Observed Errors in Distance Estimation

2010-01-0046
Published
04/12/2010

Mark Strauss
Ruhl Forensic, Inc.

James Carnahan
University of Illinois

ABSTRACT

In order to evaluate the variation in distance estimation accuracy, a survey was conducted during which 123 subjects estimated distances to static objects in a roadway setting. The subjects (which included many police officers) tended to underestimate distances to objects that were from 21 to 383 feet away; the average estimation error was −8.6% while the median error was − 22%. The variation in performance among individuals was extremely large, with extreme errors ranging from − 96% to + 811%. The distribution of error did not conform to a Gaussian (normal) distribution because of the skew of the observed error distribution towards large positive errors. Box plots were used to identify nine “outlier” respondents who produced a total of 15 error estimates which were extraordinary in their difference from the rest of the data. Tests for independence indicated that the likelihood of an error estimate being an outlier was not influenced by gender, age, or whether the subject was a police officer. When males were compared to females, both were found to have median estimation errors that were negative, corresponding to under-estimation. When nonparametric statistical methods were used to compare the median distance estimation errors, females' under-estimation errors were found to be larger (more negative) in a statistically significant way. In this survey, in general, the most accurate estimates were given by older males at short distances.

When asked to estimate the length of an average car, there were seven outliers. There was no statistically significant relationship between the likelihood of being an outlier and the subjects' gender, age, or whether they were a police officer. The median under-estimation errors for car length exhibited by females and younger respondents were larger, and were statistically significant.

INTRODUCTION

Accident witnesses may be requested to estimate distances in situations dealing with vehicles and roadways. Inaccuracies in testimony may be attributed to human error in estimation of distances. The purpose of this study was to determine the variation in the average human's ability to estimate distance and to statistically analyze the estimation accuracy for different sub-populations of the subjects (gender, age, and police). The data provide insight regarding the reliability of testimony and provide guidelines for quantifying the expected range of errors when estimations are given.

The review of the literature revealed no study of this scope and depth that addressed the question of how well various population groups are able to estimate distances, and specifically on a roadway setting. Given the enormous amount of time that the population spends traveling on roadways, and that roadway accidents account for a large percentage of accidental injuries and deaths, it is appropriate to examine how people evaluate distances in this setting. This will be of interest not only to accident reconstruction practitioners, but also to roadway and vehicle designers.

Of the participants surveyed, and used in the analysis, there were 77 males and 46 females, ranging from eighteen to seventy-three years of age. Subjects were of differing educational backgrounds and occupations, including students, construction workers, and police, among many others. In particular, there were 45 police officers or police trainees included. Survey participants first answered a series of background questions and then estimated three distances to static objects that were about 25 feet, 175 feet, and 350 feet away along a roadway. In addition, the subjects were asked to estimate the length of an average car, one that is quite common in the United States. By comparing estimates to the known distances, the percent error could be calculated and then analyzed. An overall average distance estimation error of −8.6% (under-estimation) was observed for the subjects in the experiment, with a range of − 96% to + 881%.

LITERATURE REVIEW

Quite a number of studies have been published on the topic of distance estimation. In many of the studies, however, the verbalized distance estimate is not examined. Instead, experimental subjects are asked to walk a perceived distance to a target, or perhaps move some other target to a distance equal to one they are viewing. In general, researchers report that when faced with longer distances, subjects tend towards under-estimation.

Strauss and Carnahan (2009) used the data from the survey presented here to compare the performance of police officers to the rest of the population, finding the difference in their average error to be statistically insignificant. Other factors such as age, gender, self-reported visual acuity, and self rated distance estimation ability were explored in this same study.

Andre and Rogers (2006) present a comparison of verbal reports and "blind-walking" for target distances up to 30m. Estimation by "blind-walking" consists of having the subject walk blindfolded to a previously seen target. At target distances of 30m outdoors, the error for blind-walking was −6% while for verbal estimates it was −22%. Subjects consistently estimated less accurately for indoor targets than outdoors.

Higashiyama and Adachi (2006) studied the ability of subjects to estimate the distance to targets, at distances from 2.5m to 45m. Although their focus was on understanding the changes in distance estimation when the subject's position was inverted, the average distance estimation error was −29% for a variety of target sizes at 50m when the subject was upright.

