Scaling automobile speed¹

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The method of magnitude estimation was used to determine the psychophysical functions for three forms of subjective automobile speed. Observers experienced linear motion across the visual field, the approach motion of an oncoming car, and "en route" motion as a passenger. All three conditions resulted in power function relations between subjective speed and physical velocity. The respective exponents were 1.0, 1.35, and 1.40. Direct category estimates of en route speed were related linearly to physical velocity, but nonlinearly to subjective speed.

Field experiments were designed to determine the psychophysical functions that relate judgments of automobile speed to physical velocity. The word *speed* is used here for the subjective variable, and the word *velocity* for a physical variable, such as miles per hour (mph) or degrees per second (deg/sec). Three different forms of speed were investigated: (1) *linear speed*, which is produced by objects that undergo linear motion across the visual field; (2) *approach speed*, which is produced by objects coming directly toward the observer; and (3) *en route speed*, which is experienced when an observer rides in or on an object.

Judgments of each of the three forms of speed are influenced by different conditions. Visually, linear speed depends on at least two parameters for its estimation, distance traveled across the visual field and duration of exposure. Acoustic stimuli such as the sound of an engine or the vehicle's tires on the pavement produce auditory cues that are generally monotonically related to physical velocity (Callaway, 1954). Approach speed depends on three visual parameters which include the rate of change of retinal size, perceived distance, and duration of exposure. As with linear speed, acoustic factors may also have an effect on judgments of approach speed. En route speed can be influenced by any combination of visual, auditory, tactile, kinesthetic, and vestibular stimuli. A major problem is how the information produced by each of these sets of stimuli is integrated and organized.

EXPERIMENT 1: LINEAR SPEED

As Rachlin (1966) has pointed out, several problems arise when one attempts to scale linear speed by means of visual stimuli that undergo linear motion. One or both of the parameters that affect linear velocity, distance, and duration may vary when different velocities are used. If distance is constant, then duration varies inversely with velocity; if duration is constant, distance varies directly with velocity. Rachlin's extensive study of subjective linear speed, distance, and duration showed that magnitude estimates of all three could be expressed as power functions of their corresponding physical variables with exponents of .75, .90, and .90, respectively. Ekman and Dahlback (1956) reported that linear speed grows as a power function of physical velocity with an exponent of 1.8 but they used a ratio production method with the stimuli confined to a fairly short range. Using circular rotation as the stimulus and a modified form of the method of magnitude estimation, Eisler and Ottander (1963) obtained a power function with an exponent of about 1.1. Mashhour (1964) found an exponent between .9 and 1.0.

Experiment 1 was designed to determine how laboratory findings compare with the way in which observers estimate linear speed in a complex environment. Because the vehicle passed through a constant visual distance, velocity varied

inversely with exposure duration, but by varying the distance from the observer to the vehicle, it was possible to study the effects of a reduced visual distance (angle) on estimates of linear speed.

METHOD

Apparatus and Materials

The experiment was conducted on a straight and level two-mile strip of asphalt pavement in Northern Wisconsin, hereafter called Road 1. A dirt side road (Road 2), situated at a 90-deg angle to Road 1, extended unobstructed for a mile in either direction. It, too, was straight and level, 33 ft wide and bordered by heavy woods and underbrush. Ss were stationed along Road 2 at distances of 100, 200, 400, and 800 ft from the center of Road 1. A 3 ft x 8 ft wooden stand on Road 1 designated the point at which S was to make his judgment; that is to say, he estimated the vehicle's speed as it passed in front of the marker. Both auditory and visual cues were used to prepare S for each trial. The driver of the test vehicle sounded the car's horn at random distances from the observation point, and E displayed a large clipboard to signal the start of a new trial.

An Electromatic Radar Speed Meter³ recorded the vehicle's velocity within one mile per hour. In order to minimize the effects of vehicle acceleration and deceleration, the driver of the test vehicle was instructed to adjust the car's velocity so that it passed in front of the observation point at a constant velocity.

The two automobiles used were a maroon 1964 two-door Ford Mustang convertible (top down), and a white 1962 two-door Cadillac Coupe de Ville.

Subjects

Fifteen college and high school students served as Ss on a voluntary basis. All were naive with respect to psychophysical experiments. Some participated in more than one of the conditions.

Design

The method of magnitude estimation was used with the initial velocity in each session designated as 1000 speed units. S saw the standard only once; on succeeding trials he was instructed to estimate the vehicle's speed in relation to the standard.

The experimental conditions are described in Table 1. There were four Ss at each observation post and 40 trials per S, two at each of 20 velocities. Velocities were programmed randomly by reference to a table of random numbers. Because the curtain of trees on either side of Road 2 formed a natural proscenium, increasing the observer-vehicle distance necessarily decreased the angular size of the visual field.

