CHAPTER FIVE

Time-to-contact

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5.1 INTRODUCTION

When one thinks of occupational injury, the mind's eye immediately conjures up a picture of accidents in the workplace. Typically, our vision encompasses a major event, usually located in an industry where the principal form of work involves considerable physical effort. A worker is lying stunned or unconscious on the ground having suffered severe trauma to a major body part. Emergency services are rendering aid and an investigation into the event is already in its beginning stages. A more contemporary vision of occupational injury might be set in the open-plan office. This time we see a worker not suffering from an acute injury but the victim of some form of repetitive strain trauma which makes continued computer-based data-entry work insupportable. Each of these visions is a valid view of the problems we try to address and solve. However, in this chapter, we want to put a third vision forward. This vision is framed in no single physical workplace, the worker is not amenable to even a general form of stereotyping and the work is itself highly diverse. The one constant across these situations is transportation. Since transportation workers occupy a mobile and frequently dangerous workplace, it is not difficult to envisage injuries as major concerns. Transportation injuries represent a significant and growing proportion of all occupational injuries. Furthermore, accidents that are confined to a specified workplace rarely affect non-workers or bystanders. In contrast, transportation-related accidents frequently affect individuals beyond the involved workers themselves. In consequence, transportation accidents can often have a much higher public profile. It is for these reasons that we want to consider the causes of transportation accidents and the technologies that are emerging which promise to alleviate their occurrence or at least mitigate their more harmful effects. To accomplish this, we are going to focus on one specific area of research with which we have direct familiarity, namely time-to-contact (Caird and Hancock, 1994; Manser and Hancock, 1996).

To illustrate time-to-contact, let us consider a specific example. Let us suppose that you are travelling on a twisting two-lane highway and have been unfortunate enough to be behind a slow, large truck for some extended period of time. On occasion, you have pulled out from behind the truck to ascertain whether a suffivanced two seemingly paradoxical statements to aid our understanding of visual perception. According to Gibson nothing can be seen but light, but paradoxically light can never be seen. First, the only thing that enters the eye is light in the form of wave particles or rays. These light waves/rays are projected from a luminous object or reflected from object surfaces in the environment. These light rays travel to the eye, enter and are projected to the back of the eye. It is on the retina that light waves/rays stimulate photoreceptors so that observers perceive their environment. Second, the contention that humans cannot see light is also true when we consider the fact that light waves or rays do not have structure, matter or weight and as a consequence cannot be seen. Seeing is a process of photoreceptor stimulation. When humans see a laser beam what is actually being perceived is the reflection of light energy off molecules residing in the air. When humans see an approaching vehicle we do not actually see the object, but instead what is perceived is stimulation of photoreceptors on the retina caused by the reflection of patterns of specific light energy off the surface of the approaching vehicle.

It is these patterns of light energy that are projected to the retina that are termed the 'optic array' by ecological psychologists examining issues in visual perception (Gibson, 1979). The optic array is not static but rather is a dynamic field and represents a directly perceived optical flow field. *Global optical flow* field patterns are one type of flow field. Global optical flow field patterns occur when the entire optical array of light is moving on the retina. For example, when a person is moving through an environment, global optical flow field patterns are generated on the back of the retina and are continually flowing off the edges of the retina in all directions. As a person moves through an environment, images appear directly in front of them in their foveal vision while images gradually are removed from sight around the periphery of the visual field. Global optical flow field patterns can also be produced on the retina while a person is moving backwards through an environment. In this case images are flowing across the edges of the retina towards the retinal centre.

A second type of optical flow field pattern has been labelled *local optical flow*. Local optical flow field patterns are characterized by discrete light patterns that change shape, position or size on the retina. Local optical flow field patterns are experienced when a person is stationary and is watching an object approaching their position. Under these conditions only a portion of the entire optic array is moving. These different categories of flow field motion can be further subdivided as either *lamellar* or *radial*. If a person is stationary and looking forward and an object travels from left to right in front of them, this is a *lamellar optical flow* field. *Radial optical flow* occurs if the object is approaching on a head-on collision course. In this situation the image is stationary on the retina expanding in all directions. Global optical flow field patterns and local optical flow field patterns might appear to be dichotomous, however, they are actually ends of a continuum. For example, often in driving the optical array contains localized optical flow fields embedded within a global optical flow field, such as when watching a car approaching in the opposite lane while driving forward yourself. Also, in driving around curves the optical flow field of the far point of the road is in lamellar flow, but the optical flow field immediately in front of the driver is radial in nature. An important question is how this compound optic flow relates to time-to-contact. However, before attempting to answer this question we need to clarify each of the various terms that have been used in relation to time-to-contact in general.