A study (Sharrack and Hughes, 1997) compared the distance estimation of doctors and patients, because clinical assessments and therapeutic decisions are often based on estimates of distance. The study was conducted with the participation of up to 97 hospital physicians and 62 patients. The subjects were given a questionnaire that asked them to estimate the dimensions of the hospital ward and the distances between five familiar sites at the hospital. Subjects were familiar with the distances and estimated based on memory. The hospital physicians were much more familiar with the hospital sites, and their average error was lower than that of the patients. For short distances (6.6 m) the average error for patients was 164% while for the physicians it was 53%. For long distances (319 m), the patients' average error was 42% while for physicians it was only 6.3%. The range in estimates was extremely large as "the difference between minimum and maximum estimates was up to 62.5-fold."

In a completely different kind of study (Lappin, et al., 2006) looked at several settings and the effects that the different environments and contexts have on distance perception. The settings (or "contexts") used were a lobby, a hallway, and an open field. Within each context, there were target persons placed first at 15 m and later at 30 m away. In these experiments, the subjects were asked to locate the midpoint from themselves to a target person by having an adjustment person walk towards (or away from) the subject until they were told to stop at the perceived midpoint. In a subsequent experiment, the adjustment person was placed and the subject guessed whether the target was closer or further from the midpoint of the target persons. Some results from this study were that the midpoint distances were overestimated by 13.0%, 8.0% and 3.2% for the lobby, hall and open field, respectively. The analyses showed that both the magnitude of the estimation error and its variability exhibited statistically significant dependence on the context.

A study was conducted by Sinai et al. (1998) in order to determine the influence that ground surface has on distance estimation. They hypothesized that the brain uses a two-dimensional coordinate system with respect to ground surface as opposed to a three-dimensional system. Also, they wanted to test Gibson's theory (1950) that when the common ground surface is disrupted, the visual system is unable to establish a reliable reference frame and it consequently fails to obtain correct absolute distance. In order to test these hypotheses, an experiment was conducted where an object was placed 3.66 m away, with a gap that was 0.5 m deep and 1.3 m wide between the object and the observer. The observers were asked to look at the object; then they were blindfolded, turned 90 degrees away, and asked to walk to a distance equivalent to the distance of the object. The average distance walked of the 10 subjects was 4.6 m for an average over-estimation error of 26%. As a control, the same experiment was conducted without the gap, and the average distance walked was 3.69m, which is an error of less than 1%. When asked to set a target at the same distance (rather than walking it), the errors were 16% and −3.3%, respectively. The experiment was repeated with a wider gap, with similar results. Other experiments were performed with subjects placed at positions that were elevated with respect to the target, also with similar results.

METHODS

The study was conducted in and around Champaign-Urbana, Illinois, USA, from June 2006 until December 2006 and involved 123 subjects used in the subsequent analysis.

Subjects were from a number of different backgrounds, some with little or no experience in estimating distance, and others who took measurements and worked with distances and lengths on a daily basis. The average age of the subjects was 33.4 with the youngest being 18 and the oldest 73. Specific groups were targeted for their relevance to the topic of distance estimation by witnesses or experience in the area of distance estimation including police officers, construction professionals, and golfers. Of the group of subjects, 45 were police officers or police trainees. Because part of the study was conducted on the University of Illinois campus, subjects of many different ethnicities and educational backgrounds were included.

The study was conducted during daylight hours, at nine different locations. The locations were selected for their similarity, most of which were along one-way and two-way roads, with cars parked periodically along the curb. Of the surveys, 67% were conducted along two-way roads with two lanes total, 7% were conducted along two-way roads with four lanes total, 15% were conducted along one-way roads with one lane, 5% were conducted along one-way roads with two lanes, and 6% were conducted in a very large parking lot. Weather conditions, a brief description of the roadway design and the total number of cars parked between the participant and the furthest target were recorded. Prior to the survey taking place, three static objects were selected at each location: one at shorter distances of 22 to 30 feet, one at medium distances from 148 to 211 feet and one at long distances, from 330 to 383 feet from the participant. The actual distance to each object was measured and recorded. Target objects selected were typical roadway objects (i.e., parked vehicles, traffic signs, light poles, etc.). The influence of target object type will be presented in a future publication.

