

Age Differences in Estimating Vehicle Velocity

Charles T. Scialfa, Lawrence T. Guzy, Herschel W. Leibowitz, Philip M. Garvey, and Richard A. Tyrrell
Pennsylvania State University

Automobile accidents among older adults may be related to difficulties in judging the speed of other vehicles. To examine this possibility, 3 groups of observers in the young adult, middle-aged, and older adult age ranges were asked to estimate the velocity of an isolated automobile traveling at 15-50 mph (24-80 kph). Across all age groups, perceived and actual velocity were related by a power function with an exponent of 1.36. Age was significantly and positively correlated with intercepts, but negatively correlated with exponents; that is, older observers showed less sensitivity to changes in actual velocity. Results bear on the issues of ontogenetic changes in accident involvement and sensitivity to motion.

Although nonvisual factors play a role in effective driving performance, driving is predominantly a visual task. Hills (1980) estimated that more than 90% of the information impinging on the driver is visual in nature. Among the many visual tasks required by the driver, estimating the velocity of other vehicles appears to be one of the more salient. Velocity estimation plays a role in various traffic maneuvers, including intersection crossing, merging, and overtaking. Underestimations of vehicle velocity may place drivers attempting these maneuvers at greater risk of accident involvement. This may be particularly true for older persons, in whom a disproportionate number of both pedestrian and driver accidents may involve errors of velocity estimation (Faulkner, 1975; Hills & Johnson, cited in Hills, 1980; Sheppard & Pattinson, 1986). The data reported in this article were gathered to determine whether the ability to estimate vehicle velocity changes systematically over the adult life span.

Speed Estimation and Scaling

The manner in which human observers process velocity information remains unclear, but evidence suggests that such information is used to make decisions about some driving maneuvers. For example, increasing traffic velocity leads to reductions in the minimum time gaps allowed when crossing against traffic flow (Bottom & Ashworth, 1978). Velocity estimation is often inaccurate, however. Many drivers err in estimating the last moment to safely overtake a vehicle in the presence of oncoming traffic (Jones & Heimstra, 1964; Kaukinen, 1972), and at

least some authors (Leibowitz, 1985; Mackie, 1972) have argued that overtaking accidents are due in part to misjudgments of the oncoming vehicle's velocity. Such an argument raises the question of whether observers can judge velocity in either absolute or relative terms, and the available literature does not suggest a simple answer.

Laboratory-based research, which often uses impoverished visual scenes and magnitude estimation techniques, has shown that young observers are quite capable of producing relative scales of subjective velocity. Rachlin (1966), for example, presented observers with a small circular target moving at 0.94-230 degrees per second under both constant duration and constant distance conditions. Although power functions relating actual to scaled velocity accounted for the obtained data, the exponent averaged 0.75; slower velocities tended to be overestimated, whereas faster velocities tended to be underestimated. Ellingstad and Heimstra (1969) asked subjects to estimate the time taken for a temporarily concealed luminous target to reappear. Dividing concealment distance by time estimates yielded subjective velocity estimates. In contrast to Rachlin's findings, there was a trend toward best estimations at higher velocities. Furthermore, there appeared to be two groups of observers, those who underestimated and those who overestimated at lower actual velocities. Kennedy, Yessenow, and Wendt (1972) presented highly practiced observers with a row of "dim dots" (p. 134) moving at velocities ranging from 0.76 to 11.1 degrees per second. They found that a power function with an exponent of approximately 1.0 described their data, indicating both absolute and relative accuracy in speed estimation. Janssen, Michon, and Buist (1971) measured subjective translatory velocity of one and two light points moving at 1.2 min/s to 2.5 degrees per second. In the one-light condition and for the entire range of velocities, an additive constant model with an exponent of 0.99 fit the data. Considering only higher velocities, a simple power function with exponents ranging from 0.78 to 0.99 provided the best fit.

Algom and Cohen-Raz (1984, 1987) have used functional measurement methodology (Anderson, 1970) and have provided some of the most complete data on subjective scaling of velocity. Observers were required to view a small circular target

This research was supported by a grant from the National Institute on Aging (AG-00110-02).

We thank the Pennsylvania Transportation Institute for the use of their test track; the Oneonta, New York, Police Department for the use of their radar unit; and especially Joyce A. Blake-Guzy for her invaluable assistance in data collection.

Lawrence T. Guzy is now at the State University of New York at Oneonta.

