardless of the attention goals of the observer, and that awareness of targets takes place in a different part of the brain than the processing of spatial details. This evidence for the functional compartmentalization of the brain is consistent with behavioral findings showing that unattended stimuli have an influence on internal representations, as well as the results showing that detecting what has changed and where the change has taken place follow different time courses.

In a relatively rare study, Reddy et. al. (2008) were able to record activity from individual cells in a human brain, in the medial temporal lobe, while the person was performing change detection tasks. Perhaps not surprisingly, they found that the firing rates in these cells increased during actual change detection in comparison to the activity level when subjects missed a change. These results lend support to the interpretation of the studies using ERP and imaging data that the increased activity level measured in these signals corresponds with higher levels of neural signals, which is thought to mediate information processing.

Additionally, Rolls (2008) argues that data from single cell recordings showing the dynamic allocation of receptive field sizes around objects of interest in neurons in the visual processing centers of the brain may underlie an internal mechanism for visual selective attention. In this view, attending to a specific object in the world tunes neural mechanisms, resulting in acute processing of the object of interest, but perhaps at the cost of having access to a wider field of information. Related to this notion, Summers (2006) found that patients with traumatic brain injuries show several attention impairments, including increased change blindness as compared to non-injured people. Brain injured patients have effectively reduced levels of distractibility, which appears to be necessary for the detection of unexpected targets, and may correspond, as suggested by Rolls, with reduced receptive fields in areas of the visual cortex.

Something different is happening when changes are not detected, but known about, than when no change is correctly detected or when changes are detected. Todd et. al.'s (2005) results showing suppression of activity suggests that certain critical areas of the brain may be inactive when blindness occurs. Even though other parts of the brain are showing activity corresponding to the signal or changes in the signal, if no change detection occurs, the mechanism responsible for the change may be in active – perhaps due to memory load or some other area that is causing temporary reduction. Reduced receptive fields go along with this.

4.3 Inattentional and Change Blindness and Human Development

Studies of human development reveal that many perceptual and cognitive abilities change over the life span. Therefore, understanding inattentional blindness and change blindness requires consideration of how these phenomena are manifested at different ages.

Fletcher-Watson et. al. (2009) studied inattentional and change blindness in children aged 6 – 12 years and compared performance to a group of adults. Using a modification of the flicker test paradigm, change detection was measured for a variety of different potential object changes. Changes with high and low semantic relevance to the overall scene were also utilized. The results showed greatest change detection in all age groups for the changes with the highest semantic relevance. The children performed comparably with the adults and the oldest children nearly matched the performance of the grownups.

Memmert (2006) tested groups of subjects of different age levels (ranging from 7 years to 23 years) and with different levels of expertise. All were shown the video from Simons and Chabris (1999) and asked to count the number of basketball passes. While counting performance was comparable among the age groups, those who had more expertise with the game of basketball were more likely to notice the gorilla than those with less or no expertise. Attempts to monitor eye movements revealed that children may have been fixating the area of the scene in which the gorilla stood, but still may not have reported seeing it. As with the previous study, children performed comparably to adults when expertise was taken into account, showing the same potential for inattentional blindness.

Smith and Milne (2009) studied change detection in a group of children with autism spectrum disorder (ASD), and compared performance with a group of typically developing children. In accordance with their hypothesis, these authors found that children with ASD detected more change errors than other children, suggesting they are less prone to inattentional and change blindness. Children with ASD are thought to process information differently than others, paying less attention to context-dependent cues and having an ability to notice many more aspects of the surrounding environment.

On the other end of the age spectrum, older adults appear to have a harder time detecting change than younger adults. Veiel (2005) found age-related differences in the speed of change detection, error rates and patterns of eye movements. The behavior of older adults was described as more cautious. Similar results were found by Rizzo et. al. (2009), showing increases in change blindness associated with increased age, dementia, and general declines in executive function. Interestingly, Rowe et. al. (2006) showed older adults had better recognition of unattended distracter items than younger adults, suggesting that they are more easily distracted and therefore less able to focus attention.

Unlike the children with ASD in the previous study, this type of distractibility may not coincide with better change detection performance.

Batchelder et. al. (2003) conducted a study comparing change detection in a group of older (mean age 68.5) and younger (22.3) drivers. The participants were shown images for 10 seconds that either were static, or that contained a changing element, and asked to either identify the change or indicate that no change had taken place. Older drivers were slower, less accurate, and had more false positives than the younger drivers. Consistent with the other studies presented on older adults, these results indicate that change detection declines with advancing age. Additionally, the increase in false positives suggests an increase in cautiousness. However, the increase in latency may negate any benefit derived from being more careful.

5. <u>Research on Inattentional and Change Blindness in Transportation</u>

The potential danger posed by inattentional and change blindness to drivers has prompted a number of studies of these phenomena in the context of driving. Several general findings are first presented, followed by a series of results pertaining to the effects of task demands on driving and change detection, followed by studies on expectations, change detection and driving. The specific challenges faced by older drivers are considered next.

5.1 Inattentional and Change Blindness in Driving

Galpin et. al. (2009) attempted to study change blindness in traffic scenes in order to compare expert and novice differences on change detection. Flashes in the visual display at one-second intervals allowed objects to be changed in the visual scene and potentially induce change blindness. The changes that were manipulated included object location and the relevance of the object to the overall scene. Experts were experienced drivers and the novices were non-drivers. The results did not show any expert novice differences. However, the results did reveal that non-relevant objects in the center of the image were the hardest changes to detect. These results are consistent with prior studies indicating the importance of the meaningfulness of change for detection. Failure to find any differences between drivers and non-drivers suggests that the task did not really test driving skill in a significant way. However, Edwards et. al. (2008) worked with inexperienced (18 – 20 year olds) and experienced (35 – 48 year old) drivers in a similar study. The insertion of a changing object in an image with an intersection was used for change detection and the decision to make a left turn. Eye tracking data showed that inexperienced drivers tended to fixate on other vehicles in making the turn decisions, while experienced drivers tended to focus on signs and signals.

Recarte and Nunes (2006) assessed the effects of mental workload on visual detection during an actual driving task in an automobile. Mental workload was manipulated by having the driver perform a variety of tasks, ranging in difficulty from relatively concrete processes to more abstract thought. The results revealed that visual detection was compromised as mental workload increased. The results were discussed with respect to the influence of endogenous stimulation, or internal thoughts, on driving performance and safety. Although external distractions can be kept to a minimum by eliminating cell phone use, not playing music, and avoiding conversation, this study points out that a driver's own mental processes can be a form of distraction that uses mental resources and limits the capacity for change detection.

Mccarly et. al. (2001) found that carrying on a conversation disrupted change detection and increased the number of fixations on objects in the road environment while viewing images of traffic scenes. In half of the conditions, participants were required to carry on a conversation while detecting changes in the environment. The requirement to carry on a conversation resulted in worse change detection and increased fixations on the road than when no conversation occurred. Performance comparison between a group of younger (mean age approximately 21 years) and older (mean age approximately 68 years) revealed that the older drivers were worse at change detection overall, particularly during the conversation conditions, and had a harder time with changes that affected the semantic relevance of the target. These authors noted that the influence of the conversation was not due to the use of a cell phone, since the participants were able to talk in a 'hands free' situation. Therefore, conversations, independent from cell phone use, can have a detrimental effect on change detection. Treffner and Barrett (2004) using an automobile driving task, and Strayer and Johnston (2001) using images presented on a computer came to similar conclusions.