RESULTS AND DISCUSSION

In order to compare the results with those reported by other investigators, mph were converted to deg/sec to represent physical velocity (Brown, 1961). Because the angular size of the visual field was small in each condition, angular velocity could be used advantageously without introducing significant errors.⁴

As others have found, apparent linear speed, S , can be represented by a power function of physical velocity, V , by the equation

Table 1
Linear Speed—Experimental Conditions and Results

Condition and Vehicle	Velocity—Range mph	deg/sec	Velocity—Standard mph	deg/sec	Observer-Vehicle Distance (ft)	Angular Size of Visual Field	Exponents of Power Functions	Goodness of Fit Criteria (correlation)
A Cadillac	4-80	3.4-68	22	17	100	37	1.01	.973
	4-80	1.7-34	22	8.5	200	12	1.00	.969
	4-80	.85-17	22	4.25	400	6	.98	.978
	4-80	.43-8.5	22	2.12	800	4	1.03	.992
B Mustang	4-95	3.4-80	32	30	100	37	1.03	.988
	4-95	1.7-40	32	15	200	12	.98	.975
	4-95	.85-20	32	7.5	400	6	1.05	.994
	4-95	.43-10	32	3.75	800	4	1.01	.968

$$S = kV^b$$

where k depends upon the units used, and b is the exponent of the function. Figure 1 shows the results from Condition A. The results obtained in Condition B were similar. Table 1 lists the exponents of the functions (the slopes in log-log coordinates) determined by the method of least squares, and r^2 , a measure of the goodness of fit of each line. Under all the conditions tested, linear speed grows as a power function of physical velocity with an exponent of about 1.0.

Although the results agree with those reported by Eisler and Ottander (1963) and Mashhour (1964), these exponents are slightly larger than those reported by Rachlin (1966). The difference in results may be due to the size of the stimulus range. Rachlin (1966) reported that with a short stimulus range, a steeper function is obtained than when a wide range of stimuli is used. In the present study, the stimuli were varied within a range of about 23:1 which is considerably less than the range of 200:1 that Rachlin used.

In the present study, acoustic stimuli produced by the vehicle may have provided additional cues for speed estimation, especially at close observer-vehicle distances. Such a factor did not operate, however, at the 800-ft post where the vehicle's noise was not detectable until the car approached 45 mph. The results from 800 ft were nevertheless similar to those obtained at the other distances.

Increasing the observer-vehicle distance from 100 to 800 ft, which reduced the angular size of the visual field from 37 deg to 4 deg (determined by survey), did not influence judgments of linear speed. It should be pointed out, however, that as the angular size of the visual field changed, the stimulus range changed in direct proportion. That is to say, at the 100-ft post, the vehicle passed through a visual angle of 37 deg at velocities ranging from 3.4 deg/sec to 80 deg/sec (Condition B), while at the 800-ft post the vehicle passed through a visual angle of 4 deg at velocities ranging from .425 deg/sec to 10 deg/sec. Although the absolute angular velocities at each post were different, the relative velocities within each series were identical.

EXPERIMENT 2: APPROACH SPEED

This series of experiments was designed to study the psychophysical laws that govern speed estimation when S judges the speed of a vehicle as it approaches him head on. Visual perception of approach speed depends on the rate of change of retinal size, perceived distance, and duration of exposure. At extremely long ranges it is difficult to estimate approach speed because the rate of change of the retinal image is negligible. The observer-vehicle distance was manipulated in the present study in order to determine the range within which S can accurately judge approach speed. Acoustic factors may also affect judgments of approach speed, especially in a field study of this type. Such cues are usually directly related to

velocity, although these cues are presumably not useful when the distance from the observer to vehicle is great.

METHOD

The test vehicles traveled on a straight and level asphalt road along which S s were stationed at distances of 200, 400, 1000, and 2500 ft. At the 200-, 400-, and 1000-ft posts, S s were actually situated about 8 ft from the center of the road so that, in effect, the oncoming vehicle did not approach them head on, but at a slight angle. As the vehicle approached the observation point, E signalled the S s by two-way radio that a new trial was to begin. S was allowed to view the vehicle for 5 sec before recording his judgment. During the 5-sec observation period, the test car spent approximately one-half its time behind the observation point, and the other half in front of it.

The method of magnitude estimation was used with the standard stimulus designated as 1000 corresponding to the physical velocities shown in Table 2. The four conditions tested are described in Table 2. For Conditions A and B there were four S s at each observer post, and 40 or more trials per S , two or more at each of 20 velocities. For Conditions C and D there were 23 S s with one trial per S at each of 20 velocities.

The four test vehicles used were a black two-door 1962 Chevrolet Corvair, a white two-door 1962 Cadillac Coupe de Ville, and two brown four-door 1962 Oldsmobiles.

