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BEHAVIORAL ACCIDENT AVOIDANCE SCIENCE: UNDERSTANDING RESPONSE IN COLLISION INCIPIENT CONDITIONS

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Abstract

Road traffic accidents are the single greatest cause of fatality in the workplace and the primary cause of all accidental death in the U.S. to the age of seventy-eight. However, behavioral analysis of response in the final seconds and milliseconds before collision has been a most difficult proposition since the quantitative recording of such events has largely been beyond cost feasibility for road transportation. Here, we report a new and innovative research strategy that permits just such a form of investigation to be conducted in a safe and effective manner. Specifically, we have constructed a linked simulation environment in which drivers are physically located in two adjacent, full-vehicle simulators acting within a shared single virtual driving world. As reported here for the first time, this innovative technology creates situations that provide avoidance responses paralleling those observed in real-world conditions. Within this shared virtual world we tested forty-six participants (25 female, 21 male) who met in two ambiguous traffic situations: an intersection and a hill scenario. At the intersection the two drivers approached each other at an angle of one-hundred and thirty-five degrees and buildings placed at the intersection blocked the view of both drivers from early detection of the opposing vehicle. The second condition represented a 'wrong' way conflict. Each driver proceeded along a three-lane highway from opposite directions. A hill impeded the oncoming view of each driver who only saw the conflicting vehicle briefly as it crested the brow of the hill. We recorded driver avoidance responses of steering wheel, brake, and accelerator activation to the nearest millisecond. Qualitative results were obtained through a post-experience questionnaire in which we asked participants about their driving habits, simulator experience and their particular response to the experimental events which they had encountered. Our results indicated that: 1) we created situations which provided avoidance responses as they have been recorded in real-world circumstances, 2) the recorded avoidance responses depended directly upon viewing times, and 3) the very short viewing times in this experiment resulted in a single avoidance action, largely represented by a random choice of swerve to either right or left. The present results lead us to posit that in order to be able to design accident avoidance mechanism that respond appropriately in the diverse situations encountered, we need to pay particular attention to mutual viewing times for drivers. The general implications for a behavioral science of collision-avoidance are evaluated in light of the present findings.

BEHAVIORAL ACCIDENT AVOIDANCE SCIENCE: UNDERSTANDING RESPONSE IN COLLISION INCIPIENT CONDITIONS

1. Introduction

The greatest single cause of fatality in the workplace is road traffic accidents. This startling fact is masked by two fundamental but obscuring issues. First, the workplace is traditionally considered to be a static location and so accidents which occur in vehicles in diverse locations are often excluded from the figures concerning workplace injury. Second, transportation accidents are themselves considered a single epidemiological category and so the traffic injuries associated with work are included in the general count of all road traffic crashes. The result of this form of categorization is that vehicle injuries are frequently overlooked or even excluded in the examination of the hazards of working life. Ergonomists work very hard to improve workplace safety and while we especially respect the achievements of allied researchers involved in traffic safety we believe that a fruitful marriage can be made between ergonomic knowledge and the problems posed by traffic accidents. It is this overarching theme that motivates our work.

The present traffic safety community labors against a particularly insidious problem, which is that road traffic accidents are often considered by the public as somehow pre-destined. This popular fatalism is evident especially in high-profile accidents such as the one that resulted in the death of Princess Diana[1]. Although the fund subsequently established in her name provides millions of dollars of support in areas as safety critical as mines decommissioning, it directs no substantive funds toward road accident reduction, the cause of her death! Indeed, such fatalism is reflected also in the fact that the vast majority of safety resources which to date have been directed to the accident question have focused overwhelmingly on crash survival. We are second to none in our admiration of those who have made crucial advances in air bag, crush zone, and restraint technology, they have assuredly saved many thousands of lives. However, it is almost as if collision were a given and the primary safety mandate is the protection of those already involved in such untoward events.

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[1] In exposing many of the supposed conspiracy theories associated with the accident, Gregory (1999) was able to write: "In the shock of Diana's death, many had sought to impose a kind of romantic unity on her senseless end,

We believe this emphasis needs to be changed and that a formal science of ***behavioral accident avoidance*** should be established which draws heavily upon the armory of knowledge and tools possessed by those in Ergonomics research. We claim no unique precedent in this establishment and indeed point to the fast growing technical developments of collision-warning and collision-avoidance technologies of Intelligent Transportation Systems (ITS) as evidence of such burgeoning concern. The human-centered approach is clearly one in which those in Ergonomics provide the lead. Thus, when the vehicle is the workstation, there is a crucial role for those in both physical and cognitive ergonomics in the battle against this silent but most deadly of occupational hazards. Further, we see this marriage as one that benefits both traffic safety and ergonomics since the fundamental issues of human error and response limitation are a strong mutual concern of each (see Hancock 2000). The field of behavioral accident avoidance has only recently become open to empirical investigation through technical innovations in linked simulation and it is this approach we have helped pioneer to produce the results first reported in this work. As a first step, we address the larger picture of accident occurrence as found in major epidemiological accident databases.

1.1. *Accident Information*

While the number of motor vehicle collisions relative to the number of vehicles on the road has diminished, the increase in the absolute number of collisions and thus the total number of people killed and injured indicates the persistent and destructive global impact that motor-vehicle accidents have. In 1998, in the United States alone, there were over 6.3 million police reported traffic crashes. Over 37,000 people lost their lives and 4.3 million people were injured (NHTSA, 1998). More than four million collisions involved just property damage and it is reasonable to assume that there were many more collisions of lesser severity that went unreported to any database. Our efforts here are initially most relevant to multiple vehicle collisions and in 1998, there were 16,184 such fatalities. Of these 46.3% (7,489) occurred with vehicles approaching at an angle, 32.4% (5,243) occurred in a head-on configuration, 11.7% (1,896) were rear-end collisions and 3.7% (599), were side angle collisions. This national pattern

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speculating on a marriage which would lend an air of a classical tragedy to what was ***a thoroughly ordinary death in an avoidable car crash.***" (p. 125). (Bold and Italics ours).

is also reflected in crash statistics for the State of Minnesota. In 1998, Minnesota reported 92,926 traffic crashes in which 650 people lost their lives and 45,115 were injured. Of this total, 65.95 % (61,289) involved multiple vehicles in which both were in motion.

One level of clarification of these findings can'be found by examining reported vehicle tracks prior to collision. These data are derived from diagrams in police reports and are presented in table 1. Examining the adjusted figures, we find that the top three categories of crash each involve multiple vehicle configurations. These include; rear-end collisions, left-turns against on-coming traffic and right-angle crashes (see Hancock, Rahimi, Wulf, & Briggs 1988, Hancock, Caird, & Johnson 1991, Caird & Hancock 1999). Each of these is particularly relevant to the form of investigation considered in the present experimental procedure. Thus, crash data confirm that inter-vehicle collision is a crucial concern and one that addresses the majority of crashes including fatality and major injury. These collective findings confirm the societal damage resulting from road traffic accidents and, further, show the relevance of our particular concern for injury and fatality reduction. In this sense, the epidemiological data serve to focus and direct our efforts.