Velichkovsky et. al. (2002a) utilized eye movement tracking to implement change blindness in static images and in a driving simulator. Equivalent results were found for insertion and deletion of objects, with fastest performance for the insertion of driving relevant stimuli. Changes inserted using blanks between images were detected as easily as when they were inserted during an eye blink. The changes coinciding with eye movements took longer to detect. These results are likely due to the relative static position of objects between images when blanks are interspersed or when the eye blinks. Velichkovsky et. al. (2002b) further studied eye movements in relation to change detection while driving and noted significant differences in the duration of fixations when an object is detected. These authors note the possibility of developing techniques for monitoring eye movement patterns to determine whether object detection is occurring or whether change blindness may result.

Creaser et. al. (2001) used a change detection paradigm to assess detection of pedestrians and cars in intersections. Longer left turn decisions were found when changes were detected than when no changes occurred. Faster responses to pedestrians than cars were found for meaningful than for non-meaningful targets. Wallis and Bulthoff (2000) found that drivers have greater concentration along the path of travel, while passengers have a wider field of view, but that observer motion, in general, increases blindness to specific types of changes, including changes in orientation. Clifasefi et. al. (2006) was able to demonstrate that both inattentional and change blindness are worse for drivers under the influence of alcohol, utilizing blood alcohol levels as low as 0.04%, which is approximately half of the legal limit for adult drivers in many states. Together, these results point out the importance for drivers to learn to adopt good change detection strategies while driving. This includes anticipating their direction of travel when making turns, and considering the potential for impairment resulting from even modest amounts of alcohol.

5.2 Task Demands and Expectations in Change Detection

Previously presented material has shown that change detection becomes worse when task demands increase. Lee et. al. (2007) assessed change detection in a driving simulator while manipulating both cognitive load and visual attention. Periodic blanking of the out-the-window view was used to simulate glances away from the road, and an auditory processing task was used to increase cognitive load. Although disruptions in visual attention had a larger impact on change detection in the position of other vehicles than the processing of auditory information, both reduced driving safety. Similar results were found by Lee (2007), further supporting the understanding that increased cognitive loads decrease a driver's ability to detect changes on the road, integrate information, and focus attention where it is needed.

Koustanai et. al. (2008) focused on the role of driver expectations. In a simulated driving task, two types of expectations were established through repetition. One regarded information on the environment and particular dangers posed by different locations, such as intersections. The second were expectations based on specific actions that can be taken while operating the vehicle. The results of the study revealed that action-based expectations often get priority over environmentally derived expectations. While basing one's driving decisions on the expectations about actions, the unique hazards imposed by the environment that can be anticipated, such as a driveway from which a car can enter the road, appear to be ignored. These findings extend the understanding of actions and expectations discussed previously in the work of Hayhoe and various colleagues, showing that expectations are used for planning actions and that anticipating potential dangers may require additional thought.

In a related study, Arndt (2006) was interested in whether people would check the back seat of a car before taking it for a ride. Child sized mannequins placed in a prone position in the back seat of an SUV were not noticed by 47 of 50 drivers who were asked to take an SUV for a ride around a closed track at night. These results indicate that planning and executing the action took precedence over familiarity with the immediate environment. Perhaps, therefore, the development of instructional sets to motivate people to better understand their environments will result in the modification of expectations to include anticipation of environmentally relevant hazards.

Pearson and Schaefer (2005) manipulated the centrality of items of interest, the relevance of items to the driving task and the instructional set indicating the importance of change detection. The changes that occurred included either disappearances of items or changes in position. The results showed that disappearing items were detected the best, indicating change blindness was more likely to occur for positional changes. However, the effects of change blindness were significantly reduced by the instructional set highlighting the importance of change detection. This result suggests that the development of good change detection skills may be possible through the development of appropriate instructions.

In contrast to the driving studies that have been presented, Fick (2007) conducted three experiments using an aircraft threat detection task. Unexpected targets were detected at various locations in the first experiment, with higher probability of detection found when fixations were closer to the target or when several fixations were occurring in the area of the target. The presence of aircraft that were supposed to be ignored was found to interfere with detection of unexpected targets in the second experiment. In the third experiment, perceptual and cognitive load was manipulated, and improvement in detection of the unexpected targets was found when the task demands were reduced. Collectively, the results from all three of these experiments are supported by results discussed previously. Improved change detection is expected when the target is closer to the center of the visual field, unexpected targets interact with other items to the degree they share similarities, and change detection is known to improve as task demands go down. The replication of these findings in this context increases the understanding of the generalizability of the research findings on inattentional and change blindness.

5.3 Inattentional and Change Blindness in Older Drivers

Declines in change detection with advancing age have been documented, raising particular concerns about how this affects driving skills. Bao and Boyle (2009) studied visual scanning in young (18 – 25 yr old), middle-aged (35 – 55 yr old) and older drivers (65 – 80 yr old). Eye movements were measured while driving through different types of intersections that required either a straight through, left turn, or right turn decision. The results were quantified in terms of looking to the left, looking to the right, and checking the rear view mirror. The results showed that young and older drivers had lower scanning rates than middle-aged drivers, with older drivers worst over all. The differences in scanning between young and middle aged drivers are attributed to skill level. The performance of the older adults is attributed to declining processing speed, and perhaps over reliance on experience. Reductions in scanning, however, are thought to contribute to increases in the risk of change blindness. Hoffman and Yang (2006), report on the development of a tool that measures scan patterns in drivers, called Driver Scan. These tools are thought to provide diagnostic information on driving ability and potentially can be used to screen drivers for additional training or to indicate that driving privileges should be terminated.

Caird et al. (2005) compared change detection performance over a range of ages in a driving related task in which participants viewed images of traffic scenes and objects were manipulated for possible change detection. Drivers in the age groups above 65 years old tended to have more change detection errors and were slower in decision-making. Caird et al (2001) used a similar technique, but limited the exposure time to images of intersections and found greater errors in older drivers. Together, these results suggest that older adults have slower processing of driving-related information when it comes to making turn decisions. Perhaps more importantly, their reduction in processing speed results in greater errors when they are forced to make decisions at a faster pace, which further implies that they may not be able to handle complex traffic situations.

Rizzo and Stierman (2004) assessed performance while 160 older drivers completed a complex auditory task while also driving a vehicle. Drivers made more errors and had additional difficulty controlling the vehicle in the auditory processing condition. These results are consistent with previously reported studies showing that increasing cognitive load reduces selective attention ability and change detection. However, the participants with various sub clinical neurological impairments did not differ from those without these conditions. These authors interpreted the results in light of the low-danger of the traffic conditions encountered. Had the errors detected in the study actually taken place in a more complex traffic situation they would have posed a serious safety risk. The drivers were thought to be relying on learned behavior from years of driving practice. In the relatively low-danger setting in which they are still driving they can remain relatively safe.

6. <u>Research on Mitigation of Inattentional and Change Blindness in Transportation</u>

Various attempts have been made to develop and test methods for improving change detection. Following a general discussion about what is needed, studies are reviewed on techniques that appear to decrease change detection, and then studies on techniques that appear to improve change detection are presented.

Divita et. al. (2004) point out that the increasing complexity in the design of newer operations environments often requires operators to monitor information from several sources on different displays. Divita and Nuggent (2000), for example, documented significant amounts of change blindness in the use of workstations in military applications. When information is distributed across multiple displays it generates opportunities for changes to go undetected, particularly when the type of information differs between the different views. These authors call for new design concepts that will reduce the potential for change blindness when operators are working across multiple displays.