Correspondence concerning this article should be addressed to Charles T. Scialfa, who is now at the Department of Psychology, University of Calgary, Calgary, Alberta, Canada T2N 1N4.

moving in a circular track on an otherwise blank cathode ray tube. Magnitude estimates were obtained under conditions where distance and duration were combined factorially. In both studies, the group mean exponents relating actual to perceived velocity fell below unity, suggesting a compressive scale. Despite the observed departure from absolute accuracy in velocity estimation, Algom and Cohen-Raz (1984, 1987) concluded that their data were consistent with a model in which human velocity estimation was determined by the integration of information concerning temporal and spatial extent.

The findings just summarized lead to the conclusion that although observers may exhibit errors in velocity perception that depend on target velocity, they are quite capable of producing subjective velocity scales. These scales typically have an exponent below unity. On the other hand, subjective velocity scales derived from the observation of real or simulated driving environments have produced greater variability in obtained exponents, which often exceed unity. In an early study, Barch (1958) had drivers make periodic decelerations to 40 and 30 mph (64 and 48 kph) following prolonged driving at 50 mph (80 kph). There was a tendency toward underestimation of speed, which was more pronounced at 30 mph (48 kph). Although the number of speeds produced was too small to generate velocity scales, because there were greater overproductions at lower speeds, an exponent greater than 1.0 might be expected. Unfortunately, because Barch required drivers to maintain a 50-mph (80-kph) speed for prolonged periods, their estimates may have been due in part to adaptation effects. Adaptation produces systematic underestimates of observed speeds below adaptation level. When asked to produce these lower speeds, subjects will give an overestimate (Denton, 1976). Denton (1966) avoided long-term adaptation and used a ratio production procedure in which drivers were asked to halve or double their driving speeds. Below 55 mph (88 kph), the exponent relating produced to requested velocity was 1.96 for halving and 1.54 for doubling conditions. Similarly, Matthews and Cousins (1980) had drivers produce speeds of 20–50 mph (32–80 kph) while driving variously sized vehicles with which drivers were unfamiliar. Drivers consistently produced overestimations at low speeds, but there was a trend toward underestimation at higher speeds, and exponents ranged from 0.66 to 0.89. In a second experiment, drivers operated their own vehicles. The slopes relating requested to produced velocity were similar to those obtained in Experiment 1. Evans (1970) had passengers estimate the speed of a vehicle in which they were traveling at 10–60 mph (16–97 kph). Observers provided speed estimates while they had full sight and hearing and also when they were prevented from using visual cues, auditory cues, or both. A tendency to underestimate speed was found in all but the attenuated sight condition, where observers underestimated lower and overestimated higher speeds. In the full-viewing condition, power functions were fit to two segments of the velocity scales: Below 40 mph (64 kph), the exponent was 1.32; from 40–60 mph (64–97 kph), the exponent was 0.96.

Although the *in vivo* data from Evans (1970), Denton (1966, 1976), Barch (1958), and Matthews and Cousins (1980) are intriguing, they all involve observers who were seated in a moving vehicle. As such, sensory information mediating self-motion perception presumably played a role in velocity estimation. Sev-

eral other investigations of velocity perception have used magnitude estimation to generate subjective velocity scales with stationary observers, in which the task is similar to that involved in intersection crossing. Semb (1969) found subjective velocity scales with an exponent of 1.0 when the observed vehicle crossed the line of sight and an exponent of 1.35 when the vehicle approached from the straight-ahead. Hills and Johnson (reported in Hills, 1980) also used magnitude estimation to generate subjective scales of velocity. Across three road-site-speed-limit conditions, slower speeds were overestimated, and faster speeds were underestimated. These data are similar to those reported by Scialfa, Kline, Lyman, and Kosnik (1987), where a life-span sample of observers estimated speed from videotaped sequences of a single vehicle traveling at 20–60 mph (32–97 kph). To be sure, the comparison of two-dimensional and three-dimensional scales is tenuous. Three-dimensional scenes provide binocular cues to depth that are not available in filmed driving scenes. Also, two-dimensional presentations often minimize the need for pursuit eye movements. To the extent that information from eye movements is used in estimating velocity, the minimization of eye movements may lead to systematic changes in perceived velocity (Dichgans, Korner, & Voight, 1969; Raymond, 1988). In fact, the average slope¹ in the Scialfa et al. (1987) data was 0.68, considerably below that found in three-dimensional scaling studies and similar to the exponents reported when eye movements to track the target are largely unnecessary (e.g., using small visual fields).