[Insert Table 1 about here]

1.2. *Accident Evaluation*

Accidents are examined by many different disciplines at many different levels. We have illustrated this in Figure 1 with a Cartesian coordinate system using the axes of space and time of progressively increasing magnitude. For example, the epidemiological perspective we have initially employed examines accident patterns on a very large scale. Typically, databases are National in scale and often are compiled yearly thus they integrate over large spatial and temporal scales. As we have shown, such information helps us to frame National policy and show general areas in which to focus more specific research, i.e., the problems of very young and older drivers as shown by classic 'bath-tub' curve. At the other end of the scale we have mechanical engineers involved with crash severity mitigation technologies such as 'crush zones' 'airbags' and similar developments. Their window on the accident process is framed in terms of milliseconds and inches since this is the 'scale' of their phenomena of interest. In the growth of any one area of research, scientists endeavor to expand their range of concern, for example, traffic engineers have traditionally constructed models of traffic flow to better help design and manage roadways. Often, such models focused upon freeway flow with 'node' points every mile of freeway model. Today, such researchers are refining their spatial and temporal scales, advocating the addition of arterials and local streets and digitizing at the scale of yards while significantly increasing the temporal frequency of their sampling also. Thus, in the search for causation it is often the case that scientists appeal for explanation to levels of other spatio-temporal levels of analysis.

[Insert Figure 1 about here]

Here, we argue that to truly understand accidents, we have to examine such phenomenon at the behavioral level of analysis. We have to comprehend events over the range of meters and seconds, since these are the scales of immediate human perception (James 1890, Hancock & Chignell 1995). Until recently, quantitative information concerning behavioral response in accident events has been most difficult to collect since we cannot intentionally expose any individual to that level of danger. Subjective accounts of such events experience severe problems associated with interference to memory recall. While some forms of reconstruction can inform as to pre-collision physical maneuvers, almost no technique can elucidate the human perceptual, cognitive, and motor responses that occur in the last fateful seconds before impact. Thus we affirm that the present experimental innovation provides a new 'window' on the accident process that we hope to exploit to provide new information on such crucial events in transportation and many realms beyond.

1.3. *Investigative Rationale*

In view of the above observations, there should be relatively few experimental research reports on driver performance in incipient crash circumstances and indeed this is the case. Beyond the vehicle trajectories and subjective report, it is immensely difficult to assemble this portrait of momentary driver response. Most existing research has concentrated on who gets into dangerous or accident-likely situations (Hakinnen 1979, Summala 1996,1987, Rothengatter 1997, Trimpop & Kirkcaldy 1997, Berthelon, Mestre, Pottier, & Pons 1998). However, evaluating and comprehending quantitative aspects of behavioral response in the vital milliseconds before collision has rarely been reported. Such research that does exist concentrates mainly on obstacle avoidance maneuvering where the obstacle put in the field of travel is 'controlled' in some preset fashion, (Barrett, Kobayashi, & Fox 1966, Rundkvist 1973, Rice & Dell'Amico 1979, Malaterre, Ferrande, Fleury, & Lechner 1988, Lerner, Huey, McGee, & Sullivan 1995). Whenever another vehicle was present it was controlled by the experimenter (Malaterre et al. 1988, Lechner & Malaterre 1991). Such approaches render very important data, however, they are limited in that they cannot ascertain and evaluate the reciprocal action between drivers who mutually adapt to the incipient demands.

There are other forms of investigation, which could inform us as to behavior in collision-likely conditions. These can be divided into three basic categories. The first category focuses on time-to-contact, time-to-passage, and curve negotiation (see for example, Manser & Hancock, 1997). The questions here concerns the nature of the information drivers use to determine 'safe' behavior with respect to the constraints of the roadway and the actions of other drivers (Sidaway, Fairweather, Sekiya, & McNitt-Gray 1996, Caird & Hancock 1994, Manser & Hancock 1997). The relationship to collision is an implicit one with the often unstated but pervasive expectation that poor time-to-contact performance will be correlated and causally linked with collision involvement. This is especially the case when drivers in the real world are required to judge motion-in-depth, such as in the case of an on-coming vehicle at a left-turn. Evidence for such a correlational relationship is sparse and a causal relation in the real world has still to be demonstrated. Nevertheless, the obvious fact that time-to-contact estimates and collisions are both intimately involved with navigating around complex, changing environments cannot be denied and it is upon this general basis at least, that such research is hopeful of adding to crash comprehension (see Hancock & Manser, 1997). While time-to-contact research is providing an important theoretical foundation it does not represent the whole picture of collision avoidance.

The second relevant field of research that is directed to determining crash causation is epidemiology. As we noted, epidemiology seeks to understand what exogenous factors contribute to crash involvement, such as age, gender, etc. Endogenous factors such as cognitive and or visual impairments, attitudes or risk taking behavior, reaction time, field dependence and close following behavior are often inferred from epidemiological information (Heyes &

Ashworth 1972, Babarik 1968, Elander, West, & French 1993, Shinar 1993, Summala, 1996). While much information has been gleaned from this form of investigation (see Evans, 1991), many causal mechanisms have yet to be clarified. It has been suggested and there is some evidence that variations in attention are related causally to accident involvement (Kahneman, Ben-Ishai, & Lotar 1973). However, as might be suspected, providing on-line evaluation of momentary attention as accidents occur imposes exceptionally difficult methodological challenges, although such challenges are being taken up. The third contributory field concerns traditional traffic engineering. This includes elements of the driving environment such as road characteristics, control devices, and traffic flow and how these factors 'cause' possible hazardous situations (Rajalin, Hassel, & Summala 1997, Steyvers & de Waard 1997). The confluence of this collective evidence provides a general framework for behavioral accident avoidance, however, it does not inform us as to the exact behavioral response just prior to the accident or more importantly inform us as to what characteristics of response permit successful avoidance.

In this work, we are trying to determine what reaction patterns occur when driver encounter an accident likely situation and more importantly successfully avoid collision. The determination of a near-accident situation is largely up to the driver and may be construed as the point at which other road users to enter their 'safe field of travel' (Gibson & Crooks, 1938). Drivers generally adapt to changes in the traffic system, whether these changes occur in the vehicle, in the road environment, in the weather and road surface conditions, or in their own skills or state. Such reactions occur in accordance with their motivations (Summala 1987, Summala 1997, Summala & Mikkola 1994). One of the few experimental evaluations of such response is the report of Rizzo, Reicach, and McGehee (1997). These authors developed a graphic tool for analyzing driver performance and possible errors that may lead to crashes. Their participants were a group of older, licensed drivers, who were cognitively impaired due to mild or moderate Alzheimer disease. They report the advantage of using a high fidelity simulator in combination with this experimental evaluation tool as a new way of looking at accidents and individual differences in driver behavior. Another relevant study relating to the issue of individual differences in driver response is that of Babarik (1968) where it is argued that people getting into (multiple) rear-end accidents are not necessarily slower drivers than others, but actually faster. Drivers that are faster to react to somebody else braking in front of them, change the ratio of the cars to inter-vehicle space and make it harder for following drivers to avoid them. Thus slow reaction may be an advantage in this common driving maneuver.

Our hypothesis of multiple vehicle accidents is a specific one. We view the sequence of events as a form of Markov process in which the avoidance actions of each driver are necessarily linked together and act to negate each other. Thus our hypothesis is amenable to modeling through a closed-loop feedback architecture. A critical feature of the model is that the timing of the respective avoidance actions fall within the respective response times of the two involved drivers. Thus, while each driver seeks specifically to avoid the other, their sequential responses act to nullify their goal of mutual avoidance. The fact that these 'conditions' in which the respective responses become 'locked' together are rare, is reflected in the relatively infrequency of accidents in general as set against the opportunity of their occurrence. Below, we examine our dynamic systems based theory in a specific situation but we are especially aware that our conception can well address other collision configurations and indeed a accident etiology in a wide spectrum of other circumstances well beyond transportation.