5.4 A TIME-TO-CONTACT TAXONOMY

One of the sources of confusion concerning time-to-contact is the different terms that have been used in relation to the general phenomena. Apparently there have been no explicit attempts to clarify this confusion and to provide a formal taxonomy for the different labels that have been attributed to this phenomenon. Each of the following terms have been employed: *arrival time* (Schiff and Oldak, 1990; DeLucia, 1991; Caird and Hancock, 1994), *time-to-arrival* (Schiff and Oldak, 1990), *time-to-coincidence* (Groeger and Brown, 1988; Groeger and Cavallo, 1991; Groeger *et al.*, 1991), *time-to-collision* (Purdy, 1958; Schiff, 1965; McLeod and Ross, 1983; Brown and McFaddon, 1986; Cavallo *et al.*, 1986; Cavallo and Laurent, 1988; Tenkink and Van der Horst, 1990; Groeger and Cavallo, 1991), *time-to-contact* (Lee, 1976; Tresilian, 1991), *time-to-go* (Carel, 1961) and *time-to-passage* (Kaiser and Mowafy, 1993). At first it might appear that these terms have been used generally to represent the ability to estimate when a moving object will reach a second object or observer in space. However, this has not always been the case. Here, we provide a definitive taxonomy that describes what is meant by each of these terms in detail. First, we show a diagrammatic representation of the conditions that compose this taxonomy

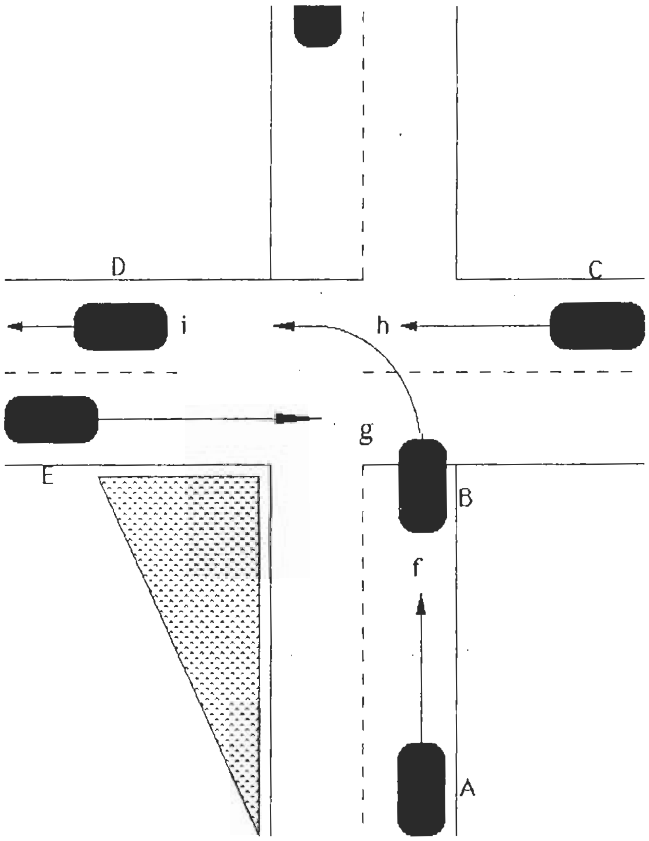

Figure 5.1 A diagrammatic representation of a typical driving situation.

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(Figure 5.1) and finally we provide a real-world example where each of these facets of the general time-to-contact realm exert their specific influence. Figure 5.1 depicts a traffic intersection. Although the vehicles in this depiction are being 'driven' on the right-hand side of the road it is obvious that comparable situations occur when the vehicles are driven on the left-hand side of the road.

(i) *Time-to-contact:* The term time-to-contact indicates that a stationary observer (in vehicle B) views a vehicle (E) approaching them on a collision course. The traditional research approach to such conditions depicts a vehicle approaching the observer and, while en route to that observer, the approaching vehicle disappears from the scene. The observer has to indicate, typically via a button press, when the approaching vehicle would have reached their position had it not disappeared. In this situation a radially expanding optical flow field pattern is generated on the back of the retina.