Aging, Accident Involvement, and Speed Estimation

Although elderly persons as a group (i.e., incidents per 1,000 drivers) do not contribute excessively to driving accidents, when rate (i.e., incidents per 100,000 km) is considered, the older driver is overrepresented in both accidents and cited traffic violations (Brainin, 1980). They also have a unique profile of such traffic incidents. Compared with younger drivers, they are infrequently involved in accidents or violations attributable to excessive speed or in major violations, such as driving recklessly or while intoxicated. They are, however, more likely to be involved in accidents and traffic citations involving failure to heed signs, yield right-of-way, or turn safely (California State Department of Motor Vehicles, 1982; Harrington & McBride, 1970). The extent to which accidents of these types can be attributed to age-related differences in perceptual functioning has not been determined. It is certainly the case that these accidents have multiple causes, and several lines of evidence suggest that the older adult's accident involvement may stem, in part, from an inability to judge accurately the speed of oncoming vehicles.

Detection of angular movement and movement in depth have been related to accident involvement (Henderson & Burg, 1974). Although Brown and Bowman (1987) found no evidence for an age-related decline in velocity discrimination for small luminance targets, older adults are less able to detect changes in direction of motion (Ball & Sekuler, 1986). Storie (1977) found

¹ The exponents were not reported by Scialfa, Kline, Lyman, and Kosnik (1987). Their data have been reanalyzed recently by Scialfa to provide the curve fits discussed in this article.

that, relative to younger drivers, elder male drivers have a larger percentage of accidents that can be attributed to perceptual errors, including distractions and poor estimation of distance or speed. Sheppard and Pattinson (1986) interviewed elder pedestrians who had been involved in rural automobile accidents. The data indicated that a failure to perceive motion or to accurately judge velocity accounted for many of the accidents reported.

Of greatest relevance for our investigation, Hills and Johnson (cited in Hills, 1980) divided their observers into younger (31–40 years) and older (61–70 years) adult groups to examine potential age sensitivity in velocity estimation. Although no significance tests were included in Hill's (1980) report of these data, it was argued that older drivers gave "lower speed estimates than younger drivers" and that "the slopes of their error characteristics were steeper for the older drivers, indicating a poorer sensitivity to vehicle speed" (p. 202). Visual inspection of the data, however, suggests that this is true for only two of the three road sites tested. At the third road site, the younger adults exhibited steeper slopes. Furthermore, although viewing time apparently was controlled, the influence of other factors (e.g., traffic characteristics and weather conditions), particularly as they might interact with age, is unknown.

In contrast, Scialfa et al. (1987) were able to control these factors to a much greater degree. The vehicle that served as the stimulus for velocity judgments was the only vehicle in the scene, and lighting, traffic, and road environment characteristics were held constant across the speeds judged. Observers were divided into young adult (mean age = 32.6 years) and older adult (mean age = 63.8 years) groups. For each observer, linear functions were fit to their speed estimation data, and the resulting slope and intercept parameters were analyzed to determine whether they varied between age groups. In contrast to Hills and Johnson's data, slopes did not vary across the age groups; however, intercepts were significantly higher in older adults, indicating that the elderly judged cars to be traveling more quickly than was judged by the young. To the extent that velocity estimates from two-dimensional scenes can be generalized to roadway settings, the Scialfa et al. (1987) data could be used to argue that velocity estimation per se does not differentially contribute to the accident profile of older adults, because the errors would be expected to lead to more conservative driving actions. Still, it is obvious that further work is needed. Particularly valuable would be data on age-specific variation in judgments of automobile velocity under controlled three-dimensional viewing. To this end, in this investigation, a life-span sample of drivers observed a test vehicle traveling a closed circuit at 15–55 mph (24–88 kph). Their velocity estimates were evaluated to determine the degree to which observers can estimate relative velocity, actual velocity, or both and how this ability might change with age.

Method

Subjects

Twenty-nine men and women volunteered to serve as observers. Young adults were drawn from undergraduate and graduate courses, and other volunteers came from within the university community. The

young adult group contained 5 men and 4 women aged 20 to 27 years ($M = 22.22$). The middle-aged group included 4 men and 6 women aged 40 to 54 years ($M = 47.30$). The older adult group contained 6 men and 4 women aged 55 to 74 years ($M = 65.3$). All observers had at least 12 years of formal education, were living independently, and reported themselves to be in good health and free from known visual pathology. None had been hospitalized during the previous year, nor were any observers currently under a physician's care for a serious illness or condition. All but 1 younger observer held a current driver's license and were regular drivers. For all observers, binocular acuity (at distance) was better than 20/40, and Vistech contrast sensitivity was within normal limits for the observer's age group (Scialfa et al., 1988).

Apparatus and Materials

Data were collected at an automotive test track operated by the Pennsylvania Transportation Institute of The Pennsylvania State University. The test track was a 1-mi (1.609-km), uniform-surface oval that was visually isolated from other vehicle or pedestrian traffic. The surrounding area was a combination of level farmland in the immediate vicinity and mountainous forest in the distance. All observations were made during daylight, although the ambient light level ranged from full sun to heavy cloud cover.