2. Experimental Method

In order to answer the question of how drivers perform in an accident-likely situation, a simulated environment was constructed in which two drivers meet each other in the same virtual world in a situation that has a strong potential for an accident. Driver performance is assessed by velocity control, braking, as well as steering response. We chose the respective scenarios in this study based upon accident statistics for the State of Minnesota and the whole United States. In the U.S., the three most common accidents situations are the angled, head-on, and rear-end collision. For Minnesota, the situation is somewhat different, since the accident statistics are differently grouped. However, when we sum left-turn oncoming traffic, right-turn cross traffic and right angle collisions together, we end up with a percentage of over 24%, which is comparable to the numbers reported for the whole USA. Simply providing possible crash scenarios does not necessarily mean that the crash will end up in that same category. We cannot predict driver performance to that detail. This means that we need to provide scenarios that will include as many as possible of the prominent categories of accidents: angle (right/left and turning), head-on, and rear end. For this particular study we choose two major crash types, the head-on collision and intersection collisions.

2.1. *Experimental Facility*

In order to accomplish the task of investigating collision-likely conditions, we used the dual simulation facility at the Human Factors Research Laboratory at the University of Minnesota that is shown diagrammatically in figure 2.

[Insert figure 2 about here]

This configuration is represented two adjacent, full-vehicle simulators, which share a common, virtual-world. The vehicles 'appear' to one another in a shared virtual world and thus the drivers can interact with each other. In comparable forms of simulation, the alternate vehicles either follow prescribed, pre-set paths and essentially do not interact with the human driver at all, or they follow some form of avoidance algorithm generated in the software, which represents a programmer's view of avoidance behavior not normal dynamic response. It is only in our shared environment that live drivers mutually interact with one another.

One of the vehicles (a 1990 Honda Accord) was located in front of a flat screen display that was nine feet from the driver's eye point. An Electrahome three-lens projector projected a 7.5 by 5.5-ft. field of view composed of a 1024 by 768-pixel display. Sound feedback was provided through a Sony Stereo receiver with home theater speakers and a base shaker system that gave a representation of road and vehicle noise as calibrated to the momentary speed of the vehicle. A second vehicle (a 1990 Acura Integra) was located in a wrap around simulator, whose dimensions were 549 cm at maximum and 492 cm diameter at the floor. The eye-point of the driver was located 8.5 ft from the screen. Sound feedback was provided by a satellite-subwoofer speaker system in the vehicle trunk and high-powered subwoofers under the driver's seat.

2.2. *Scenario Description*

In order to explore driver behavior enacted in collision-likely conditions, the first requirement is to generate such conditions. This presents a number of conceptual and methodological challenges. In order that the findings from such simulation research be valuable in understanding real-world collisions, the development of the scenarios have to be as realistic as possible. That is, the drivers cannot be in the position of 'expecting' either a collision, or a near-collision event. Further, in order to understand the unconstrained behavior of drivers, it is not possible to then constrain their behavior in terms of free-control of the vehicle. Therefore, one of the first problems to be faced is how to coordinate the actions of the two drivers without their being aware of the on-coming event. We achieve this objective through use of traditional traffic control devices by having the drivers stopped at a traditional stop-light. When both drivers are in position, we let them proceed into one of the two scenarios, see figure 3. As a result, we developed two scenarios that sought to answer these concerns and these are illustrated in figure 4 and 5.

[Insert figures 3, 4, and 5 about here]

The first scenario involved an unregulated, off-angle intersection. Both drivers approached the intersection and their mutual sight distance and therefore time prior to conflict could be controlled through the imposition of obstructive buildings positioned on the two corners of the intersection. This is a realistic circumstance for collision, although in many countries, sight distances at intersections are regulated to avoid this form of crash. In the second scenario, two drivers were placed on a uni-directional, three-lane highway and told to proceed in a safe manner obeying the traffic central laws. The drivers proceeded toward each other while their mutual progress was obscured by a hill whose dimensions and characteristics were manipulated in software, in order to influence sight distance and thus time for avoidance. This general condition is the equivalent in the real world to a 'wrong-way' incursion along a one-way thoroughfare. Thus the circumstance was unusual but not unrealistic.

2.3. *Experimental Participants*

Forty-six participants (25 female, 21 male) were recruited from staff and students of the University of Minnesota. All participants included in the analysis currently held a Minnesota driver's license; they had normal, or corrected to normal vision, and were between the ages of 18 and 80 years. Specifically, the mean age was 22.14 years of age (std. 4.07 year). All drivers completed a driving questionnaire concerning their driving experience and driving habits and were debriefed as to the nature of the experimental procedure and their reactions to the procedure following completion. The rules and regulations of the permission of the Human Subjects Committee were adhered to at all times.

2.4. *Experimental Procedure*

Participants came into the Human Factors Research Laboratory in pairs. Unbeknownst to each other, these two participants drove in the same simulated environment together. If, however, one of the two participants did not show up, one of the experimenter's would driver the flat-screen simulator and act as an unresponsive driver, meaning, the experimenter drove at a constant speed of 45 mph and was totally inactive when an accident likely situation occurred. These cases are referred to as a 'single-case' and were subject to separate analyses. Participants were randomly assigned to either the wrap-around simulator, or the flat screen simulator. In the single-case trial, however, the participant always drove in the wraparound simulator.

All participants were given practice that lasted five minutes, or until they felt comfortable driving the vehicle in our simulated environment. At the end of practice all participants were asked via a standardized checklist if they felt comfortable enough to proceed with the next stage of the experiment. The experimenter then stepped out of sight and both participants were presented with four subsequent scenarios. Participants were asked to accelerate up to 45 mph, in the lane that they were positioned in, at the start of the trial. During the trial they were informed that it is their task to drive at a safe and comfortable speed and obey any traffic laws that may apply. In this way driving behavior is structured as it occurs in the real world, but not constrained unrealistically. All scenarios started with a red traffic light displayed on the screen. Participants were instructed to start driving when it turned green. The first and third scenarios consisted of a straight two-way road with buildings on either side. Other vehicles occurred both in the driver's own lane and the on-coming lane, but no accident likely situations occurred. In these two scenarios that each lasted about 2 minutes, the two cars were not coupled.

The two cars were coupled into the same simulated environment in the second and the fourth scenario. After confrontation in the second scenario, both participants drove for another minute and were then uncoupled to drive the third trial. This trial again lasted two minutes where other traffic again was present but no accident likely situations occurred. Participants were then coupled again and the fourth scenario was displayed. Following confrontation participants would drive for another minute until the experimenter reappeared and told them the experiment had ended. Immediately after the experiment, participants were asked to fill in a questionnaire that consisted of questions about themselves and their driving habits, a survey on accidents the participants were involved in the past, and their remembrance of perceptions and actions before and during the accident. Questions about the feeling of control of the simulator and car and questions to gain information on the remembrance of perceptions and actions of the participants during the trials and possible accidents were also asked. After completing the questionnaire participants were debriefed as to the purpose of the study. The experimenter finally ensured that all participants left the experiment feeling relaxed and comfortable.

2.5. *Experimental Design*

In only one trial scenario (the intersection) the participants have a different viewpoint of the simulated world approaching from different directions to the 'target location'. The 'target location' is where the two cars are in an accident-likely situation and where avoidance strategies were measured. The intersection scenario is a case in which the two participants are both positioned in front of a stoplight and start driving at the same time when the traffic light turned green. In this way we can ensure, as far as possible, that the participants are coupled in a timely manner and thus give the greatest probability of conflict. After 200 meters both cars approached the intersection where the view from the other car is blocked by a building standing at the corner of the intersection. The two drivers cannot see each other and because there are no stop signs positioned at the intersection this is an accident-likely situation. The second coupled trial scenario involves the hill. Both cars started driving through a rural environment and were positioned on the middle lane of a three lane one-way road. They each start at a stoplight at the base of the hill. Both participants presumably 'assume' that no traffic will face them, but they are driving in the same lane on the same road approaching each other head on. They are not able to see however, because of the intervening hill. At the crest, or a little beyond (the 'target location') the two cars meet and it is here that avoidance strategies are measured. To examine avoidance strategies, we examined three responses: swerving, acceleration, and braking. We look upon braking and acceleration as active responses whereas releasing the accelerator is a more passive, waiting response. We recorded the 20 seconds before during and after the point of closest approach. Even if drivers did not collide, they often swerve off the road seconds after the avoidance maneuver, as they don't appear to be able to stabilize due to, for example, distraction or shock.

