

RESOURCES FOR ECOLOGICAL PSYCHOLOGY

A Series of Volumes Edited by:

Robert E. Shaw, William M. Mace, and Michael T. Turvey

Reed/Jones • *Reasons for Realism: Selected Essays of James J. Gibson*

Warren/Shaw • *Persistence and Change*

Kugler/Turvey • *Information, Natural Law, and the Self-Assembly of Rhythmic Movement*

McCabe/Balzano • *Event Cognition: An Ecological Perspective*

Lombardo • *The Reciprocity of Perceiver and Environment: The Evolution of James J. Gibson's Ecological Psychology*

Alley • *Social and Applied Aspects of Perceiving Faces*

Warren/Wertheim • *Perception & Control of Self-Motion*

Thines/Costall/Butterworth • *Michotte's Experimental Phenomenology of Perception*

Jansson/Bergström/Epstein • *Perceiving Events and Objects*

Flach/Hancock/Caird/Vincente • *Global Perspectives on the Ecology of Human-Machine Systems (Volume I)*

Hancock/Flach/Caird/Vincente • *Local Applications of the Ecological Approach to Human-Machine Systems (Volume II)*

LOCAL APPLICATIONS OF THE ECOLOGICAL APPROACH TO HUMAN-MACHINE SYSTEMS

edited by

Peter Hancock
University of Minnesota

John Flach
Wright State University

Jeff Caird
University of Calgary

Kim Vicente
University of Toronto

 LAWRENCE ERLBAUM ASSOCIATES, PUBLISHERS
1995 Hillsdale, New Jersey
Hove, UK

Chapter 1

Perceiving and Driving: Where Parallel Roads Meet

William Schiff and Wendy Arnone

New York University

1.0 Introduction

Perceptual psychology has followed several roads to the present state of the art. The road emerging from classical sensory psychophysics has had a major influence on the practice of human factors and human engineering. This avenue assumes that our senses basically serve as energy transducers, responding to energy variables such as wavelength and intensity of light, frequency of sound, and so on. Following this sensory transduction, perception is then considered as an elaborative process by which information stored in memory becomes integrated with current sensory input. With this sort of theoretical framework, automobile driving then emerges as a complex psychomotor process in which prior knowledge is combined with current sensory input. In this light it would make sense to inform human factors practitioners about the sensitivities and limitations of our sensory (and motor) apparatus.

It would seem likely that it is largely from this model that current driving measures have elected to screen drivers for sensory sensitivities (e.g., color and acuity), for basic perceptual discrimination (e.g., coded sign shapes), and to ask (cognitive) questions pertaining to rules of the road or state laws.

Another road to the current state of the art has emerged from Gibson's functional psychophysics. As applied to automobile driving, such an approach reaches back at least to 1938, to a seminal paper with Crooks (Gibson & Crooks, 1938). This approach suggested that rather

of course, exceptions (e.g., Bruce & Green, 1990). A similar state of affairs exists in the human factors field. Respected texts having fairly comprehensive treatment of perception as it may relate to their fields often bypass Gibson's alternative approach (e.g., McCormick, 1957; McCormick & Sanders, 1976; Sanders & McCormick, 1987; Wickens, 1984).

When we think of driving, we should think first of the issues of motion perception, because the driver is often in motion, and parts of his traffic world are too. Perception and judgment of such motions are surely central to perceptual issues in driving. But if one looks in the perceptual texts, one usually finds motion perception treated as something of an afterthought, perhaps a consequence of the static snapshot assumption, with motion often viewed as another illusion. Phenomena of illusory motion have a fully researched history, from Wertheimer's Gestalt treatment of phi and other related simple motions, to more recent ones, such as Wallach's kinetic depth effect and the familiar Ames rotating trapezoidal window illusory motion phenomena (e.g., see Schiffman, 1990). It is of interest that most perceptual texts (and technical works as well) seem to convey the impression that most of the motion registered by the human visual system is continuous rotation at a constant velocity around a vertical axis at a fixed distance from the eye. This sort of motion is perhaps most frequently examined in traditional theories of motion perception and in perceptual texts. The driver sees very few instances of this sort of motion. This assumption has strong historical roots in Gestalt psychology, which shares the same view of illusions. It may also get a boost from the fact that much of the motion we perceive in man-made devices (motion pictures, video pictures, commercial signs, computer displays) is indeed phi-based motion, rather than the natural optical motion occurring when we walk, drive, or fly.