Velocity estimations were made on two sections of the track, designated "straight" and "curved." The straight section described an arc of 4°, and the curved section described an arc of 120°. For both sections, estimates were made while the vehicle traveled 400 ft (122 m) beginning 600 ft (183 m) ahead of the point where the track passed the observation vehicle.

The observation vehicles were two full-sized, four-door automobiles. These vehicles were located 12 ft (3.66 m) from, and oriented perpendicular to, the test track. Observers were seated on the passenger side (both front and rear), which allowed a clear view of the test vehicle along its entire excursion. The test vehicle was a burgundy four-door compact (Mazda GLC DeLuxe). The test vehicle's speedometer was calibrated at the beginning and end of data collection with a commercially available radar unit (Prefect Traffic Radar System TR6).

Design and Procedure

Testing was conducted in a single session approximately 90 min in duration. Observers were tested individually or in pairs in each of the two observation vehicles. For a given series of velocities, one vehicle was positioned for curved-track viewing, and the second was positioned for straight-track viewing. Thus, two groups of observers were tested in a given session. The task can be best described by paraphrasing instructions that were given to the observers:

During the course of this study, you will watch a car traveling on two sections of this test track at varying speeds. What we want you to do is to estimate to the best of your ability the speed of the car during the time that we tell you to view it. There will be many trials, and each trial will go like this: You will look straight ahead through the windshield. As the test car reaches the point where we want you to begin viewing, you will hear a message, "Begin viewing." At that time, you should look at the moving car and continue watching it until you hear the message, "End viewing." At that time, you should look away from the vehicle and indicate on your answer sheet the speed at which you think the car was traveling. We would like you to estimate speed in two ways: First write down your answer in miles per hour. Second, on your answer sheet you see a line. We want you to indicate on this line the speed of the vehicle. If you think that the car was traveling very slowly, then place your mark toward the left end of the line. If you think that the car was moving very quickly, then put your mark toward the

right end of the line. Try to use the entire line. [The 100-mm line was labeled VERY SLOW, MEDIUM, and VERY FAST, at the left end, midpoint, and right end, respectively.] You may talk to each other during the course of the study, but we do not want you to talk about the experiment until we are finished. Do you have any questions?

This procedure of asking observers to give their estimates in miles per hour is not identical to the traditional magnitude-estimation task in which a neutral metric is used. Our decision to use miles per hour as the metric was based on the assumption that some observers would use this metric regardless of instruction, because it is so familiar to them. In mandating the metric, we eliminated one source of interindividual variability and in so doing could meaningfully compare and interpret age-group differences in intercepts. This would not have been possible had observers been left to choose their own metric.

Subjects were presented with three trials at each of eight speeds ranging from 15 to 50 mph (24–80 kph) in 5-mph (8-kph) steps. Vehicle speed was randomly ordered on a group basis; that is, all observers tested at the same time were given the same order of speeds, but other groups received a different random order. Order of road curvature was counterbalanced across groups so that equal numbers of observers in each age group viewed the curved or straight track first.

Results

The general approach to data analysis was a two-stage effort, requiring first, curve fits to individual velocity scales, and second, tests of fit parameters to those factors influencing velocity estimation. For each observer, arithmetic mean speed judgments were calculated for each speed, road type, and order condition. These mean velocity judgments were used then to fit linear functions to each observer's velocity scale in both linear and logarithmic coordinates. Fits of the velocity scales were quite good. Collapsed across age, viewing order, and road type, the mean r^2 was .973 and .969 for linear and log coordinates, respectively. The linear coordinate fits were significantly better than those based on logarithmic coordinates, $F(1, 28) = 7.62$, $p = .01$.

Parameters derived from the curve fits were then entered into analyses of variance (ANOVAs) to determine whether age, road type, or viewing order exerted any effects on the velocity scales. This procedure was used for both miles per hour and millimeter judgments, but only the ratings in miles per hour are discussed herein. The omission of millimeter judgments is justified for three reasons. First, although parameter estimates for slopes and intercepts differed across the two response formats, significance tests based on these parameters were largely redundant. Second, because millimeter judgments were always made last, it is conceivable that observers simply transposed their miles-per-hour judgments onto the 100-mm scale, attempting to be consistent across the two response formats. Finally, because mid- and endpoints were labeled on the 100-mm scale, it is possible that it was responded to as an ordinal scale, in which case parametric tests may be inappropriate.