Durlach and Chen (2003) also report significant change blindness in military applications. The results are consistent with the literature reviewed so far, such as increased change blindness with increased task demands and increased eccentricity from the center of the visual field, masking effects from concurrent activities, and particular difficulty detecting small changes in the peripheral visual field. Similar to Divita et. al., these authors call for new system designs. In particular, the design of a change detection tool is suggested that helps a person know what has changed. Related research in this area shows promising results using software that tracks changes and provides direct feedback as to what has changed on the current display. This approach helps the users maintain or reacquire situation awareness (Smallman and St. John, 2003).

Part of the difficulty with implementing efforts to mitigate inattentional and change blindness, however, is the acceptance of people of the magnitude of the problem. As noted earlier, Levin (2002), and Levin et. al. (2002) have documented a phenomenon they have termed ‘change-blindness blindness’, in which people report not believing that they would be susceptible to change blindness. Therefore, in addition to specific system design applications, training people on strategies for improving change detection, and educating people on the problem through public awareness may also be helpful.

6.1 Research on Improving Change Detection

Apfelbaum et. al. (2008) attempted to use an augmented vision device to help improve change detection. The original intent of their apparatus was to assist people with low-vision deficiencies by superimposing a cartoon-like image over the real-world scene. The cartoons are thought to enhance the detection of critical targets that would otherwise be difficult to detect by people with these disorders. However, when a change blindness task was utilized, the apparatus had no apparent effect on improving change detection. Despite the improved contrast provided by the enhanced visual image, inattention to the information prevented detection. In a related study, Krupenia and Sanderson (2006) found that wearing helmet mounted displays, in some situations, actually worsened change detection. As noted earlier, improving the salience of the undetected targets is not sufficient for change detection. Providing additional information through a vision-augmenting device that must be integrated by the observer will likely increase the perceptual and cognitive load, a condition known to reduce change detection.

Lee et. al. 2001 evaluated a speech interface for an in-vehicle e-mail application. Since visual interfaces for selecting messages, and constructing responses would require too much heads down time while driving, a speech interface was developed as an alternative means for allowing the driver to multi-task. The response times of participants were measured to the onset of the brake lights on the car in front of them, while the participants were driving and using the e-mail application. The speech interface increased response times. Richard et. al. (2002) were also interested in developing better in-vehicle communication interfaces, but found that completing an accompanying auditory task increases response times to visual targets. As with cell phone use, the problem of increasing communication is not the interface as much as it is the fact that two-way communication increases task demands and reduces the effective use of visual selective attention.

The complexity of the phenomena on inattentional and change blindness will likely mean that many different types of mitigations will be needed for different situations, ages, and levels of expertise. Zeifle et. al. (2008) developed an intersection assistant for drivers and evaluated it in a driving simulator with younger and older drivers. A visual and an auditory interface were each evaluated and compared to performance without the device. As might be expected, older drivers drove more slowly than younger drivers, but more importantly, car handling performance decreased with the use of both interfaces for all participants, with the greatest distraction during the use of the auditory interface. The auditory interface had the best acceptance between the two and was rated as more helpful by the drivers. These results highlight the somewhat counterintuitive finding that attempts to help improve performance by adding information end up reducing it instead. However, declines in performance are not always noticed by people if they believe the information presented is helpful.

In contrast to these findings, Victor et. al. (2005) reported better overall centerline gaze and driving performance when information was presented through an auditory interface than when presented with a visual interface. Ho and Spence (2005) found that providing drivers with verbal cues was effective at directing their attention to specific locations. Similar assistive devices are under development as well (e.g., Mickale Fitschet al.; 2008), and the current divergence of results indicates that more work is needed in this area to find an appropriate balance between aiding drivers in making decisions without affecting driving performance.

Automated alerts have often been used to draw attention to potentially dangerous situations, but overuse becomes a problem and alerts can lose their effectiveness. Barnett et. al. (2006) studied the effect of using alerts for improving situation awareness in a military application. Their results demonstrated that automated alerts were helpful at improving situation awareness for non-military participants. However, the situation awareness did not improve for the soldier participants. These results are consistent with the results presented so far on expert and novice differences. Although the software used in the study to generate the automated alerts was designed to support military operations, the participants were already processing the information sufficiently to maintain a high level of situation awareness. The novices, on the other hand, were unaware of what information was significant and the alerts proved to be helpful.

In addition to specific interface technologies for mitigating change blindness, some researchers have attempted to use training on the changes as a means of improving performance. Neuman and Durlach (2004) studied the effects of practicing with specific changes in targets in a military display application. Their results indicate that sensitivity to the specific change increased as a result of the practice. However, this result did not generalize to other changes. These authors suggest that this may be due to an unintended aspect of the practice sessions that held other types of targets constant. Therefore, participants may have been learning both what is expected to change and what is not expected to change, which would be consistent with the research on expectations and change blindness discussed previously. In a related study, Becker and Vera (2007) found that learning specific changes just prior to having to detect them resulted in a reduction in change blindness. These authors determined that this effect was not due simply to priming of low-level visual mechanisms. Taken together, these results support the need for further research into strategies for reducing change blindness through just-in-time practice and training.

Aside from better alerting mechanisms and improved training, another possible way of improving change detection is the inclusion of additional people on the task. Tollner (2007) reports that teams generally have lower levels of change blindness than individuals performing the same task. The difference is even greater if communication is encouraged among the team members. While this result may seem counterintuitive with respect to results on the negative influence of conversations on change detection while driving, the critical difference here is that the conversation is in support of change detection. In this case, the conversation is likely to help each person use his or her own resources more efficiently, ultimately reducing task demands such as memory load, and may help compensate for the effects of eccentricity. Knott and Neilson (2007) also found some performance advantages for communication among pairs of observers than for individuals, although change blindness was still prevalent.

A few studies provide specific guidelines for developing systems that will reduce inattentional and change blindness. Durlach (2004) provides guidance for both system design and training. Suggestions for the design of systems are paraphrased and summarized in the list below:

- Information should be integrated prior to being displayed in order to reduce the workload of the viewer;
- Care should be given in the choice of using teams versus individuals since multiple crew members may distract one-another from their respective duties [the results of Tollner, and Knott and Neilson not withstanding];

- Consider efficient information coding to minimize the display space needed as well as to indicate the age and change status of information;
- Develop change detection tools that can summarize the change history of the displayed information (e.g., see Smallman and St. John, 2003)
- Provide customization tools that allow a user to redisplay information in ways that highlight the salience of information to him or her; and
- Develop decluttering tools that allow significant changes to be identified quickly.

With regard to training, a summary and paraphrase of Durlach's suggestions include:

- Training needs to focus on the process for which a tool is used (i.e., getting the job done), and not on the use of the tool;
- Training should focus on the specific changes that need to be detected, with appropriate feedback, and include the range of contingencies and expectations that are likely to be experienced in actual practice;
- Familiarization should be provided on the specific symbology and patterns of information that are likely to be seen; and
- Training should be provided that enhances the general skills of change detection.

Schlienger et. al. (2008) evaluated the influence of visual animation and sound to support change detection in a complex display. A summary of the suggestions based on their results indicates that:

- The observer can be made aware of changes in the display using animation or sound;
- Unchanging sounds can be used with essential static information to support the notion that the information doesn't change;
- Animation can be used with dynamic information as an indicator of the changing nature of the data; and
- The combined use of animation and sound can be used to highlight changing situations.