(ii) *Time-to-passage:* Similar to time-to-contact, time-to-passage describes a stationary observer (vehicle B) viewing an approaching vehicle (C) and at some point during the vehicle's approach the vehicle disappears from the driving environment. However, unlike time-to-contact, the approaching vehicle is not on a direct collision course with the observer. Rather if the approaching vehicle had not disappeared from the scene it would have passed just in front of the observer. Again, the observer's task is to respond when they felt the approaching vehicle would have passed in front of their position. In this situation the type of optical flow field is local and the pattern is primarily radial in nature when the vehicle is at a distance. However, when the vehicle is close to the observer the flow field pattern becomes lamellar in nature.

(iii) *Time-to-go:* Time-to-go is similar to time-to-contact and time-to-passage in that a stationary observer (vehicle B) is viewing an approaching vehicle (E). In time-to-go the approaching vehicle can be on a collision course or a by-pass course for the observer and the approaching vehicle can disappear en route to the observer or can travel the entire distance to the observer. The observer is required to respond when they feel they should move, or more accurately accelerate, in order to avoid collision with the approaching vehicle. In Figure 5.1, this would mean that vehicle B would have to drive across the intersection and make a left-hand turn before a collision with vehicle E occurred. The optical flow field patterns in this situation are identical to those in time-to-passage.

(iv) *Time-to-arrival (arrival time):* We view the terms time-to-arrival and arrival time as synonymous. In time-to-arrival a moving observer (vehicle A) is approaching a stationary target (vehicle B) or point in space (point f). At some point during the observer's approach to the stationary target or position in space the scene becomes blank or the observer's vision is obstructed. It is the observer's task to estimate when they would have reached the predetermined target or position in space had the scene not gone blank or had their vision not been obstructed. In time-to-arrival a global optical flow field is generated on the retina.

(v) *Time-to-collision:* Time-to-collision involves having a moving observer estimate when they will collide with another moving object. In Figure 5.1 the moving observer (in vehicle B) is required to determine when they will collide

M HANGER

with vehicle C at location h. In this scenario, the optical field pattern for the observer consists of localized flow embedded within a global optical flow field pattern.

(vi) *Time-to-coincidence:* Time-to-coincidence refers to a collision between a moving object (vehicle E) and a stationary object (vehicle B) which another individual (in vehicle A) observes from a distance. In this configuration one or both moving objects disappear before coinciding with the other object. The participant's task is to indicate when the moment of coincidence between the two objects would have occurred. In this scenario there are two localized optical flow field patterns generated on the retina.

(vii) *Unperceived time-to-contact:* There is a final form of contact perception, which is the structural and functional failure to perceive the approaching object. Obviously, under any of the conditions we have indicated, it is possible for an individual to have objects within their visual field and yet, for a number of functional reasons connected to neuropsychological and neurophysiological processes, fail to register and respond to an object's presence. There are extensive questions associated with these 'higher' level functions that we have not addressed here. However, there is an even more simple failure which we cannot pass by without comment: an individual may well be struck by an object that they never perceived. In visual terms this might mean an object approaching from the rear (with no rear mirror) or approaching in the blind spot. We should, however, note that auditory time-to-contact might prove of use in alerting an individual in this situation. We have labelled this *unperceived time-to-contact* and used the global lamellar case as one exemplar. In many occupational accidents caused by collision, not having seen the object, or vehicle, causes a considerable percentage of events.

At this juncture, it is our purpose to relate what the observer perceives (that is the flow field characteristics) with the environmental configurations used in the various research situations presented above. As can be seen in Figure 5.2, we divide flow field characteristics into global and local, with radial and lamellar components under each.

We appreciate that the real world often presents complex combinations of these characteristics, however, one initial taxonomic differentiation is based on these four divisions. As can be seen from Figure 5.2, we have located each environmental configuration within its predominate flow field. There are some which do not fit precisely into this categorization. However, the taxonomy identifies one form of flow field not investigated under this regimen, that is a global, lamellar condition. We can imagine a number of situations in which this occurs, e.g. looking out of a moving train window or glancing over to another competitor at the end of a sprint race. Without a specific environmental reference, the closest comparable condition is time-to-passage.

In the present taxonomy, we have tried to include all basic conditions identified by contemporary researchers. In evaluating time-to-contact type scenarios, it is clear that initial experimental effects have focused on a restricted number of relatively simple situations and drawn on dichotomies of whether the observer or the environment represents the major source of movement. However, it is also clear that in the real world, when observers either move or are stationary, objects in the flow field also approach and recede in complex patterns. Therefore, our present approach represents a working framework rather than an exhaustive description.