3. Experimental Results

For the purposes of analysis, the results from the two scenarios were examined individually. In the intersection scenario, we evaluated the reactions of 13 pairs of drivers compared to the hill scenario in which we examined responses from 16 driver pairs. Decisions to exclude data for specific pairs from analysis were based on a number of factors. The first factor, consisting of four cases, involved the intersection scenario and was represented by a significant discrepancy in velocity between the two participants (>30 kilometers per hour at point of first sight). This led to situations where only one of the two participants briefly saw another vehicle passing the intersection far away in the distance and in these cases, neither of the two drivers engaged in any avoidance behavior. These velocities discrepancies are evidence of just how difficult it is to create collision-likely conditions when no direct control can be exert over driver response. The second exclusion of three cases involved the hill scenario and was justified by the fact that one of the two participants decided to drive in a lane other than the middle one by changing lanes prior to encountering the conflict situation. Again this represents an individual driving decision which our protocol permitted but which essentially negated the sought after avoidance response. In one hill trial, the speed difference between the two vehicles meant that the cars encountered each other near the base of one side of the hill. This led to a situation with greatly extended viewing times and therefore was incompatible with all other recorded trials. However, from this trial, information was individually very useful and we employed this particular result as illustrative of a multiple response avoidance event that is the basis of a following investigation. We discuss this particular trial later in greater detail.

For the analyzed trials, point of first sight and point of closest approach were calculated using the following procedure. First, we determined the distance between the two vehicles throughout the whole trial by using the following coordinate equation:

$$d = \sqrt{((x\ coordinate\ of\ car\ \#1) - (x\ coordinate\ of\ car\ \#2)2) + ((y\ coordinate\ of\ car\ \#1) - (y\ coordinate\ of\ car\ \#2)2)}.$$

Once the distance between the cars for every data point was determined the respective points at which the two drivers are able to see each other for the first time are specified. These were calculated as 56 meters for the hill scenario and 209 meters for the intersection scenario. The point of closest approach is specified as the location where the minimal value of *d* is recorded. The following results are discussed in terms of first, the intersection trials and then the hill trials.

3.1. *Intersection Scenario Results*

The mean age of the eight males and eighteen female drivers in this scenario was 21.4 years. All had valid drivers' licenses that had been in their possession for an average of five years and they drove an average of 600 miles per month. Each participant was asked to answer a debriefing questionnaire designed to elicit responses concerning their driving habits, their perception of the simulator and the simulator controls, their perception of the trial conditions, and their perception of their own behavior and performance. The questionnaire was composed of a combination of Likert-type, forced choice, and open-ended questions. Of their own on-road driving, they reported using city streets and highways more often than rural roads and almost never following a car too closely but almost always knowingly driving faster than the posted speed limit. They only periodically drove faster than the weather, traffic or road conditions allowed. Eight participants had been involved in a self-reported accident. In general participants reported normal driving behaviors and felt comfortable in the simulated environment. They felt in control of the steering, gas and brake and drove at a speed that felt safe and comfortable. Twenty-five out of the forty-six participants felt their vision of traffic was obscured during part of the experience with most comments related to the intersection situation. This was reasonable given that our intended manipulation of sight distance in the intersection was specifically through the use of buildings to obstruct such sight distance. Characteristics of the participants based on the results of the questionnaires specific for these trials can be found in table 2.

[Insert table 2 about here]

In respect of the quantitative results for the intersection trials, the first outcome was that the intersection scenario evoked considerably fewer active avoidance maneuvers compared with the hill scenario. Only nine participants felt it likely at some point in the trial they were getting into an accident and only two drivers reported having experienced an accident. Speed differences between drivers had an overwhelming influence here since any significant difference meant that no conflict occurred. The closest point of approach had a wide range (5.47–44.33 meters), resulting a mean of 19.4 meters and a standard deviation of 14.22 meters. Given the longitudinal difference for an accident (i.e., instant co-location of the two virtual vehicles) was only 4.5 meters and the comparable lateral distance was 2.0 meters, it is evident that few actual collisions occurred. Although accident-likely situations in this particular scenario were thus infrequent, it is interesting that only three participants chose to register no response reaction at all as they approached the intersection. An overview of the response behaviors that participants manifested can be found in table 3. As is evident, the strongest response pattern is one of conservatism in the uncertain situation as represented by the reduction of speed. However, this is a relatively passive and cautious response consisting of an 'Off Gas' reaction. Positive brake activation was itself relatively rare. Few drivers exhibited any form of aggressive response, although there was one participant who sped up in order to 'beat' the other driver to the intersection. In keeping with our hypothesis, drivers who respond with different strategies, e.g., cautious versus aggressive, do not meet in this present scenario since they start at a common distance from the intersection. However, those with common response strategies do tend to encounter each other. Although this might, in general, be considered a limitation of the present intersection scenario, examining collision-likely conditions between drivers of difference response type can be accomplished in this configuration by staggering start distance. However, since the hill scenario answers this particular concern and produced significantly more conflicts it is to these results we now turn.

[Insert table 3 about here]

3.2. Hill Scenario Results

Thirty-two drivers, with a mean age of 22 years, participated in the sixteen trials. They drove six hundred miles per month on average and they had possessed a valid Minnesota Driver license for approximately six years. They classed their own driving as 'normal' and reported driving on city streets and highways 'almost always' as to 'almost never' on rural roads, which is a reasonable pattern given our local Metropolitan sample. The drivers reported almost never following a car too closely, almost always driving faster than the posted speed limit, but never faster than the road or weather conditions would allow. Fifteen participants reported having been involved in an accident and filled in our special questionnaire on these accidents. In relation to simulator control, participants felt in control of the steering, the gas, the brake and the car in general drove at a speed that was safe and comfortable.

Twenty-three participants reported that they felt their vision was obscured at some point in the trial. When asked more specifically about the obstruction all of these individuals referred to problem of not being able to see over the hill. While this accords with our experimental design to control mutual sight distance, it suggests that participants were aware of the problem of the configuration of this road. Five participants reported having lost their attention at some point in the trial. When asked directly they again referred to the road configuration as the reason for this. Twenty-nine participants reported in retrospect that they felt they were getting into an accident. They referred to a fear of another car at the other side of the hill but this was after the event had occurred. Characteristics of the drivers based on the questionnaire results are presented in table 4.

[Insert table 4 about here]

All driver pairs experienced an accident-likely event in this scenario. The closest distance between the two cars ranged from 2.91 meters to 0.374 meters. This means that all drivers needed to perform a control maneuver to avoid colliding with the car that entered their forward 'safe field of travel' (Gibson & Crooks, 1938). Twelve participants reported a crash in this situation. The distance between the cars is measured from the midpoint of each car model. When the cars are positioned head on towards each other the minimum distance without being in collision is 4.5 meters. A smaller distance is required when the cars are passing each other, at which point the minimum distance is only 2 meters. If, at the point of closest approach, the distance between two cars does not exceed 2 meters they have collided. In 8 of the 16 pairs this was the case and a collision did occur. Two participants reported a collision that in fact, according to the quantitative data for point of closest approach represented a very near miss. Ten participants correctly identified collision, and four reported not to have collided while in fact they did. All participants performed at least one avoidance maneuver and these are detailed in table 5. A representation of one of these individual avoidance maneuvers is illustrated graphically in figure 6.