For Conditions A and B, eight high school seniors served as S s. For Conditions C and D, 23 Northland College students were the S s. All S s participated on a voluntary basis.

Fig. 1. Psychophysical functions relating magnitude estimates of linear speed to physical velocity in deg/sec for four observer-vehicle distances. The straight lines in log-log coordinates suggest that apparent linear speed grows as a power function of physical velocity. The exponents, from left to right, are 1.01, 1.00, .98, and 1.03. Each point is the geometric mean of eight observations, two observations at each velocity for each of four S s. The interquartile ranges are indicated by vertical lines.

Table 2
Approach Speed—Experimental Conditions and Results

Condition and Vehicle	Range of Velocities, mph	Standard Trial mph	Observer Vehicle Distance	Exponent of Power Function	Goodness of fit Criteria (correlation)
A-Corvair	3-74	21	200	1.39	.976
	3-74	21	400	1.31	.969
B-Cadillac	4-72	23	200	1.32	.957
	4-72	23	400	1.37	.985
C-Oldsmobile	1-65	30	1000	1.31	.921
D-Oldsmobile	1-64	26	2500	.73	.684

RESULTS AND DISCUSSION

Magnitude estimates of approach speed are well described by a power function for relatively short observer-vehicle distances. The data for Conditions A and B were combined for observer-distances of 200 and 400 ft. Figure 2 shows the results obtained from distances of 200, 400, and 1000 ft. Figure 3 shows the results from the 2500-ft post, and Table 2 lists the exponents of the functions and goodness of fit criteria.

For distances of 200, 400, and 1000 ft, the power functions have exponents of about 1.35; however, the function for an observer distance of 2500 ft (Fig. 3) is too irregular to be described by a simple power function. Figure 2 also shows that judgments from the 1000-ft post are more variable than at the 200- or 400-ft posts. It appears that as the observer-vehicle distance increases it becomes difficult, if not impossible, to scale approach speed in a monotonic fashion. At long observer-vehicle distances and with relatively short exposure duration, retinal size does not change appreciably during the exposure. As indicated by the variability and inconsistency that characterize the low end of the scale in Fig. 3, this effect seems to be more pronounced at slower velocities.

Bjorkman (1963) has studied a phenomenon similar to the approach situation reported here. He found that Ss made consistent errors in predicting when two approaching cars would meet. Ss' estimates were systematically biased in the direction of the midpoint between cars. The results of the present study illustrate that at an observer-vehicle distance of

1000 ft, which is similar to Bjorkman's study, the error is one of overestimation of approach speed. This supports Bjorkman's finding that a S will predict the meeting point to be nearer himself than it objectively is.

EXPERIMENT 3: EN ROUTE SPEED

Suhr (1958) has shown that when Ss are asked to identify simulated and actual en route velocities, there is a tendency to overestimate high velocities and to underestimate low ones. The present experiment was designed to compare the scales obtained with two different psychophysical procedures of magnitude estimation and category estimation.

En route speed may be judged visually by using distance and duration, but when the eyes are closed, auditory, kinesthetic, and vestibular cues become important. As a first attempt to differentiate the effects of such stimuli, in some conditions S was blindfolded, in others his ears were plugged, and in still others both blindfolds and ear plugs were used.

METHOD

Subjects rode in vehicles whose speedometers had been calibrated by the Electromatic Radar Speed Meter. The experiments were conducted on relatively untraveled asphalt roads in Northern Wisconsin. E drove the test vehicle with the speedometer covered so that only he could see it. Velocities ranging from 5 to 75 mph were programmed randomly before the start of each session. Each trial lasted for 5 sec with a 15-

Fig. 2. Magnitude estimates of apparent approach speed. The exponents are, from top to bottom, 1.31, 1.35, and 1.37. Each point from the 200- and 400-ft posts is the geometric mean of 16 judgments, pooling four Ss. At the 1000-ft post, each point represents the geometric mean of 23 observers. The interquartile ranges are indicated by vertical lines.

Fig. 3. Approach speed is plotted as a function of physical velocity for an observation distance of 2500 ft. The slope of the best fitting straight line (not shown) is .73. Each point is the geometric mean of 23 observations, pooling 23 Ss. The interquartile ranges are indicated by the vertical lines.

Table 3
Magnitude Estimation of En Route Speed—Results (Based on Repeated Observations from Five Observers)

Condition and Vehicle	Sensory Restrictions	Exponent of Power Function	Goodness of Fit Criteria (correlation)
A-Cadillac	Blindfolds and Ear Plugs	1.38	.965
B-Cadillac	Blindfolds	1.45	.989
C-Cadillac	Ear Plugs	1.42	.976
D-Mustang	None	1.41	.971
E-Cadillac	None	1.37	.983

to 20-sec intertrial interval during which the vehicle's velocity was altered. Each condition consisted of 50 trials.