The remnants of classical psychophysical assumptions are to be seen in human factors texts and journals as well as in perceptual texts. For example, McCormick's justifiably popular introductory text in *Human Factors Engineering* (McCormick & Sanders, 1976) includes a major section concerned with "man in motion" in which illusions during self-motion are given major attention. The relatively small section on vehicle driving (5 pages in 1976 edition) refers to sensory components, treats information input to the vehicle driver as objects (other vehicles, road signs, etc.), and concludes that "the driver 'processes' the information somehow, leading up to his control responses" (McCormick & Sanders, 1976, p. 399). Further material acknowledges the role of perception of

one's own speed. The section also treats reaction time, which includes time required for recognition and motor responses, and the mechanics of vehicle control devices (pedals, etc.). This rather brief treatment of such an important human factors topic as driving may be contrasted with an earlier discussion of classical psychophysics extending over 8 pages, including static visual acuity, color discrimination, dark adaptation, luminance contrast, and so on. This example is meant only as an indication of the continuing tutorial impact of assumptions and traditions, and not as a criticism of this particular book; it is but one example of the state of the fields of perception and human factors as they may impact on automobile driving research and applications.

Along with the classical psychophysical view that sensory sensitivity factors are foundational (although an inadequate basis for perception), we find a related assumption that because sensory phenomena cannot account fully for perception, our senses frequently lead us to error—the illusory assumption of the classical psychophysical view (e.g., see Coren & Girgus, 1978; Leibowitz, 1965, pp. 42–49). Indeed, it has been thought for many decades that if sensation is an accurate reflection of the external world, given the facts of illusions, that is, mistaken percepts, the basis for these errors must be postsensory, that is, perceptual. This set of related theoretical underpinnings may not only leads to possibly exaggerated "bells-and-whistles" treatments of illusions in perceptual textbooks, journals, and museum exhibits dealing with perception (e.g., see Schiff, 1988), it also may lead the applied researcher to illusory hypotheses. A recent example from the automobile driving literature may serve to demonstrate this point.

A leading researcher in the field of perception and driving analyzed possible causal factors potentially responsible for the very serious problem of motorists' crashes at railroad crossings (Leibowitz, 1985). Over 700 persons are killed each year in the United States alone while trying to drive across railroad crossings. A prime hypothesis advanced to partly explain such accidents was the size-velocity illusion. In this illusion (usually demonstrated with abstract two-dimensional laboratory displays) larger objects tend to be perceived as moving more slowly than smaller objects moving at the same velocity, in the same trajectory. From these findings it might indeed follow that motorists who are used to judging car-sized objects approaching transversely (approximately perpendicular to the line of sight) might misperceive the locomotive's approach speed and fatally misjudge whether there was time to safely cross the tracks before the train arrived at the crossing.

There are additional assumptions encased in this hypothesis,

driving. No relationship has appeared in the literature between color sensitivity and accidents (e.g., Allen, 1969; Cooper, 1990; Richards, 1966). This is fortunate because 8% of the male population is color defective, yet likely drive as safely as those with full color discrimination capability. Traffic engineers have added blue to the green lights, yellow to the red lights, and red-green defectives have little difficulty in using color codes found in driving.¹

Again, the real issue is whether the beginning driver responds appropriately to such traffic signals, based on whatever kind of contextual information is available, and not the psychophysical sensitivity of the sensory system. Stereopsis may be related to maneuvers while parking. Whereas mishaps in such locations are bothersome for insurance companies as well as other drivers, they seldom result in serious injuries!

Precise measurement of these sensory sensitivities appears to bear no relationship or minimal relationship to safe motor vehicle operation; this fact is borne out by so much research that it is difficult to be skeptical (see Burg, 1971). But the few sensory sensitivities that may prove of predictive value in averting driving accidents, for example, bilateral field restriction, are seldom if ever tested in licensing examinations (see Keltner & Johnson, 1987).