Initially, all effects were tested in Age (3) \times Road Type (2) \times Order (2) ANOVAs on both slopes and intercepts. Because neither road type nor order exerted any significant main effects or interactions, the data were collapsed across these variables for subsequent analyses. The average slope and intercept values are shown for each age group and for the total sample in Figure 1.

Older adult's intercept values were somewhat higher than those in the young adult group. Also, slope values, all of which were in excess of 1.0, decreased in the elderly, suggesting that speed judgments may not grow at the same rate across the adult life span (i.e., sensitivity to velocity differences was less in older adults). In fact, the ANOVA revealed a significant age effect on intercepts, $F(2, 23) = 3.59$, $p = .044$, and a marginally significant age effect on slopes, $F(2, 23) = 3.29$, $p = .055$.

In light of the relatively small sample size, statistical power considerations led to the examination of age differences in slopes and intercepts via simple regression analysis that tested continuously scaled age effects separately for each velocity scale parameter. The age effect on intercepts was significant for both linear, $F(1, 27) = 9.50$, $p = .005$, $r = .51$, and log fits, $F(1, 27) = 6.71$, $p = .015$, $r = .45$. The age effect was also significant for slopes in both linear, $F(1, 27) = 6.40$, $p = .018$, $r = .44$, and log coordinates, $F(1, 27) = 7.48$, $p = .011$, $r = .47$.

Although it is important to demonstrate age differences in slopes and intercepts, from an applied perspective it is also important to know (a) whether there are significant age differences in estimated speeds at speed values that are common to the driving task and (b) whether the age differences at these speeds place the older driver at greater risk of accident involvement. To this end, each subject's regression parameters were used to predict judged velocity at 15 and 55 mph (24 and 88 kph), speeds representing two ends of the range of speeds typically encountered by U.S. drivers in urban settings. The predicted values for cars traveling at 15 and 55 mph (24 and 88 kph) are shown for each age group and for the entire sample in Figure 1. There were significant differences between actual and predicted judged speed at both 15 mph (24 kph), $F(1, 26) = 28.39$, $p < .001$, and 55 mph (88 kph), $F(1, 26) = 21.33$, $p < .001$. Specifically, observers underestimated at low velocities and overestimated at higher velocities. It appears that there may have been some discernible age differences in predicted speed, but this was only true for predicted speed estimates at 15 mph (24 kph), $F(1, 27) = 4.55$, $p = .04$, $r = .38$, when the predictions were based on linear coordinate fits.

Although speed estimates that are predicted from scales are generally more reliable than the obtained speed estimates used to construct the scale, knowing whether there were age differences in the obtained estimates themselves may also be of interest. To examine this possibility, obtained speed estimates at 15 and 50 mph (24 and 80 kph) were regressed separately on age. In neither case was the age effect significant ($p > .20$).

Discussion

Within the motivating context of this experiment, there were three questions to be addressed concerning subjective scales of vehicle velocity. First, can observers scale velocity? This is a question of relative speed estimation because a compressive or expansive psychophysical function is a scale nonetheless. Second, and of greater applied importance, to what degree do observers' velocity estimates differ from real velocity? Last, and not unrelatedly, are there age differences in either relative or absolute velocity estimation, and how might these differences affect the older driver or pedestrian?