	Global	Local
Lamellar	Unperceived Time-to-contact	Time-to-coincidence
Radial	Time-to-arrival	Time-to-contact Time-to-passage Time-to-go

Figure 5.2 Taxonomy of optical flow field characteristics.

5.5 TIME-TO-CONTACT: CONTEMPORARY RESEARCH

As indicated in the previous section, to estimate time-to-contact researchers have used situations in which an object, typically a vehicle, is approaching a participant on a collision course and at some point en route the approaching object vanishes from the scene. The participant's task is to press a button when they felt the approaching object would have reached their position. This experimental technique has been labelled the 'removal paradigm' (Manser and Hancock, 1996). Results of experiments using the removal paradigm have indicated that there are several external and internal factors which influence the ability to estimate time-to-contact accurately.

One of the exogenous factors influencing estimates of time-to-contact is the velocity of the approaching vehicle. Specifically, when a vehicle is approaching a participant at higher velocities estimates of time-to-contact are more accurate than when the vehicle approached at lower velocities (McLeod and Ross, 1983; Schiff *et al.*, 1992). A second external factor influencing estimates of time-to-contact is the period of time a participant is allowed to view an approaching vehicle. Results indicate that when observers were allowed to view the approaching vehicle for longer periods of time, estimates of time-to-contact became more accurate (McLeod and Ross, 1983; Schiff and Oldak, 1990; Caird and Hancock, 1994). A third external factor related closely to viewing time is viewing distance. Research has indicated that participants' estimates of time-to-contact were more accurate when participants were allowed to see the vehicle for greater approach distances (Tresilian, 1991). This effect remained even when the viewing time was held constant and total viewing distance was manipulated.

In addition to the external factors influencing estimates of time-to-contact there are several internal factors. One of these internal variables is the sex of the observer (McLeod and Ross, 1983; Schiff *et al.*, 1992; Caird and Hancock, 1994). It has been found that males were more accurate than females in estimating time-to-contact as actual time-to-contact increased. In addition, it has been found that males' estimates of time-to-contact were significantly less variable than females' estimates of time-to-contact (McLeod and Ross, 1983; Schiff and Oldak, 1990; Caird and Hancock, 1994). Only one study has reported no difference for the sex of the observer (Schiff *et al.*, 1992). Our recent work has indicated that the presence of a sex effect is contingent on the precise nature of the kinematic conditions under consideration (Manser and Hancock, 1996). Another internal influence affecting estimates of time-to-contact is the inherent limitations and capabilities of the human visual system. Manser and Hancock (1996) have shown that participants are more accurate when the vehicle approaches from a head-on collision course (an approach directed towards the front of the participant) as opposed to alternative angles of incidence (e.g. an approach directed towards the side of the participant).

One of the persistent characteristics in time-to-contact studies is the tendency to underestimate, progressively, time-to-contact as actual time-to-contact increases. This phenomenon permeates the research database as far back as 1958 when Knowles and Carel examined whether participants could determine the amount of time before a head-on collision would occur in the absence of familiar environmental cues such as size, distance and speed. One of their findings was that participants could determine time-to-contact fairly accurately up to about 4 s, beyond that estimates of time-to-contact were underestimated progressively. Later, Carel (1961) reported that estimates of time-to-contact were underestimated progressively as actual time-to-contact increased. The data from Carel's study were fitted with a straight line, which resulted in a slope of 0.74. More recently, Schiff and Detwiler (1979) used film footage to display a vehicle approaching on a head-on collision course in an effort to examine the effects of vehicle approach velocity and vehicle viewing distance. The results of their studies indicated that estimates of time-to-contact were underestimated at roughly 60% of actual time-to-contact. Similar underestimations were found by Schiff and Oldak (1990), Schiff *et al.* (1992) and Caird and Hancock (1994). In particular, in Caird and Hancock's experiment one of four vehicles approached a stationary participant on a collision course and was removed from the driving scene at one of two distances. The results of their experiment indicated that participants' estimates of time-to-contact were similar to other studies, with a slope of 0.56. Recently, Manser and Hancock (1996) investigated the effects of vehicle approach trajectory and vehicle approach velocity on estimates of time-to-collision. Our results also indicated that participants underestimated time-to-collision progressively as actual time-to-collision increased.