Finally, there is the road test. This is a possible ultimate criterion for whether the testee has sufficient knowledge and skill to drive in public. Such tests are typically conducted on closed courses, or in low-density, low-speed traffic in an area neighboring the licensing site. They are typically conducted in full daylight, on dry pavement, and last between 10 and 30 min (shorter tests seem to be increasingly the rule due to cost factors). They are little more than minimal skill screens for minimally skilled beginning drivers, most of whom have spent less than 50 hours behind the wheel. A major component of such road tests, one that is often carefully scored and weighted, is the parallel parking test. (How many people have been injured, maimed, or killed while parallel parking? Note that today, most parking is not even parallel, but diagonal, and located in grocery store and shopping mall parking lots.) The testee who cannot maintain minimal control of the vehicle may be screened out by such subtests, but they hardly seem functional given the brief nature of the road test. Then, the novice driver is usually asked to

turn right and to turn left (whether he or she signals is very important); the novice driver must stop and start at a traffic light, stop at a stop sign (i.e., obey all traffic signs), turn into the lot, and stop the car smoothly before a license is granted. Thus, the road test, too, appears to be a minimally functional coarse screening test that bears little functional relationship to driver skill, alertness to potentially dangerous situations, ability to deal effectively with traffic environment stressors, and driver alertness.

Numerous attempts have been made to construct more suitable tests for driver licensing or relicensing. Almost all measures presumed requisite "basic abilities" that should apply to a wide range of driving situations. From DeSilva's early (1935) attempts to much more recent ones (e.g., Olson, Butler, Burgess, & Sivak, 1982), similar notions from the classical psychophysical view have dominated. All such tests rest on assumptions that it is possible (and desirable) to predict perceptual aspects of driving performance from some combination of mostly static vision tests (e.g., contrast sensitivity, acuity, color vision) plus general abstract measures of a more perceptual nature (e.g., depth perception—again, using static displays). One recent foray into integrated visual function tests was sponsored by the National Highway Traffic Safety Administration (NHTSA) (Shinar, 1977) and included tests for static acuity under normal, low, and glare illumination conditions; dynamic acuity; central movement in depth; central and peripheral angular movement; and field of view. The most useful measure for predicting overall accidents was acuity under low illumination levels, but dynamic visual acuity predicted daytime accident rates best. None of the measures accounted for large amounts of accident variance.

Although specific road tests have been devised that appear more closely related to driving skill (e.g., Olson et al., 1982), it is not clear that the skills chosen are the most appropriate ones; nor is it clear that road performance tests are practical, when one takes into account their administrative cost and the need for many specialized facilities. More recently, there have been rumblings about computer-video driving tests, with California being a likely site for testing (see Viets, 1990). Concerned agencies and individuals continue to call for the development and validation of functional driving tests (e.g., NHTSA, 1989). Several are being used for research (e.g., Schiff & Oldak, 1993), but none has yet emerged in a licensing bureau.

¹The first author is a red-green defective, has held licenses in 3 states, has driven 43 years without an accident, and has never had even a near-miss due to color defect.

curves can be safely negotiated), they will tend to be ignored,² or the driver will strike a compromise between the natural constraints of the road configuration and car maneuvering capabilities and those recommended by traffic control signs. It is these factors rather than legal taboos per se (maximum speed laws) that tend to govern the driving speeds of drivers, although the visible presence of police increases the likelihood of adherence to posted laws.

8. When an obstacle suddenly cuts off the field of safe travel inside the minimum stopping zone, an entirely new field of travel may open up, for example, the shoulder of the road in emergency situations. The field of safe travel is limited by a number of factors, including obstacles that encroach on it, the distances at which daytime vision and nighttime vision become inadequate due to purely optical factors, the margins of road illuminated by headlights, constriction of the field by glare from other's headlights, or horizon cropping, as by brows of hills one is traversing. All these should yield deceleration when they diminish the field-zone ratio.