The collection of results in this section point out a variety of approaches for improving change detection. Presently, however, are no clear answers. As noted earlier, the variety of elements that have an impact on inattentional and change blindness suggest that a multi-faceted approach will be needed.

7. Summary and Recommendations

The review provided in this document has focused on the phenomena of inattentional and change blindness. The working definitions of these concepts have been that inattentional blindness is a failure to notice or become aware of a change in the environment, typically due to focused attention on a specific task. Change blindness is a failure to notice or become aware of a change in the environment, typically due to a situation that masks the features of the objects in the environment that have changed. The term blindness, however, is somewhat misleading since unattended information still has some impact on the person.

Theoretical considerations of the research suggest that some kind of internal representations exist of the information that is presented. However, the level of detail in these representations is not clear. Research from eye movements shows that a fixation is not necessary for an object to be detected, and that fixation on an object doesn't mean that it will be noticed. Therefore, it is unlikely that internal representations match exactly what the eyes are pointing at.

A number of different parameters have been studied in change detection research. It has been consistently found that the greater the distance an object is from the center of the field of view the less sensitive a person is to change detection. Focusing attention increases this result. The potential for inattentional and change blindness varies somewhat between the conditions in which a person is aware of what the potential changes could be and the conditions in which the person is not aware of the possibility for changes. Larger differences often are needed when a person is not aware that changes in the environment are possible in order for the change to be detected.

Inattentional and change blindness have been found for abrupt or sudden changes and for changes that take place very slowly. Therefore, failure to detect a sudden change, or transient in a signal, although sufficient, is not a necessary condition for inattentional and change blindness. The instructions given to a person while completing a task has a direct affect on inattentional and change blindness. The attention goals of a person determine what information is actively processed and what information is ignored. Task demands also have an effect. As the perceptual or cognitive load increase during a task, the possibility for inattentional and change blindness increases. For example, the more items there are to be monitored in the environment or the more complex the analysis is that someone is performing, the more likely it is that inattentional and change blindness will occur.

A person's expectations, both explicit (e.g., based on instructions) and implicit (e.g., derived from experience) have a direct bearing on inattentional and change blindness. The mind keeps track of what is likely to change and what is not, and actions are planned based on this information. Changes that occur in objects that are not expected to change can lead to inattentional and change blindness.

Evidence for inattentional and change blindness have been found to occur in vision, hearing, and in the sense of touch. Interactions also occur between senses. For example, tactile information can mask a visual change and result in change blindness. Studies of children have shown that they perform similarly to adults by age 12. Older adults show significant increases in inattentional and change blindness. Expertise at a task results in different ways of processing information, different visual scanning patterns and different conditions under which inattentional and change blindness occur.

Finally, children with autism show less inattentional and change blindness than children without autism. This may be due to a predisposition to attend to fewer contextual cues than others. Patients with traumatic brain injury show increases in inattentional and change blindness as compared to uninjured people. These patients are not as easily distracted as others.

Transportation-specific research has shown that older drivers scan differently than younger drivers and show significantly more inattentional and change blindness errors. Additionally, increased cognitive load undermines a person's ability to detect changes in the road environment. The consumption of alcohol decreases change detection in drivers, and the use of cell phones while driving decreases sensitivity to changes in the road as well. It has also been found that drivers often are unaware of the environment inside the car and repetition of the same route reduces the expectation that something may change.

Research on information interfaces, such as auditory interfaces for an e-mail application, generates a significant distraction for drivers. Visual interfaces lead to significant reductions in scanning the environment. Auditory interfaces may be less problematic, especially if the driver does not have to respond verbally.

Recommendations

Several studies revealed possible approaches to mitigating inattentional and change blindness. However, more research is needed to develop these concepts into functional mitigation techniques. The list below outlines potential fruitful areas for further research and development efforts:

1. Knowing what changes to look for in a situation may improve change detection. Research is needed in different transportation disciplines (auto, rail, aviation, air traffic control, maritime, etc.) to identify types of information that can change for the operator, whether in the field of view while operating a vehicle or on a display screen. Crash and near-crash investigations could also include an analysis of what changes in the environment were available but undetected. Reviewing compilations of these changes could be included in recurrent training programs. The changes could also serve as the basis for new operator alerting concepts.

2. Teams appear to be able to mitigate inattentional and change blindness, especially if the members communicate. Caution must be followed, however, so that the team members do not distract one another. Research on optimal team performance for the mitigation of inattentional and change blindness will lead to

more effective teams. Additionally, the use of artificial intelligence agents, embedded in system software, may be able to act as virtual team members, calling the attention of an operator (or controller, pilot, etc.) to a changing condition much in the way a teammate would. Research on operator interaction with software agents as team members is needed to further develop this concept.

3. Display designs have been developed that attempt to maximize change detection. These results have not been integrated into design concepts or guidelines for their use. These concepts require further research to figure out how to integrate the various approaches and to develop guidelines for their implementation, including:
    a. clutter reduction for the highlighting of salient changes;
    b. displaying a change history to help orient the viewer to significant developments in the environment;
    c. defining minimum processing times for change detection to allow the brain sufficient time to complete the task;
    d. the use of spatially relevant tactile and auditory feedback to help orient a person to significant changes in the environment; and
    e. the use of sounds and animations to help highlight both static and dynamic information.

4. Eye movement patterns appear to reveal information about when a person is focusing attention and when the potential for inattentional and change blindness is occurring. Therefore, more research is needed into eye movement patterns for determining the conditions that lead to inattentional and change blindness and for discovering techniques for helping a person to regain their awareness of their surroundings.

5. Research has shown that conversations extraneous to the task at hand should be avoided in order to improve task performance. In part this appears to be due to the limited capacity people have for carrying on conversations while performing additional complex perceptual tasks. Research is needed in order to understand what makes tasks compatible for minimizing inattentional and change blindness.

6. Research has shown that most people do not believe they are susceptible to the problem inattentional and change blindness. As with wearing seatbelts and the proper use of infant car seats, public awareness may be helpful in getting people to understand the significance of the problem. Mass-media demonstrations and education may be effective at getting people to realize they need to develop good change detection skills. A series of television public service announcements, for example, could be developed with different inattentional blindness demonstrations in the context of automobile driving as a way of proving to people that they are susceptible to the problem and to increase their awareness while driving. This approach could also be taken with pilots, railroad engineers, air traffic controllers, etc.

7. Practice with change detection, particularly with software tools or simulations, has been shown to promote better change awareness. A variety of approaches to training people on change detection could be implemented through video games, computer software, applications for hand held devices and similar technologies. Research and development efforts are needed to determine what types of practice and what types of devices provide the best mitigation and positive transfer of training to specific transportation applications.

8. Change-detection education could be included in all aspects of transportation, capitalizing on many of the research and development efforts listed above. A change-detection curriculum for different high hazard situations may be helpful for both novices and experts to help people understand their own culpability. Effective curriculum development in one transportation modality can be adapted for others. Additionally, the design of instructions for operators should include information on change detection. Research on the instructional set showed that focusing on change detection improved performance. Information on potential for complacency developing from repeating the same behavior (i.e., following the same route each day), or reminders to become aware of the surroundings should be included. The development of checklists to assess compliance may be helpful for this purpose as well.

9. Inattentional and change blindness mitigation research is needed at all levels, from simple laboratory studies, to simulator projects, to field studies with actual vehicles. Laboratory studies, including the use of simulators, will allow for safe evaluation environments. Current simulation capabilities include aircraft, vehicle, locomotive cab, operations control rooms and air traffic control towers. Field research, however, allows for the transfer of the research from laboratory settings to actual operations. A research program in inattentional and change blindness needs to consider the value of all levels of research.