McLeod and Ross (1983) examined the effects of viewing time on estimations of time-to-collision using a slightly different research technique: their experimental film segments depicted participants travelling towards a stationary vehicle. While travelling towards the stationary vehicle the film segment went blank and the participant asked to respond when they felt they would have collided with the stationary vehicle. McLeod and Ross found that participants underestimated time-to-collision at approximately 60% of actual time-to-collision. When these data are fitted to a straight line the slope is 0.58. Using a similar experimental technique, Cavallo and Laurent (1988) had participants travel as passengers in a vehicle which was approaching a stationary object. Cavallo and Laurent examined the effect of driver experience levels, distance evaluations and vehicle approach speeds on estimates of time-to-collision. The results of their study indicated that estimates of time-to-collision were systematically underestimated. Similar to previously presented studies, when the data were fitted to a straight line the slopes were 0.73 and 0.57 for experienced and beginner drivers, respectively. Other experiments have revealed the tendency to underestimate time-to-arrival (Kaiser and Mowafy, 1993). Figure 5.3 shows a depiction of the slopes indicating this propensity to underestimate time-to-contact. It should be noted that recently Cavallo (personal communication) has divided results from previous research into two categories based on whether the participant is stationary, estimating when an object will reach their position, or whether the participant is moving through the environment estimating when they will reach a particular point in space. Cavallo found that the regression lines for participants who were stationary and estimating when a dynamic object would reach their position overestimated time-to-contact up to about 1.5s. After 1.5s participants began to underestimate time-to-contact progressively. Interestingly, the regression line for participants who were moving through an environment showed that they never overestimated time-to-arrival, but consistently underestimated it. There are several potential reasons for the differences in slope values between the two conditions and these are reflected in part in the taxonomic structure we have proposed.

Several authors have suggested underlying reasons for these persistent underestimations. Schiff and Oldak (1990) suggest that participant underestimations are due to a biological tendency to err on the side of safety to protect oneself from collision or contact in a potentially dangerous situation. From an ecological

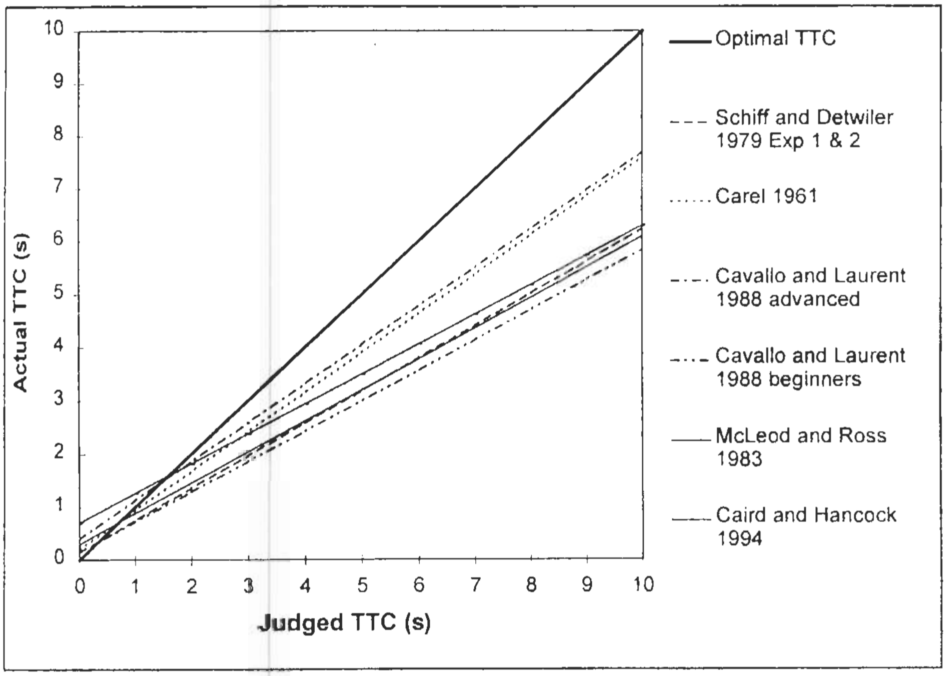

Figure 5.3 Results of previous time-to-collision (TTC) research for the cited studies. The collective findings show that participants underestimate time-to-collision and that such underestimation grows with the absolute duration of actual time-to-collision.