9. Overdriving brakes or headlights leads to contraction of the objective field of safe travel until it approaches the minimum stopping zone, or does so without a corresponding contraction of behavioral capabilities. Learning safe driving habits involves semi-automatic perceptual-motor habits in which a safe margin is maintained between the minimum stopping zone and the field of safe travel. (Gibson, 1966) later called this the "margin of safety," which is found in much of the literature on driving [e.g., AAA, 1985a; Leibowitz, 1965, p. 51; Schiff & Oldak, 1990; Schiff, et al., 1992].

10. Clearance lines radiate from obstacles, that is, a negatively

²Both authors have driven extensively in states restricting speeds on high-speed divided highways to 55 mph. In spite of the legal taboos, average traffic flow rates on these roads range between 65 to 70 mph—unless police are evident. Here is a contemporary instance in which Gibson's point about goals (desire to complete long-distance trips in a reasonable time span) and natural laws—constraints of roads, traffic (flow rates) and vehicle capabilities versus man-made laws and posted speed limits—his home. Legislators who support unrealistically low speed limits (see Pevsner, 1991) might do well to travel their own roads at "legal" speeds for 4-5 hours (instead of flying about) before voting on such legislation—which may encourage ignoring reasonable as well as unreasonable traffic laws.

valenced halo of avoidance. The more injurious potential an obstacle may have, the more it is avoided and the greater the extent of its clearance lines. (Consider the degree to which an auto driver tries to steer clear of an adjacent semi-trailer truck, versus a small sport roadster!) For a moving obstacle, the clearance lines radiate from the point where said obstacle will be located when one's own car comes closest to it, that is, the point of potential collision. Thus, one may actually steer toward the present location of a walking pedestrian with the foreknowledge that he or she will be well beyond the present location when one's vehicle arrives at the "trail." The greater the speed of a moving obstacle, the further ahead its clearance lines are projected. The correct perception of such clearance lines involves the projection of other vehicles along their paths of travel, as they may be jointly involved. Thus, passing another car traveling in the same direction, with another car approaching in the adjacent lane, requires an "estimate" (quote is Gibson & Crooks's) of the speed of obstacle(s) plus an "estimate" of the speed of one's own car.

Although the term estimate is misleading since there seems to be no conscious process calculation involved. Here is a case of a highly complex situation, involving relationships between two speeds of movement, which would not be an easy problem to solve with pencil, paper, and formulae. But for the skillful driver, the perceptual field-situation may be immediate, clear, and (let us hope) accurate. Complex "estimates" of speed and location are represented in the experience of the driver only by the simple seeing of an open or closed field of safe travel. (Gibson & Crooks, 1938, p. 465, emphasis in original; see also Reed & Jones, 1982, p. 129)

Here Gibson foresaw the "computational issue" found in the recent time-to-arrival literature (e.g., McLeod & Ross, 1983; Schiff & Detwiler, 1979; Schiff & Oldak, 1990; Tresilian, 1990; Schiff et al., 1992).

11. Driving skill consists of the organization within the field of view of a correctly bounded stopping zone for a full range of speeds, road and traffic conditions, and fields of safe travel, precisely fitted to actual and potential obstacles in the field of view at any instance. This field must conform to the objective possibilities for safe locomotion. The motion

& Detwiler, 1979; Schiff & Oldak, 1990). Paradoxically, this involves perceiving the endpoint of an event (approach, then collision) before it occurs. This class of percepts was of particular interest to Gibson because it was a prototypical example of the pickup and utilization of optical information over time, rather than an instantaneous "snapshot" as conceived in traditional theories.