[Insert table 5 about here]

As was evident in the intersection situation, the predominant response on the hill is also a passive, off the gas response. In most cases, this is not accompanied by a braking response, rather this seems to be a 'wait and see' strategy as to how the situation will develop. As for the actual avoidance maneuver itself, it is overwhelmingly a change in direction, that is lateral control of the vehicle, rather than braking which represents longitudinal control. We are very aware that our scenario promotes this form of response and indeed a valuable future contribution will be to distinguish how and in what manner the configuration of the roadway and the approaching vehicle trajectory dictates the predominant form of response. In the present circumstance, the lateral avoidance maneuver is certainly consistent with Gibson and Crooks (1938) 'field of safe travel' conception, however, it is important to note that given that each vehicle travels in the center lane, the option to go either right or left is not specified by the 'field of safe travel' proposal. As we discuss below, the response of the individuals in this experiment is informative as to our own specific hypothesis.

[Insert figure 6 about here]

Of the twenty-one participants who reported what direction they swerved in, only TWO accurately identified their own response. Given that this was a relatively benign simulation with no legal ramifications, the misidentification rate strongly illustrates the problem of memorial recall of these forms of emergency event. An important observation is that participants did not react in any systematic fashion. Right and left swerves occurred almost equally and these did not seem to be directly contingent upon any pre-emptive action on behalf of the other conflicting driver. Why this is the case is at present not clear. In point of fact, some drivers report having been taught to swerve to the right in such a condition, a most useful strategy. Therefore we performed a post-hoc calculation ascertaining that the average mutual viewing time for each pair was small (approximately 1.2 seconds on average). Given so limited a viewing time, it is evident that response patterns are essentially single reactions rather than avoidance strategies per se and thus the swerve right strategy would serve driver well in such conditions. More evidence for the restriction to a single response lies in correlations between the time of first possible sight and the onset of the first avoidance action for each driver are very high (0.998 and 0.996 respectively) as well as the fact that braking occurred only infrequently (71.8% did not use the brake pedal at all). In essence, this was a 'see and avoid' situation which did not permit enough time for multiple, linked avoidance responses to occur. Interestingly however, the correlation between the reaction times of both drivers even in this brief interval is high (0.95). This supports the contention that the behavior of the two drivers is still 'interlocked' in some fashion even for these brief mutual, viewing times. The results presented in figure 6 as well as table 6 confirm these observations. Of course we recognize the general problem of time restriction here, i.e., the drivers only have a certain 'window' of time in which to respond anyway. As a consequence of these findings, we are proceeding with subsequent experiments that open up the window of possible response by permitting longer viewing times..

[Insert table 6 and figure 7 about here]

Evidence that more extended viewing times may result in more interactive patterns of response come from the data for one pair of drivers (where the trial was designated 'Hill 18,' see figure 6). Due to the large speed difference between the two vehicles (one had crested the hill as the other began the ascent) these drivers had a much longer mutual viewing time, in the order of several seconds. This gave the opportunity to examine interaction for a greater period of time. In this case a mutual interaction did occur and although we have the evidence in the kinematic traces for the trial as illustrated in figure 6, it is perhaps best expressed by the subjective report of one of the drivers:

"When a car emerged over the top of the hill, in the lane I was in, I steered to the right, then left when the car facing me followed my direction. The car appeared to follow me when I tried to avoid it by steering right."

There is perhaps no better evidence as yet to date for the linked avoidance response hypothesis, in which the intended avoidance actions of each individual cancel each other out to result in unwanted collision.

4. Discussion

It is our hope that, using the tools and methods of the Ergonomist, we have opened a new window on the accident process by examining avoidance response at a behavioral level. In terms of the present results, we have found that when there is a relatively ambiguous driving situation in which drivers identify cues that suggest possible problems, the primary response is one of caution, expressed as an 'off the gas' action. In effect this action, by reducing velocity, serves to increase the global time-to-contact with the general problem area. As evident in the formulation of Gibson and others (see Gibson 1966, 1979, Hancock et al 1995), this action response may itself allow time for the situation to disambiguate itself and for the appropriate response action to become evident. Given the relative infrequency of accidents compared to the number of opportunities for their occurrence, it is evident that this response is overwhelmingly effective and it is only in rare or unusual circumstances that such ambiguity persists. In both of the scenarios we have investigated, the preferred acute avoidance response is one of lateral control (i.e., swerving the vehicle), as compared to our original expectation of much greater use of braking. In part, this is of course, a response to the configuration we have exposed our participants to. However, it remains a surprising finding given the supposed greater efficacy of both brake and steering response in mitigating high momentum impact.

The primary demonstration in the present experimental research was, of course, the existence proof that realistic avoidance behaviors can be created in the interactive simulation environment. As such the first, and in essence, the major contribution of this work is that a new technique is now available for the investigation and amelioration of all vehicle collisions. This conclusion is buttressed by both the objectively recorded driver responses and their concomitant subjective report of the validity of the experiences they encountered during the different scenarios. In addition, we have also addressed and provided one innovative solution to the highly intractable problem of behavior shaping. In many experiments in the behavioral research laboratory, the experimenter 'frames' the participant's response through instructions and testing protocol. In the present work, we sought specifically to overcome this form of self-fulfillment and to do so, we created purpose-specific conditions in which through the simplest of strictures 'drive safely and follow the rules of the road' we have managed to bring drivers into conflict situations which only they can resolve. Together, with these successes of methodology we have also created an interactive simulation environment in which the time-lag problem across two facilities has been sufficiently controlled to permit virtually co-incident driving. Thus the present work has exhibited technical as well as investigative success.

Having indicated these successes, it is equally important to indicate current shortfalls that provide areas in which substantive improvement is possible. In the case of the intersection scenario, the result of permitting each driver complete freedom is that the velocity differential between vehicles often negated the occurrence of conflict. This itself is evidence that providing participants freedom of action will often 'compromise' an experimental procedure to the point where the experimenter's purpose is obviated. To remedy the intersection situation, we are in the process of developing dynamic software manipulations, which, without the knowledge of either driver, or any change in the perceptual environment can momentarily change the relative positions of the respective vehicles to increase the probability of a conflict, although driver's avoidance responses will not be affected in any way.

With respect to the hill scenario, a major problem in the present experiment was mutual viewing time. With the hill curvature we have chosen, in combination with the speed selected by the drivers, the viewing time on average was sufficiently small that only a single avoidance action could be taken. In our continuing experiments we are providing longer viewing times by changing hill curvature and through the use of simulated levels of fog. However, our basic thesis concerning interaction between drivers received most encouraging support from the hill trial in which viewing time was extended by the great speed differential. In addition to these useful advances, we have had to develop some new approaches to examining the contingent dual kinematic traces, an illustration of which is shown in figure 6.

With respect to the specific findings of the present experiment in the two different scenarios, the hill trial showed unequivocally that the reaction times of the drivers permitted only a single avoidance maneuver. Overwhelmingly these maneuvers consisted of a swerve in a single direction. In respect of the limitation of viewing time this is not surprising. Further, the swerving tactic may well have been encouraged by the presence of an open lane on either side of the on-coming vehicle. We expect that specific avoidance patterns (i.e., swerving, braking, or swerving and braking) will be contingent on the characteristics of the roadway in a manner consistent with Gibson and Crooks' (1938) notion of the 'field of safe travel'. Our present methodology that we have developed permits the first true test of this proposition over sixty years since its postulation.