K HANGER

approach in visual perception it would seem reasonable that humans would have developed, over millennia, the tendency to underestimate time-to-contact in order to enhance the chance of avoiding a dangerous collision. Kaiser and Mowafy (1993) suggest underestimations may be due to a distortion of the visual/temporal space or that they could be a by-product of the cognitive extrapolations required of participants.

Although the explanations presented above have merit, a simpler alternative explanation is possible. This alternative explanation relates to the manner in which visually specified information has been used by humans throughout their evolution. In naturally occurring situations, when an object is approaching an observer, the approaching object travels the entire distance to the person or becomes occluded by another object while en route to the person. These naturally occurring situations are quite different from the traditional removal paradigm which has been used to examine various time-to-contact issues. Consequently, the degree to which people underestimate time-to-contact may well be an undesirable by-product of a fallacious research approach. Specifically, sudden vehicle disappearance in the removal research paradigm is a visual anomaly that humans have not been exposed to and have not learned to adapt to throughout their evolution. Our most recent investigation (Hancock and Manser, 1996) studied vehicle approach velocity, participant gender and participant age under an 'occlusion' condition as compared with the 'removal' condition. The results indicated that participants' estimates of time-to-contact were significantly more accurate when they viewed the former, more ecologically valid, research paradigm. These data confirm that participants are more accurate at estimating time-to-contact than the previous consensus indicates. Figure 5.4 depicts an illustration of the research conditions used by Hancock and Manser (1996).

Having given a brief overview of some of the theoretical issues associated with time-to-contact, let us now turn our attention to some applications. First and most prominently, the results of the study by Hancock and Manser (1996) confirm that the way a research question is posed has a significant impact on the results obtained in that research. In this case, the dependent measure in each research paradigm was identical (estimates of time-to-contact), however, by making a small change in the way the approaching vehicle was removed from the driving environment large and systematic differences occurred in the dependent response.

Second, it is necessary to pose research questions in the most ecologically valid manner possible so that the results may be maximally generalizable. One method for increasing the generalizability of research results is to display the simulated world in the most realistic manner possible. However, Kantowitz (1992) warns that an increase in physical fidelity between the real world and the simulated world does not necessarily enhance generalizability. What does enhance generalizability is that the psychological processes engendered by the real world and the simulated world are comparable. We agree with this contention, but point out that very little evidence has been produced which indicates what exactly are the essential psychological processes in the real world, and in particular the realm of driving, that are critical for replication or simulation. Hancock and Manser (1996) have provided evidence that one of the key psychological processes in the real world occurs when a vehicle becomes occluded by some object in the driving environment. This leads to questions concerning research approaches. First, are there other psychological processes