In his 1958 paper on animal locomotion, Gibson stated:

Approach to a solid surface is specified by a centrifugal flow of the texture of the optic array. Approach to an object is specified by a magnification of the closed contour in the array corresponding to the edges of the object. A uniform rate of approach is accompanied by an accelerated rate of magnification. At the theoretical point where the eye touches the object the latter will intercept a visual angle of 180 degrees; magnification reaches an explosive rate in the last moments before contact. This accelerated expansion in the field of view specifies imminent collision, and it is unquestionably an effective stimulus for behavior in animals with well-developed visual systems. In man it produces eye blinking and aversive movements of the head, even when the stimulus is a harmless magnification of a shadow on a translucent screen. At lesser intensities this "looming" motion, as it might be called, presumably yields lesser degrees of aversion, or a slowing down of approach. The fact is that animals need to make contact without collision with many solid objects in their environments: food objects, sex objects, and the landing surfaces on which insects and birds alight (not to mention helicopter pilots). Locomotor action must be a balance between approach and aversion. The governing situation must be a balance between flow and non-flow of the optic array at the moment when the contour of the object or the texture of the surface reaches that angular magnification at which contact is made. (p. 188)

Shortly after this pioneering paper was published, one of Gibson's students, William Purdy, generated the mathematics of the stimulus information for time-to-contact or time-to-go, and it appeared in his thesis (Purdy, 1958) and in a theoretical treatise, including a study of humans estimating time-to-contact (T_c) with an apparently approaching surface (Carel, 1961). The simple formula for T_c is as follows, given the spatial change in optical separation (i.e., angular size change) of any two points or contours over time (t):

1. PERCEIVING AND DRIVING

$$T_c = \frac{\theta_1}{\theta_2 - \theta_1 / t_2 - t_1} \quad (1.3)$$

(note: $\Delta\theta / \Delta t$)

Formula 1.3 calculates T_c from angular size changes over time. As shown in formula 1.3, the relative rate of increase in angular separation of points or contours on the approaching object's surface is the reciprocal of the time-to-go.

The effectiveness of such information for producing avoidant behaviors (indicating impending collision was being perceived) was explored in various animal species and humans (Schiff, 1965; Schiff, Caviness, & Gibson, 1962) and by numerous other researchers (e.g., see Schiff, Benasich, & Bornstein, 1989; Schiff & Detwiler, 1979, for brief critical reviews). But it was Lee (1976) who developed the hypothesis that perceiver-actors as diverse as automobile drivers, diving birds (Lee & Reddish, 1981), long jumpers (Lee, Lishman, & Thompson, 1982), and fast-ball sports participants (Lee, Young, Reddish, Lough, & Clayton, 1983) use *tau* information to control their visual-motor behaviors. Lee's analysis of *tau* (τ) utilization in automobile braking is based on the notion that the driver may utilize the inverse of the proportional rate of dilation to control brake pressure, because, as derived from Purdy, τ = $1 / \text{rate of dilation}$, for example, between the headlights of an approaching car. Then the issue becomes one of applying sufficient pressure, to cancel dilation prior to contact. A driver's deceleration is adequate to avoid collision if τ is greater than $-1/2$ (where τ is the derivative of τ with respect to time), and a driver may maintain a safe following distance by maintaining τ at a marginal value greater than one-half (i.e., $1/2$) (see Lee, 1976, for details of derivation). Recent critiques by Tresilian (1991) and Wann, Edgar, and Blair (personal communication 1992) noted some problems regarding the adequacy of this formulation.

Numerous studies have been performed in attempts to discover whether drivers or other perceivers can indeed use *tau* information to perceive and judge time-to-contact, with a consensus that they can do so with high accuracy if the temporal value is about 2 sec or less. But when the time remaining before contact reaches 3 sec or more, estimates made by pushbutton or verbal means indicate increasing underestimation as time-to-contact increases (e.g., see Cavallo & Laurent, 1988; McLeod & Ross, 1983; Schiff & Detwiler, 1979; Schiff & Oldak, 1990; Schiff et al., 1992). The amount of underestimation is considerable, with most perceivers estimating time-to-contact at about 60% to 70% of its actual

1972; Rockwell, 1972). The driving task seems to be largely a complex set of vector detection and control processes. Studies and measures that reflect that reality will likely be far more successful than those that continue to ignore the ecological validity issue and test drivers for verbally accessed knowledge rather than performance and for irrelevant perceptual processes (Fox, 1988). Recent state-of-the-art reports may be found in Gale, Brown, Haslegrave, Taylor, and Moorehead (1991), Schiff and Oldak (1993).