5. Summary And Practical Recommendations

Our first simple and practical recommendation relates to head-on collisions. Our information confirms that in the process of driver education, young drivers be taught to 'swerve to the right' in the case of incipient, head-on collision. It is clear that in any multi-vehicle collision the opportunity for avoidance and propensity for damage and injury is contingent on the actions of BOTH drivers. Thus while one driver might make a significant avoidance response, collision may still not be avoided if the other driver makes no response, or worse makes a response which cancels out that the other. Through the recommendation of the right swerve strategy, we will maximize the chance of collision avoidance even if both drivers can make only a minor correction. Parenthetically, this should probably be recommended as a left swerve for drivers in those countries that drive on the left-hand side of the road, since these respective tactics will take drivers toward the curb in each case and away from subsequent on-coming traffic. Thus, in head-on conflicts – swerve right.

In the conception, fabrication and installation of computer-assisted collision-warning and collision-avoidance systems, currently envisaged under many ITS programs, the optimal design configuration is one that reinforces and supports the natural driver avoidance response. While it is clear that the specific situation will prove a primary influence on what tactic it is best to adopt, it is clear from the present results that a system which complements the anticipatory process and assists in vehicle slowing when approaching ambiguous situations does serve the process of support for human-centered, rather than technology-centered avoidance activities. Thus, in potentially ambiguous situations, assistive devices should focus on prediction and prevention rather than instanteous amelioration as current technologies are envisaged.

Our final recommendation is one that occurs in the vast majority of experimental papers and that is a call for further research. However, here we wish to articulate such a need in a little more detail. In the present, we have only open the crack of a new window on the accident process. What is clearly required as a next step in the process is a programmatic and sustained effort on behalf of many researchers in order to take advantage of the opportunity which dynamic, interactive simulation presents. In the very first statements of the present work we established the clear societal importance of this effort for both occupational concerns and general injury. However, also evident was that the sheer number of researchers in behavioral accident avoidance research is too small for the task. Therefore, by the present work, we appeal to fellow Ergonomists to take up this challenge. Interactive simulation can certainly address traffic collisions, however, judiciously developed such a technology can also inform many other areas of human-human-machine interaction. If only one life is saved, we shall have earned our salt.

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Table 1: *Crash Involvement Illustrated by Police Diagrams. Data from Minnesota Accident Facts 1998.*

Maneuver	Reported	Percentage	Adjusted	Percentage
Rear End	20,143	21.7	20,143	21.7
Right Angle	17,363	18.7	8,682	9.3
Ran Off Road-Right	6,703	7.2	6,703	7.2
Sideswipe Passing	5,370	5.8	5,370	5.8
Ran Off Road-Left	4,918	5.3	4,918	5.3
Left Turn-Oncoming Traffic	4,537	4.9	13,218	14.2
Head On	2,516	2.7	2,516	2.7
Sideswipe Opposing	1,381	1.5	1,381	1.5
Right Turn-Cross Traffic	510	0.5	510	0.5
Other/Unknown	29,485	31.7	29,485	31.7

In the original reported data, as given in the first column, the 'right angle' category is the second largest. This is reported, however, as a significant error. Traffic engineers have measured the 'true' number of right angle accidents to be half the number the police reports. Crashes that are coded as 'right angle' are often 'left turn into oncoming traffic.' The adjusted numbers take this into account. The large number in the category 'unknown' accounts for the fact that in many cases the diagram is left blank. (See also, Minnesota Department of Public Safety, 1998, Table 1.23).

Table 2: *Characteristics of the participants in the intersection trial based on the questionnaire.*

Question	Min	Max	Mean	SD.
Age	18	31	21.4	4.04
Year first acquired driver's license	1984	1998	1994.4	3.26
Number of miles per month	0	2000	608.4	586.3
Number of accidents involved in	0	3	.52	.87

Question in Likert-type scale, (1= always, 3= sometimes, 5= never)	Mean	SD.
How often do you drive?	1.9	0.93
How much of your driving occurs on city streets?	2.4	0.96
How much of your driving occurs on rural/ country roads?	3.5	0.81
How much of your driving occurs on highways?	2.4	0.81
How often do you knowingly follow a car in front of you too closely?	3.7	0.84
How often do you knowingly drive faster than the posted speed limit?	2.1	1.01
How often do you knowingly drive faster than weather, traffic or road conditions allow?	3.6	1.02

Question in Likert-type scale, (1= always, 3= mostly, 5= none).	Mean	SD.
I felt nauseous	4.2	1.20
I felt in control of the steering	2.8	1.10
I felt in control of the gas	2.3	1.04
I felt in control of the brake	2.5	1.24
I felt in control of the car	2.3	0.72
I drove at a speed that was comfortable	1.8	0.88
I drove at a speed that was safe	2.3	1.02

Table 3: *Avoidance Maneuvers for the Intersection Trial.*

Avoidance Maneuver	Number Occurred	Percentage
Brake	6	23.07
No Brake	20	76.9
On Gas	4	15.39
Off Gas	22	84.61
Brake Plus Off Gas	5	19.23
No Brake Plus On Gas	3	11.53
Sped Up	1	3.85

Table 4: *Characteristics of the Participants in the Hill Trial based on the Questionnaire*

Question	Min	Max	Mean	SD.
Age	18	34	22.8	4.9
Year first acquired driver's license	1981	1997	1992.5	4.4
Number of miles per month	0	2000	605.2	500.8
Number of accidents involved in	0	5	.87	1.18

Question in Likert-type scale, (1= always, 3= sometimes, 5= never)	Mean	SD.
How often do you drive?	2.03	0.97
How much of your driving occurs on city streets?	2.38	0.94
How much of your driving occurs on rural/ country roads?	3.50	0.80
How much of your driving occurs on highways?	2.20	0.79
How often do you knowingly follow a car in front of you too closely?	3.60	1.00
How often do you knowingly drive faster than the posted speed limit?	2.20	0.95
How often do you knowingly drive faster than weather, traffic, or road conditions allow?	3.50	1.10

Question in Likert-type scale, (1= always, 3= mostly, 5= never)	Mean	SD.
I felt nauseous	4.34	1.12
I felt in control of the steering	2.60	1.02
I felt in control of the gas	2.03	0.78
I felt in control of the brake	2.25	1.04
I felt in control of the car	2.25	0.72
I drove at a speed that was comfortable	1.70	0.88
I drove at a speed that was safe	2.25	1.05

Table 5: *Avoidance Maneuvers for the Hill Condition.*

Avoidance Maneuver	Number Of Occurrences	Percentage
Swerve Left	17	53.1
Swerve Right	14	43.8
No Swerve	1	3.1
Brake	9	28.1
No Brake	23	71.9
Off Gas	29	90.6
Not off Gas	3	9.4
Swerve plus Brake	8	25.0
Swerve Plus No Brake	23	71.9
No Swerve Plus Brake	1	3.1
No Swerve/No Brake	0	0

Table 6: *Driving and Avoidance Profile of both Cars in the Hill Trials.*

Measurement	Car 1	SD	Car 2	SD
Mean speed in Kilometers per Hour	56.7	12.2	59.3	8.3
Mean onset of swerve in sec.	8.78	0.63	9.13	0.61
Mean speed at onset of swerve	50.5	17.4	55.9	11.9
Mean Total Reaction Time	1.82	2.36	1.48	1.61

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Figure 1. Spatio-temporal representation of the scales of action involved in accident research. At the largest scale, epidemiology identifies trends on a National basis at an annual rate. At the lowest extreme, crash mitigation technologies developed by mechanical engineers deal with millimeters and milliseconds. The present behavioral level analysis permits the investigation of accidents the human scale of seconds and meters.