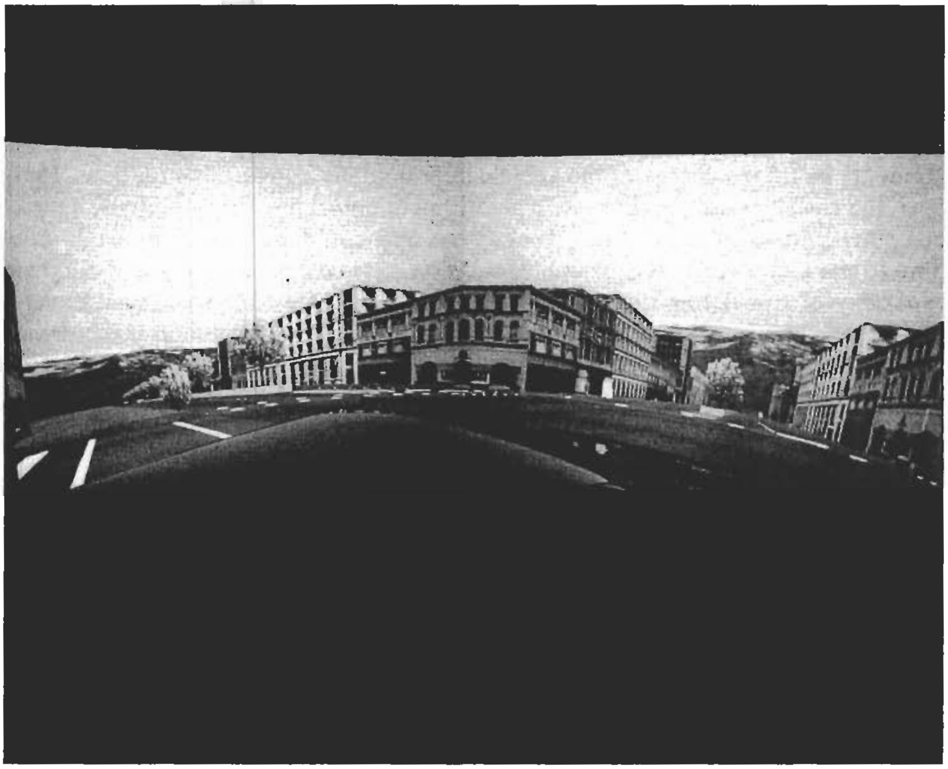

Figure 5.4 Depiction of the driving scenario used in Manser and Hancock (1996). Note that on the road approaching from the left there is a bush that serves to occlude an approaching vehicle. Note also that this is only an approximation of the actual scene. Limitations are inherent in viewing three-dimensional surfaces in a two-dimensional representation. Photograph courtesy of Neil Kveberg.

occurring in the real world which experimenters are ignoring in experimental research? The answer appears to be in the affirmative. Second, by ignoring a spectrum of potential influences, are previous data problematically confounded?

Although the results of previous studies are not totally generalizable to the real world due to the lack of a fully ecologically valid approach, there remain some important implications for real-world applications. To review briefly, studies using the traditional removal time-to-contact research paradigm and the more ecologically valid occlusion time-to-contact research paradigm have indicated that participants are more accurate in estimating time-to-contact when the approaching vehicle is viewed for greater distances, more accurate when the approaching vehicle is viewed for a greater period of time and more accurate when the approaching vehicle is approaching at higher velocities. Clearly, these results should be considered by traffic engineers who design roadways and intersections. Specifically, roadway designers should attempt to maximize viewing time and viewing distance at intersections, particularly unregulated intersections. The issue of increasing vehicle approach speed, although helpful in the laboratory for increasing the accuracy of estimates of time-to-contact, may not be a feasible alternative for real-world

MANSER

accident reduction tactics because of the possibility for greater damage and life lost at higher approach speeds. A second possible application of the results of time-to-contact studies is in intelligent transportation systems (ITS), formally known as intelligent vehicle highway systems (IVHS). New ITS applications include collision avoidance systems whose purpose is to prevent people from getting into vehicular accidents by taking charge of the vehicle in potentially dangerous situations. However, the variables used in the system algorithm to determine the potentially dangerous situations must come from somewhere and could be research results from time-to-contact studies. For example, collision avoidance systems would need the capability of calculating how well drivers could estimate time-to-contact under a variety of conditions to be able to determine at a particular moment if the drivers are capable of avoiding an imminent collision.

5.6 TIME-TO-CONTACT AND OCCUPATIONAL INJURY

We have framed all of our discussion about time-to-contact within a transportation-related realm. However, this is a very restricted view. As indicated in the opening of this chapter, time-to-contact is an absolutely vital capability for any organism hoping to survive in any environment. Therefore, the capability to perceive time-to-contact is a general one, as is its realm of application. We can well imagine any number of situations in which the ability to distinguish time-to-contact is critical in injury avoidance. Consider, for example, the construction worker: falling objects are of critical concern and a major form of injury causation. The ability to distinguish symmetrically expanding objects, that is those which will collide with the individual, from those with asymmetrical expansion, which will not, is a critical characteristic in avoidance strategy. Similarly, in semi-automated and automated manufacturing facilities the ability to distinguish potential collision courses by automated vehicles is vital in avoiding robotics-related accidents (Hamilton and Hancock, 1986). In fact, in all cases where objects collide with workers, time-to-contact specifies critical avoidance information. As we have illustrated for transport systems, such information can be augmented by the use of technical support systems. Consequently, we submit that such support systems can be of assistance in multiple realms of occupational injury prevention. It is not only single-collision events that can benefit from time-to-connect knowledge. Repetitive strain trauma, from keyboard use for example, is frequently attributed to posture while typing. However, this is to neglect the design of the keyboard and its characteristics in terms of pressure required to depress and operate keys. This, after all, is the primary task of keyboarding and this process is simply an extension of time-to-connect into a region that we call 'soft-collision.' In consequence, we believe that time-to-contact is a critical construct in battling the adverse effects of occupational injury and can add both a practical and conceptual tool to the professional's armoury in the never-ending fight to combat accidents and damage to individuals in the workplace.

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M KAISER

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