References

Aivar, M. P., Hayhoe, M.M., Chizk, C.L., & Mruczek, R.E.B. (2005). "Spatial memory and saccadic targeting in a natural task." J Vis **5**(3): 177-93.

Apfelbaum, H. L., Apfelbaum, D. H., Woods, R.L., & Peli, E. (2008). "Inattentional blindness and augmented-vision displays: effects of cartoon-like filtering and attended scene." Ophthalmic Physiol Opt **28**(3): 204-17.

Angelone, B. L., Levin, D. T., & Simons, D. (2003). "The relationship between change detection and recognition of centrally attended objects in motion pictures." Perception **32**(8): 947-62.

Arndt, S. R., Wood, C. T., Delahunt, D.B., Krauss, D., & Wall, C.T. (2006). "Who's in the Back Seat A Study of Driver Inattention." Human Factors and Ergonomics Society Annual Meeting Proceedings **50**: 851-854.

Ariga, A. & Yokosawa, K. (2008). "Attentional awakening: gradual modulation of temporal attention in rapid serial visual presentation." Psychol Res **72**(2): 192-202.

Ariga, A. & Yokosawa, K. (2008b). "Contingent attentional capture occurs by activated target congruence." Percept Psychophys **70**(4): 680-7.

Arrington, J. G., Levin, D. T., Varakin, D.A. (2006). "Color onsets and offsets, and luminance changes can cause change blindness." Perception **35**(12): 1665-78.

Auvray, M., Gallace, A.,Tan, H.Z. & Spence, C. (2007). "Crossmodal change blindness between vision and touch." Acta Psychol (Amst) **126**(2): 79-97.

Bao, S. & Boyle, L. N. (2009). "Age-related differences in visual scanning at median-divided highway intersections in rural areas." Accident Analysis & Prevention **41**(1): 146-152.

Barnett, J. S., Meliza, L. L., Ross, J.M. (2006). "Automated Feedback and Situation Awareness in Net-Centric C3 Systems at Varying Difficulty Levels." The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC) **2006**(-1).

Batchelder, S., Rizzo, M., Vanderleest, R. & Vecera, S. (2003). Trafffic Scene Related Change Blindness in Older Drivers. Driving Assessment 2003 : The Second International Driving Symposium on Human Factors in Driver Assessment Training and Vehicle Design**:** 177-181.

Becker, M. W., Pashler, H., Anstis, S.M. (2000). "The role of iconic memory in change-detection tasks." Perception **29**(3): 273-86.

Becker, M. W. & Vera, S. (2007). "Attentional filtering of transients allows for a recovery from change blindness." Perception **36**(8): 1179-90.

Noah Brerman (2009) Officer in May T Crash is Indicted, Boston Globe. Down loaded on August 15, 2009 from: http://boston.com/news/local/massachussets/articles/2009/07/09/bmta_operator_in_may_crash_is_charged_with_negligence.

Bridgeman, B. & Lathrop, B. (2007). Interactions Between Cognitive Space and Motor Activity. Spatial Processing in Navigation, Imagery and Perception**:** 107-117.

Caird, J. K., Edwards, C. J., Creaser, J.I., & Horrey, W.J. (2001). Effect of Time Constraints on Older and Younger Driver Decisions to Turn at Intersections Using a Modified Change Blindness Paradigm. Driving Assessment 2001 : The First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Aspen, CO.

Caird, J. K., Edwards, C. J., Creaser, J.I. & Horrey, W.J. (2005). "Older driver failures of attention at intersections: using change blindness methods to assess turn decision accuracy." Hum Factors **47**(2): 235-49.

Cartwright-Finch, U. & Lavie, N. (2007). "The role of perceptual load in inattentional blindness." Cognition **102**(3): 321-40.

Chen, Z. (2008). "Distractor Eccentricity and its Effect on Selective Attention." Experimental Psychology (formerly "Zeitschrift für Experimentelle Psychologie") **55**(2): 82-92.

Chen, Z. & Treisman, A. (2008). "Distractor inhibition is more effective at a central than at a peripheral location." Perception & Psychophysics **70**(6): 1081-91.

Clifasefi, S. L., Takarangi, M. K. T., Melanie, K.T., & Bergman, J.S. (2006). "Blind Drunk : The Effects of Alcohol on Inattentional Blindness." Cognitive Psychology **20**(5): 697-704.

Cole, G. G., Kentridge, R. W., Heywood, C.A. (2004). "Visual salience in the change detection paradigm: the special role of object onset." J Exp Psychol Hum Percept Perform **30**(3): 464-77.

Cole, G. G., Kentridge, R. W., Gellatly, A.R.H., Heywood, C.A. (2003). "Detectability of onsets versus offsets in the change detection paradigm." J Vis **3**(1): 22-31.

Cole, G. G. & Liversedge, S. P. (2006). "Change blindness and the primacy of object appearance." Psychon Bull Rev **13**(4): 588-93.

Creaser, J. I., Edwards, C. J., Uggerslev, K.L., & Caird, J.K. (2001). "Detection of Cars and Pedestrians While Making Left Turn Decisions." Human Factors and Ergonomics Society Annual Meeting Proceedings **45**: 1607-1611.

David, E., Laloyaux, C., Devue, C. & Cleeremans, A. (2006). "Change Blindness to Gradual Changes in Facial Expressions." Psychologica Belgica **46**: 253-268.

DiVita, J. C. & Nugent, W. (2000). "Managing Critical Events in a Multimodal Watchstation." Human Factors and Ergonomics Society Annual Meeting Proceedings **44**: 469-472.

DiVita, J., & Obermayer, R. (2004). "Verification of the change blindness phenomenon while managing critical events on a combat information display." Hum Factors **46**(2): 205-18.

Droll, J. A., Gigone, K. &Hayhoe, M.M. (2007). "Learning Where to Direct Gaze During Change Detection." Journal of Vision **7**(14): 1-12.

Droll, J. A. & Hayhoe, M. M. (2007). "Trade-offs between gaze and working memory use." J Exp Psychol Hum Percept Perform **33**(6): 1352-65.

Durlach, P. J. (2004). "Change Blindness and Its Implications for Complex Monitoring and Control Systems Design and Operator Training." Human-Computer Interaction **19**(4): 423-451.

Durlach, P. J. & Chen, J. Y. C. (2003). "Visual Change Detection in Digital Military Displays." The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC) **2003**(-1).

Edwards, C. J., Caird, J. K., Chisholm, S.L. (2008). "The Effect of Driving Experience on Change Blindness at Intersections: Decision Accuracy and Eye Movement Results." Human Factors and Ergonomics Society Annual Meeting Proceedings **52**: 1243-1247.

Fick, C. S. (2007). "Flying Under the Radar : Studying Inattentional Blindness in a Dynamic Task." Dissertation Abstracts International : Section B: The Sciences and Engineering **68**(3-B): 1966.

Fletcher-Watson, S., Leekam, S. R., Benson, V., Frank, M.C., & Findlay, J.M. (2009). "Eye-movements reveal attention to social information in autism spectrum disorder." Neuropsychologia **47**(1): 248-57.

Fougnie, D. & Marois, R. (2007). "Executive working memory load induces inattentional blindness." Psychon Bull Rev **14**(1): 142-7.

Galfano, G., Mazza, V., Tame, L., Umitta, c. & Turatto, M. (2008). "Change detection evokes a Simon-like effect." Acta Psychol (Amst) **127**(1): 186-96.