Figure 2. Schematic representation of the University of Minnesota, Human Factors Research Laboratory, wrap-around driving simulation facility. Full views available on website at: www.hfrl.umn.edu

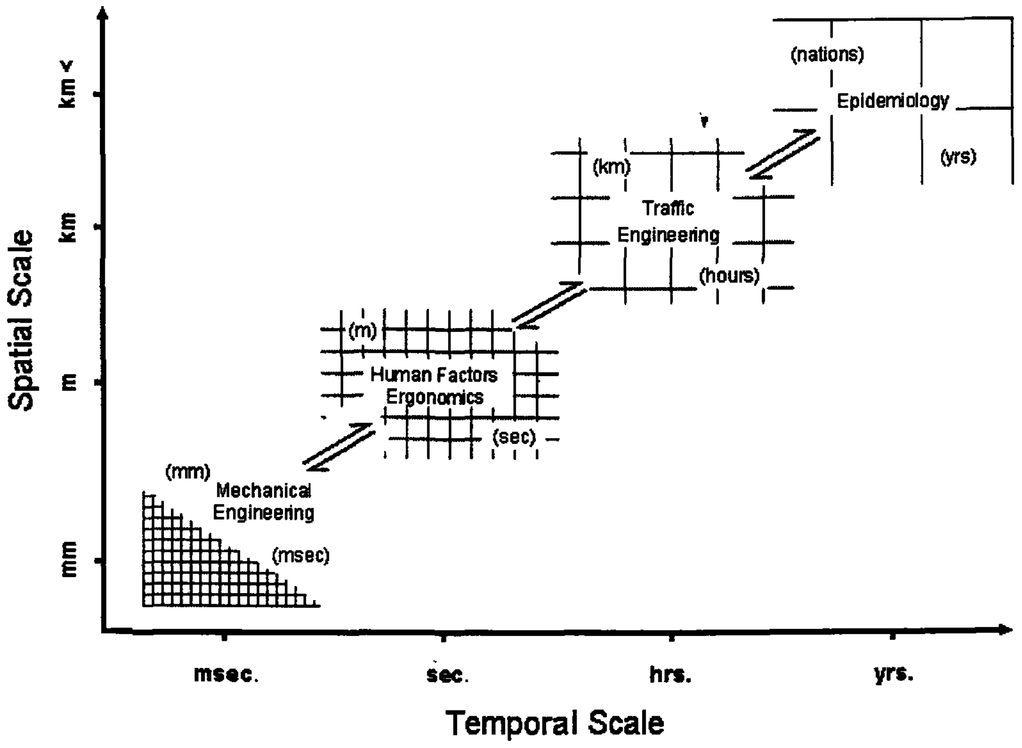
Figure 3. Driver situated in the Wrap-Around Simulator waiting for the light change.

Figure 4. Illustration of the conflict situation of head-on approach obscured by an intervening hill.

Figure 5. Illustration of the conflict situation of an intersection obscured by buildings.

Figure 6. This graph shows a 'window' of the original data stream. Once the point of closest approach is measured between the cars, 10 seconds before and 10 seconds after this point are plotted in order to examine driver performance in the few essential seconds before and after an accident likely situation. In this particular trial (Hill 18) participants meet each other after the actual crest of the hill due to different velocities which lengthens viewing times and also results in the difference between the length of the plotted lines. (A= Crest of the hill, B= Point of closest approach).

Figure 7. Illustration of the a-typical joint kinematic traces of the opposing vehicles. This measure shows vehicle lateral control through change in steering direction.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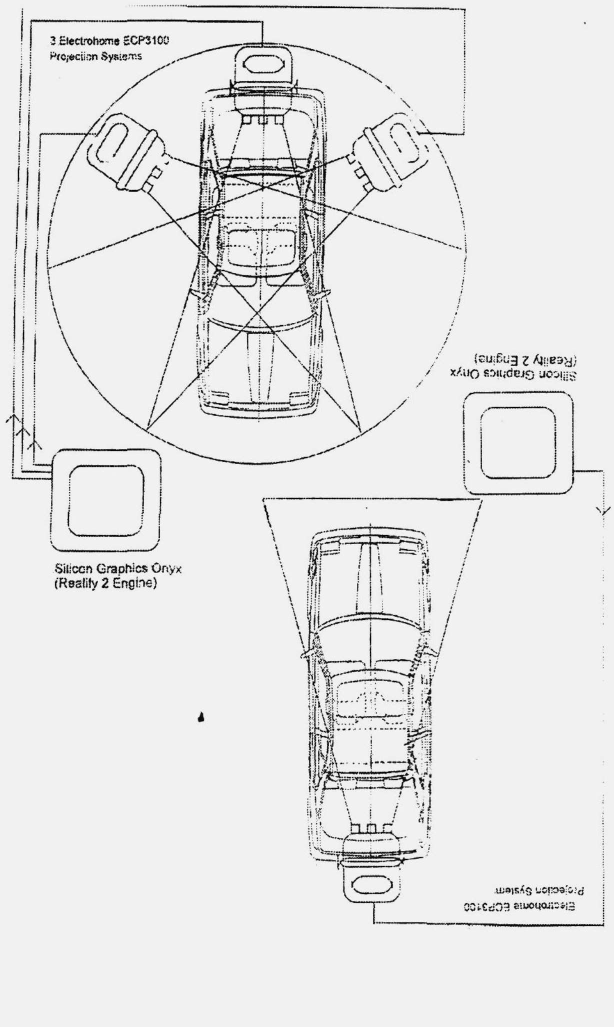
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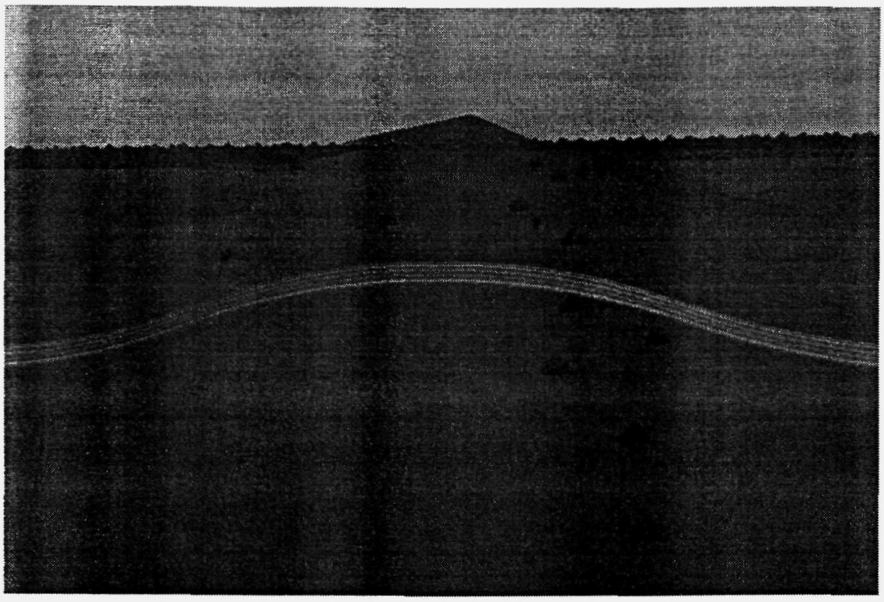