Obtained results strongly suggest an affirmative response to

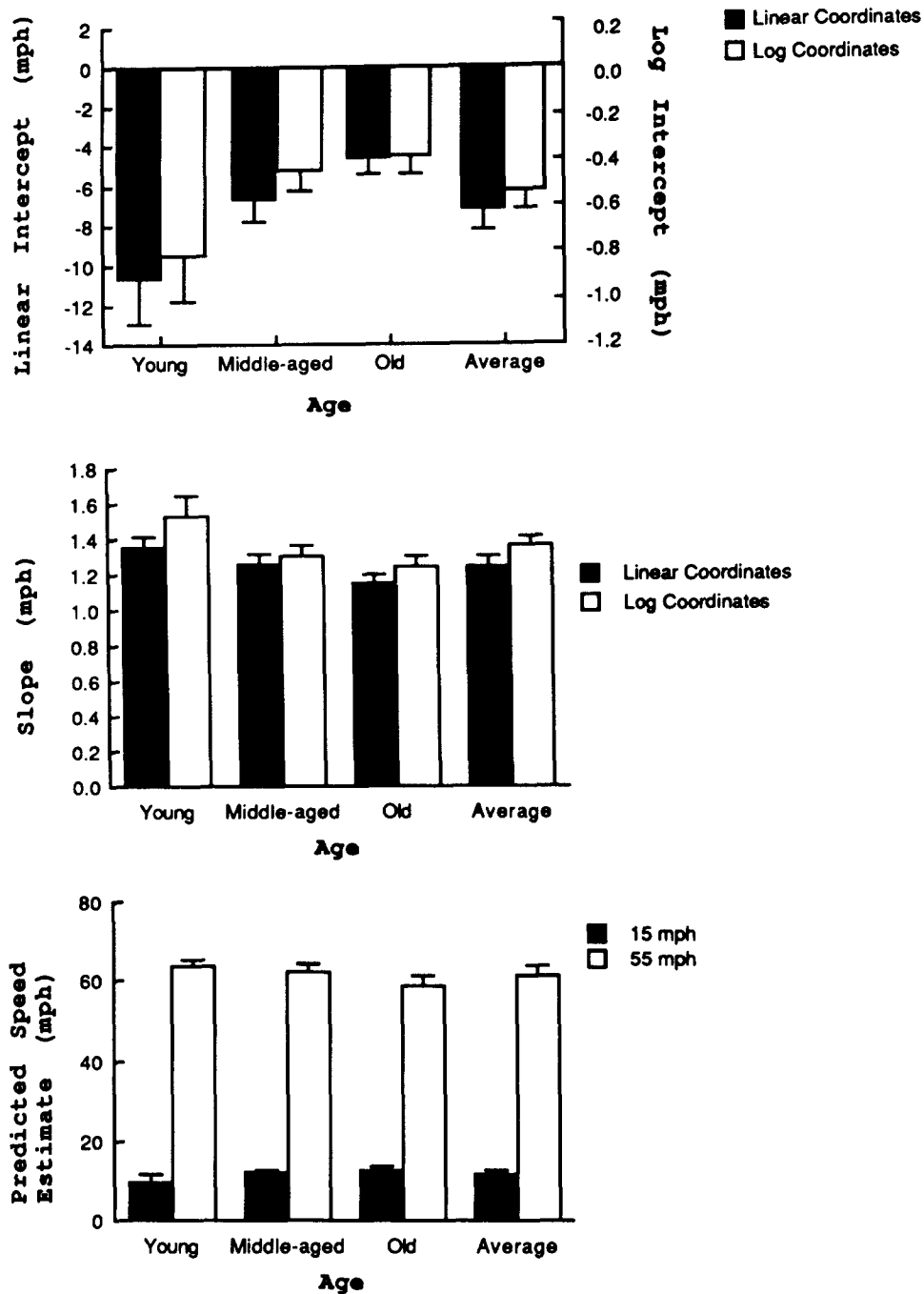


Figure 1. Parameter estimates and predicted velocities from subjective velocity scales. (Top: Intercepts for double-linear and double-log fits. Middle: Slopes for double-linear and double-log fits. Bottom: Predicted subjective velocities at 15 and 55 mph (24 and 88 kph). In all plots, vertical lines represent 1 SE)

the first question. Regardless of age, the data indicated that observers produced psychophysical functions similar to those obtained with other intensive continua (see Stevens, 1975). Averaged across all observers, the obtained exponent of 1.36 is not dissimilar to that obtained in previous efforts to scale vehicle velocity. Evans (1970) found an exponent of 1.32 for speeds below 40 mph. Denton's (1966) drivers produced ratio-setting

scales with an exponent of 1.75. The average exponent obtained in our data is, however, much higher than those reported in studies where the visual scene was devoid of stimuli other than the to-be-judged target. Algom and Cohen-Raz (1984, 1987), for example, reported exponents that ranged from .60 to .70. In fact, it is generally the case that studies that are not conducted in the field have exponents considerably below unity. Although

the reason for this discrepancy is unclear, it may well be related to the lack of background contours in laboratory-based scaling efforts. Judged velocity is greater when a target moves across a contoured, as opposed to a featureless, background (Raymond, 1988). This contour effect is probably mediated by several mechanisms, including optokinetic nystagmus (OKN). For example, if one were stationary and attempting to visually track a vehicle moving through a wooded area, the vertical contours of the trees would move across the retina. This movement, in the direction opposite to the observer's, would induce OKN. In order to successfully fixate the vehicle, the OKN must be suppressed by exerting effort in the direction of vehicle motion. Because the efferece associated with voluntary eye movements and suppression is indistinguishable, it should sum and produce a higher perceived velocity, which often would be greater when viewing faster vehicles. We have planned a study to examine the effects of contour in judgments of vehicle velocity.

The second question, that of absolute accuracy in speed estimation, is important for several reasons. It is often the case that a legal witness is asked to make statements regarding the speed of an oncoming vehicle. Yet, the literature on eyewitness testimony (e.g., see Loftus, 1979) suggests that this is an ability that has not been acquired by most observers. If observers are unable to accurately estimate velocity under the present conditions where estimation was the only task required, it is unlikely that they would be able to do so in the driving environment where they are not attending solely to the speeds of other vehicles. Absolute accuracy for speed estimation may also be important to the extent that this information is necessary to judge time to impact accurately.