A white two-door 1962 Cadillac Coupe de Ville was used for most of the experiment. In the magnitude estimation series, different physical velocities were used as the standard stimulus and different numbers were attached to each standard to eliminate potential bias and practice effects. In the category estimation series, three different sets of integers were permitted, 1-8, 1-15, and 1-25. Using a Latin square design for each method it was possible to arrange that each S judged from each of five positions in the car: (1) unrestricted, (2) with blindfolds, and (3) with ear plugs.⁵ A special series of magnitude estimations was made with both blindfolds and ear plugs. In order to determine whether a different car would influence the magnitude estimation scale, a maroon two-door 1964 Ford Mustang convertible was used in part of the study.

Five Northland College students served as Ss and they were paid on an hourly basis. None had had previous experience in psychophysical experiments, although all had had considerable experience riding in and driving vehicles similar to the test car.

E explained how the method of magnitude estimation was to be used with different numbers representing the standard stimulus; they were told to make ratios of the apparent speed based on the value assigned to the standard stimulus. E also explained the category method and emphasized that they should attempt to divide speeds into subjectively equal intervals. A few preliminary sessions were run at the start of each day to familiarize S with both procedures.

Fig. 4. Psychophysical functions relating passengers' estimates of en route speed to physical velocity in mph. The range of velocities for each curve is from 5 to 75 mph. The exponents of the functions are, from left to right, 1.38 (A—ear plugs and blindfolds, Cadillac), 1.45 (B—blindfolds, Cadillac), 1.42 (C—ear plugs, Cadillac), 1.41 (D—unrestricted, Mustang), and 1.37 (E—unrestricted, Cadillac). Each point represents the median of approximately 80 judgments, pooling repeated observations from five Ss. The interquartile ranges are indicated by vertical lines.

Fig. 5. Mean category judgments are plotted as a function of the magnitude estimation scale from Curve E, unrestricted, Cadillac in Fig. 4.

RESULTS AND DISCUSSION

Some 18,000 observations were collected. The results of magnitude estimation again support the power relation. The data from each condition in which different standards were used were combined. In all instances the judgment of en route speed grows as a power function of physical velocity. The slopes of the individual Ss' functions as determined by the method of least squares varied between 1.23 and 1.54, with a mean value of about 1.40.

Figure 4 shows the results from the magnitude estimation series and Table 3 lists the slopes (exponents) of the functions. The general power function is not affected by the use of blindfolds, ear plugs, both blindfolds and ear plugs, or the type of vehicle within the limits studied here.

The category scales were also uninfluenced by the variables mentioned in the preceding paragraph; in addition, the number of response categories did not have any effect on the function. Mean category judgments of en route speed were related to physical velocity by a linear function in arithmetic coordinates.

Stevens and Galanter (1957) investigated the relation between category and magnitude estimation scales on several perceptual continua. In order to compare the mean category assignments with the magnitude estimation function, the magnitude scale (Cadillac—unrestricted in Fig. 4) was used as the abscissa of the plot shown in Fig. 5. As is characteristic on prothetic continua, the category scale is concave downward with respect to the magnitude scale.

Although these results illustrate several psychophysical invariances with respect to the manipulation of stimulus variables, there are certain limitations that should be noted. Because it is not known what the Ss whose ears were plugged did in fact hear, we can accept the present results only as an approximation to the function obtained when the amount of acoustic input is attenuated. A better way to perform this part of the study may be to mask the vehicle's noise with white noise presented through earphones.

A most important finding is that the function remains invariant when both vision is obstructed and acoustic input is attenuated. This suggests that kinesthetic and vestibular cues provide sufficient information for scaling en route speed; however, there are few, if any, vestibular cues at constant velocity. In addition, initial acceleration is ambiguous in that blindfolded Ss who are linearly accelerating cannot tell whether they are in fact accelerating or slowly climbing (Clark & Graybiel, 1949). The present results seem to imply that kinesthetic cues are sufficient to judge relative speed in a moving car.

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NOTES

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4. When a target follows a linear path across the visual field, angular velocity changes more slowly at the periphery of the visual field than when it passes tangentially to the S. In a controlled laboratory experiment it would be possible to determine whether or not variation in angular velocity produces significant error; however, in the present experiment, the measure of physical velocity was too gross to permit such a precise calculation. For example, when the car registered 44 ft/sec (30 mph) on the Radar Speed Meter, it could have been travelling at any rate between 42.5 ft/sec and 45.5 ft/sec, an error of 2% with respect to 44 ft/sec. This variance is of the same order of magnitude as the systematic changes which occur in angular velocity between the periphery and center of the visual field.

5. The ear plugs were made from bee's wax and Ss wore attenuating earphones. Acoustic equipment was not available to measure the resultant attenuation.

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