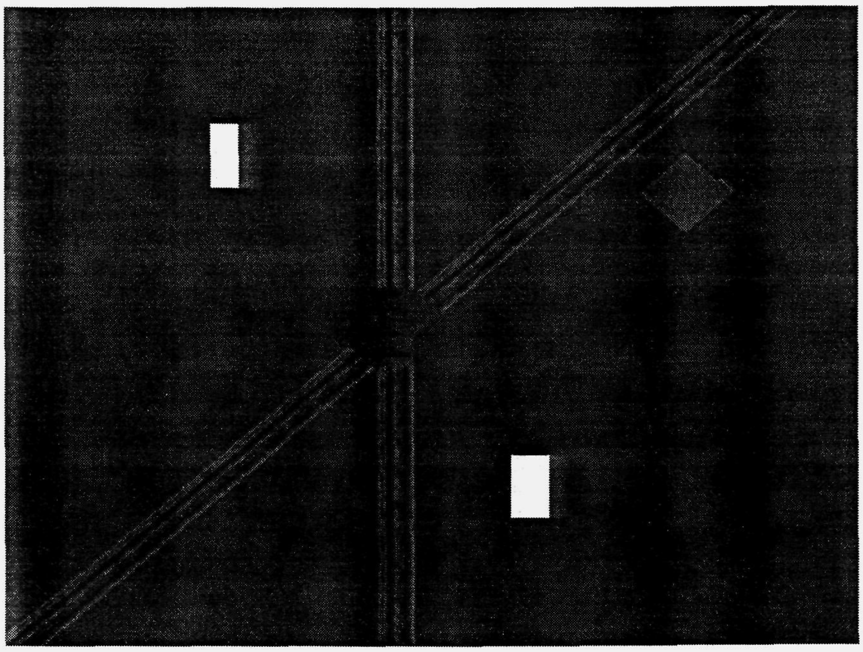

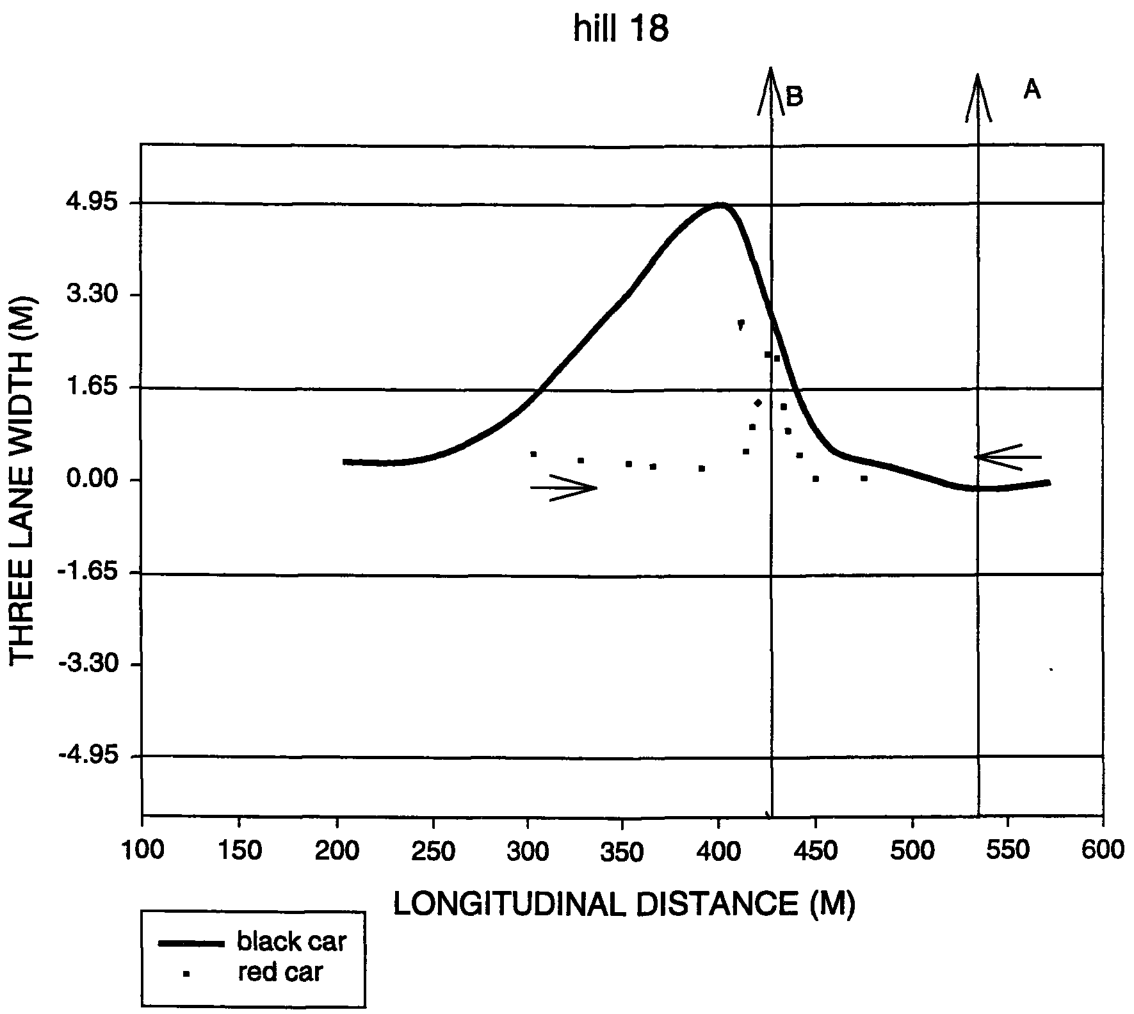
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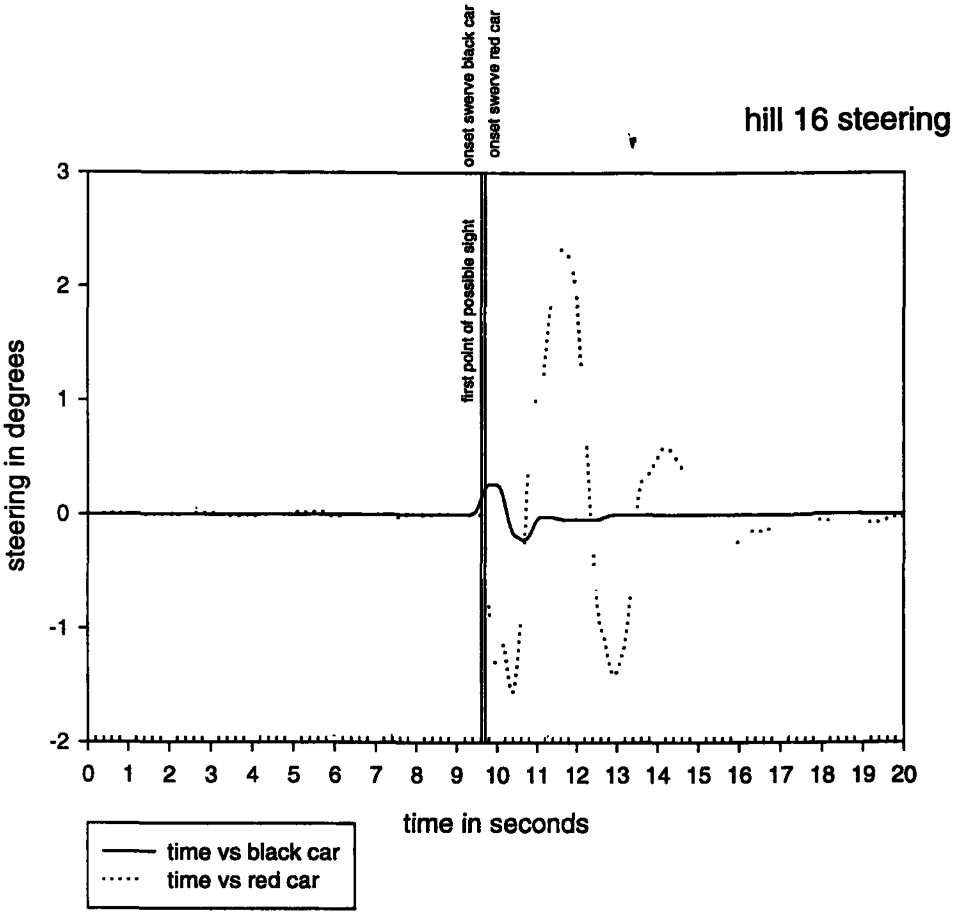
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