Accuracy can be examined only by determining the judged speeds that would be predicted on the basis of individual curve fits. Prediction of judged speed indicated that, on average, observers in this study tended to underestimate lower speeds and overestimate higher speeds. In fact, at both 15 and 55 mph (24 and 88 kph), predicted judged speeds were significantly different from actual speeds. Thus, it appears that observers are not capable of judging velocity in an absolute sense. Such a conclusion has been drawn previously and may help to explain why drivers sometimes overestimate velocity (Matthews & Cousins, 1980), underestimate velocity (Triggs & Berenyi, 1986) or both (Evans, 1970). On a more optimistic note, the obtained results suggest that at least in some conditions, observers overestimate at high speeds, with such errors presumably inducing a conservative bias regarding risk involved in making a driving maneuver in the face of a rapidly approaching vehicle.

The third issue addressed was that of age differences in scaling subjective velocity, and again, one can interpret obtained results from either a traditional psychophysical or an applied approach. Examination of the curve fits suggests that there are age differences in the rate at which perceived velocity grows with actual velocity. Specifically, the significant correlation between age and slope estimates indicated that the scale of subjective velocity becomes less expansive with age. This finding is in agreement with Hills and Johnson (reported in Hills, 1980), where, relative to the young, older observers made greater errors of underestimation at higher speeds. Hills argued that such age differences indicate lessened sensitivity to changes in

velocity. This may be true, yet Brown and Bowman (1987) have recently reported age constancy in differential velocity thresholds.

The assertion that older adults are less sensitive to changes in velocity encounters at least two problems when one interprets these data from the standpoint of driving safety. First, although the slopes of older adults' speed scales are lower in magnitude than are those of their younger counterparts, at higher speeds their estimates are actually more accurate than those of the young. This should also serve to emphasize the point that an expansive psychophysical scale such as obtained here does not imply either over- or underestimation of velocity. Second, although significant age effects were found for both slopes and intercepts, when each person's velocity scale was used to predict judged speed at 55 mph (88 kph), there were no age differences obtained. Also, there were no age differences in *obtained* speed estimates at either 15 or 50 mph (24 and 80 kph). Thus, our results do not support Hills's (1980) argument that the elderly are at greater risk for higher speeds. Even at 15 mph (24 kph), at which the linear coordinate predictions of speed showed a significant age effect, older adults judged the test vehicle to be traveling more quickly than judged by the young. The present data are thus more consistent with those of Desrosiers (1962), who found no relation between age and the accuracy of speed estimations on residential streets. Again, from the standpoint of risk, this would seem to mitigate against their accident involvement.

In summary, it appears that there are discernible age differences in the form of the psychophysical function relating estimated to actual velocity. Relative to the young, older adults tended to overestimate at lower speeds and underestimate at higher speeds. This age-specific decrease in the slope relating actual to perceived velocity may be related to an age decline in the ability to sense changes in velocity. Still, from an accident perspective, it appears as if the velocity judgments of young and old are very similar to each other across a range of speeds ordinarily encountered by the older driver.

References

- Algom, D., & Cohen-Raz, L. (1984). Visual velocity input-output functions: The integration of distance and duration onto subjective velocity. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 486-501.
- Algom, D., & Cohen-Raz, L. (1987). Sensory and cognitive factors in the processing of visual velocity. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 3-13.
- Anderson, N. H. (1970). Functional measurement and psychophysical judgement. *Psychological Review*, *77*, 153-170.
- Ball, K., & Sekuler, R. (1986). Improving visual perception in older observers. *Journal of Gerontology*, *41*, 176-182.
- Barch, A. M. (1958). Judgements of vehicle speed on the open highway. *Journal of Applied Psychology*, *42*, 362-366.
- Bottom, C. G., & Ashworth, R. (1978). Factors affecting the variability of driver gap acceptance behavior. *Ergonomics*, *21*, 721-733.
- Brainin, P. A. (1980). *Safety and mobility issues in licensing and education of older drivers* (Final Rep. DOT HS-805 492). Washington, DC: U.S. Department of Transportation, National Highway and Traffic Safety Administration.
- Brown, B., & Bowman, K. J. (1987). Sensitivity to changes in size and velocity in young and elderly observers. *Perception*, *16*, 41-47.