On the other hand, sensory capabilities may indeed limit performance in actual driving situations, and wherever they can be economically measured, measuring them seems quite a good idea, however "sensory" rather than "global" they might appear. But in devising measures of such sensitivities, it would be more ecologically valid to embed them in a driving-like task. Familiar context may aid detection and discrimination (or so research has shown). And on the other side of the coin, cluttered environments (which almost all driving environments are) may hinder even a good visual system trying to locate a sign, signal, or other detail. Thus, unless one measures sensory capabilities in environments having characteristics similar to those of driving environments, one will never know whether one is under- or overestimating the functional utility of a system that may do well (or poorly) in the static and uncluttered environment of the medical practitioner's office. It is likely that if the impairment is extreme, the ecologically invalid measure will still detect it. But it is the marginal driver who is of most concern. It may be easier to detect marginal driving skills using dynamic realistic displays, rather than the usual battery of multiple choice question, static, and overly simplified perceptual measures and isolated sensory-sensitivity measures (e.g., see Schiff & Oldak, 1990, 1993).

Good engineering and human factors design is also important, as spelled out by Norman (1988). Even the good skilled driver with good vision may become a road hazard if he or she has to look for vehicle controls that all look and feel alike, that are in the wrong place, or that display information in a way that takes longer than necessary to "decode" (see Gale, Freeman, Haslegrave, Smith, & Taylor, 1986, 1988).

Thus, in closing, it appears that researchers engaged in the study of automobile driving should incorporate information from both the classical sensory psychophysics and ecological approaches, as well as findings concerned with human factors and design. Driving involves the integrated activities of sensing, perceiving, deciding, and acting. Before any actions or decisions regarding such actions can be made, the

human factors scientist must become aware of phenomena in the perceiving and driving realm. Perceiving involves the capability of the driver to detect relevant phenomena. Sensing also involves the ability to pick up different sorts of information from the dynamic environment. For example, an individual may be fully capable of detecting an oncoming car (i.e., possess "normal" vision), but through some circumstance misjudge or misinterpret information such as closure rate, causing a collision. Or, the individual may pick up and interpret the information correctly, but as a result of poor engineering/design be unable to manipulate appropriate controls in a timely fashion.

Each of the aforementioned approaches to automobile driving research has provided a uniquely traveled road to the current state of the art. It is time for them to consider the findings from other approaches and unite the parallel universes of discourse and knowledge.

Acknowledgments

The authors of this chapter gratefully acknowledge the generosity of Michael Palij and Doris Aaronson in its preparation.

1.4 References

- AAA (1985a). *To drive at night*. Washington, D.C.: The AAA Foundation for Traffic Safety.
- AAA (1985b). *Visual perception in driving*. Washington, D.C.: The AAA Foundation for Traffic Safety.
- Allen, M. (1969, September). Vision and driving. *Traffic Safety*, pp. 8-10.
- Altman, J. (1989). *Berlitz: Blueprint France*. Lousanne, Switzerland: MacMillan S.A.
- Arnone, W. (1991a). *An examination of response times with different input devices to unknown targets in driving scenes*. Unpublished manuscript.
- Arnone, W. (1991b). *The effect of illumination level on response latency to target events in driving scenes*. Unpublished manuscript.
- Arnone, W. (1994). Assessment of time to arrival and margins of safety gaps for left turns in younger and older drivers. Unpublished doctoral dissertation, New York University.
- Ball, K. (1990). Cognition. In Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers. U.S. Dept. of Transportation, *NHTSA Conference Proceedings* (pp.