Gallace, A., Tan, H. Z., & Spence, C. (2007). "Do "mudsplashes" induce tactile change blindness?" Percept Psychophys **69**(4): 477-86.

Galpin, A., Underwood, G., Crundall, D. (2009). "Change blindness in driving scenes." Transportation Research Part F: Traffic Psychology and Behaviour **12**(2): 179-185.

Gregg, M. K. & Samuel, A. G. (2008). "Change deafness and the organizational properties of sounds.(Author abstract)(Report)." Journal of Experimental Psychology: Human Perception and Performance **34**(4): 974(18).

Harding, S., Cooke, M., Konig, P. (2008). Auditory Gist Perception: An Alternative to Attentional Selection of Auditory Streams? Attention in Cognitive Systems. Theories and Systems from an Interdisciplinary Viewpoint**:** 399-416. Berlin: Springer

Hayhoe, M. M., Shrivastava, A., & Mruczek, J.B. (2003). "Visual memory and motor planning in a natural task." J Vis **3**(1): 49-63.

Hayhoe, M. (2000). "Vision Using Routines: A Functional Account of Vision." Visual Cognition **7**: 43-64.

Henderson, R. M. & Orbach, H. S. (2006). "Is there a mismatch negativity during change blindness?" Neuroreport **17**(10): 1011-5.

Ho, C. & Spence, C. (2005). "Assessing the Effectiveness of Various Auditory Cues in Capturing a Driver's Visual Attention." Journal of Experimental Psychology: Applied **11**(3): 157-174.

Hoffman, L., Yang, X., Bovaird, J.A. & Embretson, S.E. (2006). "Measuring Attentional Ability in Older Adults: Development and Psychometric Evaluation of DriverScan." Educational and Psychological Measurement **66**(6): 984-1000.

Hollingworth, A. (2005). "The Relationship Between Online Visual Representation of a Scene and Long-Term Scene Memory." Journal of Experimental Psychology: Learning, Memory, and Cognition **31**(3): 396-411.

Hollingworth, A. & Henderson, J. M. (2004). "Sustained change blindness to incremental scene rotation: a dissociation between explicit change detection and visual memory." Percept Psychophys **66**(5): 800-7.

Horstmann, G. (2006). "The time course of intended and unintended allocation of attention." Psychological Research **70**(1): 13-25.

Horstmann, G. (2005). "Attentional Capture by an Unannounced Color Singleton Depends on Expectation Discrepancy." Journal of Experimental Psychology: Human Perception and Performance **31**(5): 1039-1060.

Jingling, L. & Yeh, S.-L. (2007). "New objects do not capture attention without a top-down setting: Evidence from an inattentional blindness task." Visual Cognition **15**: 661-684.

Johansson, P., Hall, L., Sikstrom, S., Tarning, B. & Lind A. (2006). "How something can be said about telling more than we can know: On choice blindness and introspection.(Author abstract)." Consciousness and Cognition **15**(4): 673(20).

Jones, L. A. & Sarter, N. B. (2008). "Tactile Displays: Guidance for Their Design and Application." Human Factors: The Journal of the Human Factors and Ergonomics Society **50**(1): 90-111.

Karn, K. S. & Hayhoe, M. M. (2000). "Memory representations guide targeting eye movements in a natural task." Visual Cognition **7**: 673-703.

Kimura, M., Katayama, J., Ohira, H. (2008). "Event-related Brain Potential Evidence for Implicit Change Detection : A Replication of Fernandez-Duque et al. (2003)." Neuroscience Letters **448**(3): 236-239.

Knott, C. C., Nelson, W. T., McCroskey, M.K. & Miller , B.T. (2007). "Do You See What I See? Effects of Communication on Scanning Strategies in Change Detection by Individuals and Teams of Observers." Human Factors and Ergonomics Society Annual Meeting Proceedings **51**: 1186-1190.

Koivisto, M., Hyona, J., Revonsuo, A. (2004). "The effects of eye movements, spatial attention, and stimulus features on inattentional blindness." Vision Res **44**(27): 3211-21.

Koivisto, M. & Revonsuo, A. (2008). "The role of unattended distractors in sustained inattentional blindness." Psychol Res **72**(1): 39-48.

Koustanaï, A., Boloix, E., van Elslande, P. & Bastien, C. (2008). "Formation of expectations while driving: Influence of the possibility and the necessity to anticipate on the ability to identify danger." Transportation Research Part F: Traffic Psychology and Behaviour **11**(2): 147-157.

Krupenia, S. & Sanderson, P. M. (2006). "Does a Head-Mounted Display Worsen Inattentional Blindness." Human Factors and Ergonomics Society Annual Meeting Proceedings **50**: 1638-1642.

Landman, R., Spekreijse, H., Lamme, V.A. (2004). "The role of figure-ground segregation in change blindness." Psychon Bull Rev **11**(2): 254-61.

Lee, Y.-C. (2007). "Cognitve Loads and the Guidance of Attention in Complex Dynamic Environments." Dissertation Abstracts International : Section B: The Sciences and Engineering **67**(8-B): 4634.

Lee, J.-H. & Spence, C. (2008). Spatiotemporal Visuotactile Interaction. Haptics: Perception, Devices and Scenarios**:** 826-831.

Lee, Y. C., Lee, J. D., Boyle, L.N. (2007). "Visual attention in driving: the effects of cognitive load and visual disruption." Hum Factors **49**(4): 721-33.

Lee, J. D., Caven, B., Haake, S. & Brown, T.L. (2001). "Speech-Based Interaction with In-Vehicle Computers: The Effect of Speech-Based E-Mail on Drivers' Attention to the Roadway." Human Factors: The Journal of the Human Factors and Ergonomics Society **43**(4): 631-640.

Levin, D. T. (2002). "Change Blindness Blindness as Visual Metacognition." Journal of Consciousness Studies **9**(5-6): 111-130.

Levin, D. T., Drivdahl, S. B., Momen, N. & Beck, MR. (2002). "False predictions about the detectability of visual changes: the role of beliefs about attention, memory, and the continuity of attended objects in causing change blindness blindness." Conscious Cogn **11**(4): 507-27.

Levin, D. T., Simons, D.J., Angelone, B.L., & Chabris, C.F. (2002). "Memory for Centrally Attended Changing Objects in an Incidental Real-World Change Detection Paradigm." British Journal of Psychology **93**: 289-302.

Levin, D. T. & Varakin, D. A. (2004). "No pause for a brief disruption: failures of visual awareness during ongoing events." Consciousness and Cognition **13**(2): 363-72.

Ludwig, C. J. H. & Gilchrist, I. D. (2002). "Stimulus-Driven and Goal-Driven Control Over Visual Selection." Journal of Experimental Psychology: Human Perception and Performance **28**(4): 902-912.

Macdonald, J. S. P. & Lavie, N. (2008). "Load Induced Blindness." Journal of Experimental Psychology : Human Perception and Performance **34**(5): 1078-1091.

Mack, A. (2002). "Is the visual world a grand illusion? A response." Journal of Consciousness Studies **9**: 102-110.

Mantyla, T. & Sundstrom, A. (2004). "Changing scenes: memory for naturalistic events following change blindness." Memory **12**(6): 696-706.

Martinez-Conde, S. & Macknik, S. L. (2008). "Magic and the brain.(Neuroscience)." Scientific American **299**(6): 72(8).

Mazza, V., Turatto, M., et al. (2005). "Foreground-background segmentation and attention: a change blindness study." Psychol Res **69**(3): 201-10.