- California State Department of Motor Vehicles. (1982). *Senior driver facts*. Sacramento, CA: Author.
- Denton, G. G. (1966). A subjective scale of speed when driving a motor vehicle. *Ergonomics*, *9*, 203–210.
- Denton, G. G. (1976). The influence of adaptation on subjective velocity for an observer in simulated rectilinear motion. *Ergonomics*, *19*, 409–430.
- Desrosiers, R. D. (1962). Speed estimation on residential streets. *Public Roads*, *32*, 74–76.
- Dichgans, J., Korner, F., & Voight, K. (1969). Vergleichende Skalierung des afferenten und efferenten Bewegungssehens beim Menschen: Lineare Funktionen mit verschiedener Anstiegssteilheit [Different skills for afferent and efferent movement: Linear functions with varied slopes]. *Psychologische Forschung*, *32*, 277–295.
- Ellingstad, V.S., & Heimstra, N. W. (1969). Velocity–time estimation as a function of target speed and concealment extent. *Human Factors*, *11*, 305–312.
- Evans, L. (1970). Speed estimation from a moving vehicle. *Ergonomics*, *13*, 219–230.
- Faulkner, C. R. (1975). *Ages of drivers involved in some junction accidents* (Rep. SR131). Crowthorne, Berkshire, England: Transportation & Road Research Laboratory.
- Harrington, D. M., & McBride, R. S. (1970). Traffic violations by type, age, sex, and marital status. *Accident Analysis and Prevention*, *2*, 67–79.
- Henderson, B. L., & Burg, A. (1974). *Vision and audition in driving* (Final Rep. DOT H5801265). Santa Monica, CA: System Development Corporation.
- Hills, B. L. (1980). Vision, visibility, and perception in driving. *Perception*, *9*, 183–216.
- Janssen, W. H., Michon, J. A., & Buist, M. (1971). *The perception of manoeuvres of moving vehicles. Progress Report III—Direct scaling of translatory velocity, angular distance, and angular velocity of lights*. Soesterberg, The Netherlands: Institute for Perception TNO.
- Jones, H. V., & Heimstra, N. W. (1964). Ability of drivers to make critical passing judgements. *Journal of Engineering Psychology*, *3*, 117–122.
- Kaukinen, R. (1972). *Overtaking in the dark and in the daylight*. Helsinki, Finland: Central Organization for Traffic Safety, Research Bureau.
- Kennedy, R. S., Yessnow, M. D., & Wendt, G. R. (1972). Magnitude estimation of visual velocity. *The Journal of Psychology*, *82*, 134–144.
- Leibowitz, H. W. (1985). Grade-crossing accidents and human factors engineering. *American Scientist*, *73*, 558–562.
- Loftus, E. E. (1979). *Eyewitness testimony*. Cambridge, MA: Harvard University Press.
- Mackie, A. M. (1972). *Research for a road safety campaign—Accident studies for advertising formulation* (Rep. LR432). Crowthorne, Berkshire, England: TRRL.
- Matthews, M. L., & Cousins, L. R. (1980). The influence of vehicle type on the estimation of velocity while driving. *Ergonomics*, *23*, 1151–1160.
- Rachlin, H. C. (1966). Scaling subjective velocity, distance, and duration. *Perception and Psychophysics*, *1*, 77–82.
- Raymond, J. E. (1988). The interaction of target size and background pattern on perceived velocity during visual tracking. *Perception and Psychophysics*, *43*, 425–430.
- Semb, G. (1969). Scaling automobile speed. *Perception and Psychophysics*, *5*, 97–107.
- Scialfa, C. T., Kline, D. W., Lyman, B. J., & Kosnik, W. (1987). Age differences in judgments of vehicle velocity and distance. In *Proceedings of the Annual Meeting of the Human Factors Society* (pp. 558–561). New York: Human Factors Society.
- Scialfa, C. T., Tyrrell, R. A., Garvey, P. M., Deering, L. M., Leibowitz, H. W., & Goebel, C. G. (1988). Age differences in Vistech near contrast sensitivity. *American Journal of Optometry and Physiological Optics*, *65*, 951–956.
- Sheppard, D., & Pattinson, M. I. M. (1986). *Interviews with elderly pedestrians involved in rural accidents* (Rep. RR98). Crowthorne, Berkshire, England: TRRL.
- Stevens, S. S. (1975). *Psychophysics*. New York: Wiley.
- Storie, V. J. (1977). *Male and female car drivers: Differences observed in accidents* (Rep. 761). Crowthorne, Berkshire, England: TRRL.
- Triggs, T. J., & Berenyi, J. S. (1986). Estimation of automobile speed under day and night conditions. *Human Factors*, *24*, 111–114.

Received April 23, 1990
 Revision received July 25, 1990
 Accepted August 2, 1990 ■