- Rand Research Center.
- Kebeck, G., & Landwehr, K. (1991). *Optical magnification as event information*. Unpublished manuscript.
- Kelmer, J., & Johnson, C. (1987). Visual function, driving safety, and the elderly. *Ophthalmology*, 94, 1180-1188.
- Koenderink, J. (1990). Some theoretical aspects of optic flow. In R. Warren & A. Wertheim (Eds.), *Perception and control of self motion* (pp. 53-68). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Koenderink, J. J., & van Doorn, A. J. (1975). Invariant properties of the motion-parallax field due to the movement of rigid objects with respect to an observer. *Optica Acta*, 22, 773-791.
- Lee, D. (1976). A theory of visual control of braking on information about time-to-collision. *Perception*, 5, 437-459.
- Lee, D., & Lishman, J. (1977). Visual control of locomotion. *Scandinavian Journal of Psychology*, 18, 224-230.
- Lee, D., Lishman, J., & Thompson, J. (1982). Regulation of gait in long jumping. *Journal of Experimental Psychology: Human Perception and Performance*, 8, 448-459.
- Lee, D., & Reddish, P. (1981). Plummeting gannets: A paradigm of ecological optics. *Nature*, 293, 293-294.
- Lee, D., Young, D., Reddish, P., Lough, S., & Clayton, T. (1983). Visual timing in hitting an accelerating ball. *Quarterly Journal of Experimental Psychology*, 35A, 333-346.
- Leibowitz, H. (1965). *Visual perception*. New York: MacMillan.
- Leibowitz, H. (1985). Grade-crossing accidents and human factors engineering. *American Scientist*, 73, 558-562.
- Leibowitz, H., Owens, D. (1977). Nighttime driving accidents and selective visual degradation. *Science*, 197, 422-423.
- Lewin, K. (1936). *Principles of topological psychology*. New York: McGraw-Hill.
- Lombardo, T. J. (1987). *The reciprocity of perceiver and environment*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- McCormick, E. (1957). *Human factors engineering*. New York: McGraw-Hill.
- McCormick, E., & Sanders, M. (1976). *Human factors in engineering and design*. New York: McGraw-Hill.
- McLeod, R., & Ross, H. (1983). Optic-flow and cognitive factors in time-to-collision estimates. *Perception*, 12, 417-423.
- Matlin, M. (1988). *Sensation and perception* (2nd ed.). Boston: Allyn & Bacon.
- Nagayama, Y., Morita, T., Miura, T., Watanabem, J., & Murakami, N.

1. PERCEIVING AND DRIVING

- (1979). *Motorcyclists visual scanning pattern in comparison with automobile drivers* (Tech. Paper Series No. 790262). Society of Automotive Engineers.
- National Highway Traffic Safety Administration (NHTSA). (1989, August 23-24). In Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers. Washington, D.C.: U.S. Dept. of Transportation.
- Neisser, U. (1976). *Cognition and reality*. San Francisco: Freeman.
- Norman, D. (1988). *The psychology of everyday things*. New York: Doubleday.
- Olson, P., Butler, B., Burgess, W., & Sivak, M. (1982). *Toward the development of a comprehensive driving test: Low-speed maneuvering-Highway* (Rep. No. UM-HSRI-82-4). Ann Arbor: Safety Research Institute, University of Michigan.
- Olson, P., & Sivak, M. (1986). Perception-response time to unexpected roadway hazards. *Human Factors*, 28, 91-96.
- Owen, D. (1990). Perception and control of change in self-motion: A functional approach to the study of information and skill. In R. Warren & A. Wertheim (Eds.), *Perception and control of self motion* (pp. 289-326). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Owsley, C., & Sloane, M. (1987). Contrast sensitivity, acuity, and the perception of "real world" targets. *British Journal of Ophthalmology*, 71, 791-796.
- Pevsner, D. (1991, September 29). It's time to stop poking along at 55. *New York Times*, p. 13.
- Purdy, W. (1958). *The hypothesis of psychophysical correspondence in space perception*. Unpublished doctoral thesis, Cornell University, Ithaca, NY.
- Reed, E. (1988). *James J. Gibson and the psychology of perception*. New Haven, CT: Yale University Press.
- Reed, E., & Jones, R. (Eds.). (1982). *Reasons for realism*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Regan, D. (1985). Visual flow and the direction of locomotion. *Science*, 223, 1064-1065.
- Regan, D., & Beverly, K. (1982). How do we avoid confounding the direction we are looking and the direction we are moving? *Science*, 215, 194-196.
- Richards, O. W. (1966). Motorist vision and the driver's license. *Traffic Quarterly*, 3, 3-20.
- Rockwell, T. (1972). Skills, judgment, and information acquisition in driving. In T. Forbes (Ed.), *Human factors in highway traffic safety*