McCarley, J. S., Vais, M. J., Pringle, H., Kramer, A.F., Irwin, De.E., & Strayer, D.L. (2001). Conversation Disrupts Visual Scanning of Traffic Scenes.

Memmert, D. (2006). "The effects of eye movements, age, and expertise on inattentional blindness." Conscious Cogn **15**(3): 620-7.

Memmert, D. & Furley, P. (2007). ""I spy with my little eye!": breadth of attention, inattentional blindness, and tactical decision making in team sports." J Sport Exerc Psychol **29**(3): 365-81.

Merikle, P. & Smith, S. (2005). Memory for Information Perceived Without Awareness. Dynamic Cognitive Processes**:** 79-99.

Michalke, T., Fritsch, J., Goerick, C. (2008). Enhancing Robustness of a Saliency-Based Attention System for Driver Assistance. Computer Vision Systems**:** 43-55.

Mitroff, S. R. & Simons, D. J. (2002). "Changes are not localized before they are explicitly detected." Visual Cognition **9**: 937-968.

Most, S. B., Scholl, B.J., Clifford, E.R., & Simons, D.J. (2005). "What you see is what you set: sustained inattentional blindness and the capture of awareness." Psychol Rev **112**(1): 217-42.

Most, S.D., Simons, D.J., Scholl, B.J., Jimenez, R., Clifford, E., & Chabris, C.F. (2001). "How Not to Be Seen: The Contribution of Similarity and Selective Ignoring to Sustained Inattentional Blindness." Psychological Science **12**: 9-17.

Neumann, J. L. & Durlach, P. J. (2004). "The Effect of Practice on Visual Change Detection in Computer Displays." Human Factors and Ergonomics Society Annual Meeting Proceedings **48**: 1905-1909.

Newby, E. A. & Rock, I. (1998). "Inattentional blindness as a function of proximity to the focus of attention." Perception **27**(9): 1025-40.

Niedeggen, M., Wichmann, P., Wichman, P. & Stoerig, P. (2001). "Change Blindness and Time to Consciousness." European Journal of Neuroscience **14**(10): 1719-1726.

Noe, A. (2007). Inattentional Blindness, Change Blindness, and Consciousness. The Blackwell Companion to Consciousness. M. Velmans and S. Schneider. Malden, Blackwell Publishing**:** 504-511.

Olsson, H. & Poom, L. (2005). "Visual memory needs categories." Proceedings of the National Academy of Sciences in the United States **102**(24): 8776-80.

O'Regan, J. K. & Noe, A. (2001). "A sensorimotor account of vision and visual consciousness." Behav Brain Sci **24**(5): 939-73; discussion 973-1031.

O'Regan, J. K., Rensink, R. A., et al. (1999). "Change-blindness as a result of 'mudsplashes'." Nature **398**(6722): 34.

Pappas, J. M., Fishel, S.R., Moss, J.D., Hicks, J.M., & Leech, T.D. (2005). "An Eye-Tracking Approach to Inattentional Blindness." Human Factors and Ergonomics Society Annual Meeting Proceedings **49**: 1658-1662.

Pavani, F. & Turatto, M. (2008). "Change perception in complex auditory scenes." Percept Psychophys **70**(4): 619-29.

Pearson, P. & Schaefer, E. (2005). "Toupee or not toupee? The role of instructional set, centrality, and relevance in change blindness." Visual Cognition **12**: 1528-1543.

Pizzighello, S. & Bressan, P. (2008). "Auditory attention causes visual inattentional blindness." Perception **37**(6): 859-66.

Pourtois, G., De Pretto, M., Hauert, C.A., & Vvilleummer, P. (2006). "Time course of brain activity during change blindness and change awareness: performance is predicted by neural events before change onset." J Cogn Neurosci **18**(12): 2108-29.

Psymouli, A., Harris, D., & Irving, P. (2005). "The Inspection of Aircraft Composite Structures : A Signal Detection Theory-Based Framework." Human Factors and Aerospace Safety **5**(5): 91-108.

Recarte, M. A. & Nunes, L. M. (2003). "Mental Workload While Driving: Effects on Visual Search, Discrimination, and Decision Making." Journal of Experimental Psychology: Applied **9**(2): 119-137.

Reddy, L., Quiroga, R.Q., Wiken, P., Koch, C., & Fried, I. (2006). "A single-neuron correlate of change detection and change blindness in the human medial temporal lobe." Curr Biol **16**(20): 2066-72.

Reingold, E. M., Charness, N., Pomplun, M. & Sampe, D.M. (2001). "VISUAL SPAN IN EXPERT CHESS PLAYERS: Evidence From Eye Movements." Psychological Science **12**(1): 48.

Richard, C. M., Wright, R.D., Ee, C., Prime, S.L., Shimizu, Y. & Vavrits, J. (2002). "Effect of a Concurrent Auditory Task on Visual Search Performance in a Driving-Related Image-Flicker Task." Human Factors: The Journal of the Human Factors and Ergonomics Society **44**(1): 108-119.

Rizzo, M., Sparks, J., McEvoy, S., Viamonte, S., Kellison, I. & Vecera, S. (2009). "Change blindness, aging, and cognition." J Clin Exp Neuropsychol **31**(2): 245-56.

Rizzo, M., Stierman, L. Skaar, N., Dawson, H.D., Anderson, S.W., & Vecera, S.P. (2004). "Effects of a Controlled Auditory—Verbal Distraction Task on Older Driver Vehicle Control." Transportation Research Record: Journal of the Transportation Research Board **1865**(-1): 1-6.

Rodway, P., Gillies, K., & Schepman, A.(2006). "Vivid Imagers Are Better at Detecting Salient Changes." Journal of Individual Differences **27**(4): 218-228.

Rodriguez, A., Jantzi, J., & Smith, D.R. (2005). "Change Blindness: Detecting Icon Position Change in Military Information Displays." Human Factors and Ergonomics Society Annual Meeting Proceedings **49**: 283-286.

Rolls, E. T. (2008). "Top-down control of visual perception: attention in natural vision." Perception **37**(3): 333-54.

Rowe, G., Valderrama, S., & Hasher, L. (2006). "Attentional Disregulation: A Benefit for Implicit Memory." Psychology and Aging **21**(4): 826-830.

Saiki, J. (2002). "Multiple-object permanence tracking: limitation in maintenance and transformation of perceptual objects." Prog Brain Res **140**: 133-48.

Schwarz, W. & Kuhn, S. (2008). "Better to take one long or two quick looks? Independent processing of evidence from discrete visual presentations.(Author abstract)(Report)." Journal of Experimental Psychology: Human Perception and Performance **34**(6): 1337(16).

Shalgi, S., O'Connell, R., Deouell, L.Y., & Robertson, I.H. (2007). "Absent minded but accurate: delaying responses increases accuracy but decreases error awareness." Experimental Brain Research **182**(1): 119-124.

Schankin, A. & Wascher, E. (2008). "Unvoluntary attentional capture in change blindness." Psychophysiology **45**(5): 742-50.

Schankin, A. & Wascher, E. (2007). "Electrophysiological correlates of stimulus processing in change blindness." Exp Brain Res **183**(1): 95-105.

Schlienger, C., Conversy, S., et. al. (2008). Improving Users' Comprehension of Changes with Animation and Sound: An Empirical Assessment. Human-Computer Interaction – INTERACT 2007**:** 207-220.

Scholte, H. S., Witteveen, S.C., Spekreijselt, H., & Lamme, V.A.F. (2006). "The influence of inattention on the neural correlates of scene segmentation." Brain Research **1076**(1): 106-15.

Shore, D. I. & Klein. R. M. (2000). "The effects of scene inversion on change blindness." J Gen Psychol **127**(1): 27-43.

Silverman, M. E. & Mack, A. (2006). "Change blindness and priming: When it does and does not occur." Conscious Cogn **15**(2): 409-22.

Sinnett, S., Costa, A., & Soto-Faruco, S. (2006). "Manipulating inattentional blindness within and across sensory modalities." Quarterly Journal of Experimental Psychology **59**(8): 1425-42.

Simons, D. J. (1997). "Change Blindness." Trends in Cognitive Sciences **1**(7): 261-267.

Simons, D.J. & Chabris, C.F. (1999). "Gorillas in our midst: sustained inattentional blindness for dynamic events". Perception, 28, 1059 – 1074,

Simons, D. J., Franconeri, S.L. et. al. (2000). "Change blindness in the absence of a visual disruption." Perception **29**(10): 1143-54.

Simons, D. J. & Jensen, M. S. (2009). "The effects of individual differences and task difficulty on inattentional blindness." Psychon Bull Rev **16**(2): 398-403.

Simons, D.J. & Levin, D.T. (1998). "Failure to detect changes to people during a real-world interaction". Psychonomic Bulletin & Review, 5(4), 644 – 649.

Smallman, H. S. & John, M. (2003). "CHEX (Change History EXplicit): New HCI Concepts for Change Awareness." Human Factors and Ergonomics Society Annual Meeting Proceedings **47**: 528-532.

Smilek, D., Eastwood, J.D., Reynolds, M.G., & Kingstone, A. (2008). "Metacognition and change detection: do lab and life really converge?" Conscious Cogn **17**(3): 1056-61.

Smith, H. & Milne. E. (2009). "Reduced change blindness suggests enhanced attention to detail in individuals with autism." J Child Psychol Psychiatry **50**(3): 300-6.

Sperling, G. (1960). "The amount of information available in brief visual presentations." Psychological Monographs: General and Applied, 74(11, Whole No. 498), 1 – 29.

Stirk, J. A. & Underwood, G. (2007). "Low-level visual saliency does not predict change detection in natural scenes." J Vis **7**(10): 3 1-10.

Strayer, D. L., Drews, F.A., & Johnston, W.A. (2003). "Cell Phone-Induced Failures of Visual Attention During Simulated Driving." Journal of Experimental Psychology: Applied **9**(1): 23-32.

Strayer, D.L. & Johnston, W.A. (2001). “Driven to Distraction: Dual Task Studies of Simulated Driving and Conversing on a Cellular Telephone”. Psychological Science, 12(6), 462 – 466.

Summers, M. J. (2006). "Increased inattentional blindness in severe traumatic brain injury: evidence for reduced distractibility?" Brain Inj **20**(1): 51-60.

Tatler, B. W., Gilchrist, I.D., Rusted, J. (2003). "The time course of abstract visual representation." Perception **32**(5): 579-92.

Theeuwes, J. (2004). "No blindness for things that do not change." Psychol Sci **15**(1): 65-70.

Todd, J. J., Fougnie, D., & Marois, R. (2005). "Visual short-term memory load suppresses temporo-parietal junction activity and induces inattentional blindness." Psychol Sci **16**(12): 965-72.

Tollner, A. M. (2007). "Individual and Team Susceptibility to Change Blindness." Dissertation Abstracts International : Section B: The Sciences and Engineering **67**(11-B): 6760.

Treffner, P. J. and R. Barrett (2004). "Hands-free mobile phone speech while driving degrades coordination and control." Transportation Research Part F: Traffic Psychology and Behaviour **7**(4-5): 229-246.

Treisman, A.M. & Gelade, G. (1980). “A feature integration theory of attention”. Cognitive Psychology, 12, 97 – 136.

Triesch, J., Ballard, D.H., Hayhoe, M.M., & Sullivan, B.T. (2003). "What you see is what you need." J Vis **3**(1): 86-94.

Tripathy, S. P. & Barrett, B. T. (2004). "Severe loss of positional information when detecting deviations in multiple trajectories." J Vis **4**(12): 1020-43.

Varakin, D. A. & Levin, D. T. (2008). "Scene structure enhances change detection.(Short article)(Author abstract)(Report)." The Quarterly Journal of Experimental Psychology **61**(4): 543(9).

Varakin, D. A., Levin, D.T., & Collins, K.M. (2007). "Comparison and representation failures both cause real-world change blindness." Perception **36**(5): 737-49.

Veiel, L. L. (2005). "Change Blindness in Older Adults." Dissertation Abstracts International : Section B: The Sciences and Engineering **65**(9-B): 4865.

Velichkovsky, B. M., Dornhoefer, S.M., Kopak, M., Helmert, J. & Joos, M. (2002a). "Change Detection and Occlusion Modes in Road Traffic Scenarios." Transportation Research, Part F: Traffic Psychology and Behaviour **5**(2): 99-109.

Velichkovsky, B. M., Rothert, A., Kopf, M., Dornhoefer, S.M., & Joos, M. (2002b). "Towards an express-diagnostics for level of processing and hazard perception." Transportation Research Part F: Traffic Psychology and Behaviour **5**(2): 145-156.

Victor, T. W., Harbluk, J.L., & Engstrom, J.A. (2005). "Sensitivity of eye-movement measures to in-vehicle task difficulty." Transportation Research Part F: Traffic Psychology and Behaviour **8**(2): 167-190.

Vitevitch, M. S. (2003). "Change deafness: the inability to detect changes between two voices.(experimental psychology research)(Author Abstract)." Journal of Experimental Psychology: Human Perception and Performance **29**(2): 333(10).

Wallis, G. & Bulthoff, H. (2000). "What's Scene and Not Seen: Influences of Movement and Task Upon What We See." Visual Cognition **7**: 175-190.

Wayand, J. F., Levin, D.T., & Varakin, D.A. (2005). "Inattentional blindness for a noxious multimodal stimulus." Am J Psychol **118**(3): 339-52.

Weik, K.E. (2001) *Making Sense of the Organization*, Blackwell: Malden MA.

Werner, S. & Thies, B. (2000). "Is "Change Blindness" Attenuated by Domain-specific Expertise? An Expert-Novices Comparison of Change Detection in Football Images." Visual Cognition **7**: 163-173.

White, R. C. & Davies, A. A. (2008). "Attention set for number: expectation and perceptual load in inattentional blindness." J Exp Psychol Hum Percept Perform **34**(5): 1092-107.

Wiens, S. (2007). "Concepts of visual consciousness and their measurement." Advances in Cognitive Psychology **3**(1): 349-359.

Wolfe, J. M., Oliva, A., Bucher, S., & Arsenio, H.C. (2002). "An unbinding problem? The disintegration of visible, previously attended objects does not attract attention." J Vis **2**(3): 256-71.

Wright, M. J., Alston, L., & Popple, A.V. (2002). "Set-size effects for spatial frequency change and discrimination in multiple targets." Spatial Vision **15**: 157-170.

Yeh, Y. Y. & Yang, C. T. (2008). "Is a pre-change object representation weakened under correct detection of a change?" Conscious Cogn.

Ziefle, M., Pappachan, P., Jakob, E.M., & Wallenowitz, H. (2008). Visual and Auditory Interfaces of Advanced Driver Assistant Systems for Older Drivers. Computers Helping People with Special Needs**:** 62-69.