Each participant was first asked a series of background questions in order to determine prior experience they had which might relate to measuring or estimating distances. Among many other questions, they were also asked to provide a self-rating regarding distance estimation ability and visual acuity. The participant was then asked to look at the first object and, within five seconds, give an estimation of how far the object was from the participant's current position in the units of measurement most comfortable to them. This process was repeated for objects at the three distances; the order of the distances (short, medium, long) was varied during the survey. Finally, each participant gave their estimation of the length of an average car, which was described as a 2002 Ford Taurus, if the participant asked.

The background questions asked of each subject were extensive, but the analyses presented here only categorized subjects according to their gender, their age, and whether they were police officers. Results examining the effects of occupations and interests will be reported in future publications along with the influence of the target object. These analyses will be based on multiple factor ANOVAs with the exploration of possible interactions among factors, to the extent that the data will allow. However, unlike the work presented here, they will be based on the data set with outliers excluded.

FINDINGS

Before any analyses were carried out, one subject was removed from consideration due to an “insincere” effort. The 26 year old female estimated the actual distances of 22 feet, 202 feet, and 373 feet to be 2 feet, 0.5 feet, and 3 feet, respectively. In terms of car lengths, she estimated these distances as 2.5, 2 and 7 car lengths, respectively. None of the responses indicated that she was making a serious effort as an experimental subject. The remaining 123 respondents were used in the work presented in this article.

ABSOLUTE ERROR

The absolute distance estimation errors (measured in feet) for short, medium and long distances were examined and some descriptive statistics are provided in Table 1 below. The first row of the table shows that for short distances, the standard deviation of the absolute error is nearly 4 times the mean (average) error, indicating the large variation. In particular, the maximum error observed was 48 feet. That occurred when a survey respondent (#47) gave an estimate of 25 yards (which was converted to 75 feet), when the actual distance to be estimated was 27 feet. This gave an error of 48 feet or 178% of the actual distance.

<table 1 here>

The histogram for the absolute error at short distances follows in Figure 1. The tendency for most subjects to underestimate distances becomes apparent from the histogram by noting the high frequency of occurrence of errors that are negative. Equally interesting is the propensity for some of the subjects to exhibit extremely large positive errors, which are examples of overestimation.

Table 1. Descriptive statistics for absolute error (in feet) for short, medium, and long distances

	Mean	Standard deviation	Maximum under-estimation	25th percentile	Median (50th percentile)	75th percentile	Maximum over-estimation
Short (22-30) ft	– 2.8	10.6	– 22	– 9	– 5	2	48
Medium (148-211) ft	– 7.2	223.4	– 192	–104	– 59	2	1460
Long (330-383 ft)	– 34.7	293.4	– 359	–193	– 66	29	1946

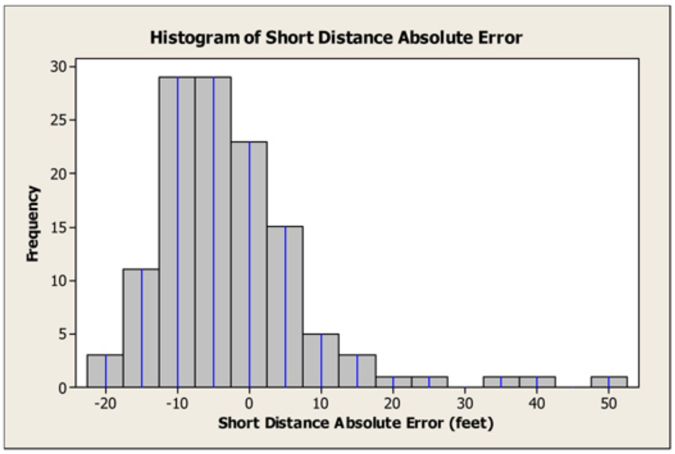

Figure 1. Histogram of absolute error for short distances (22-30) feet

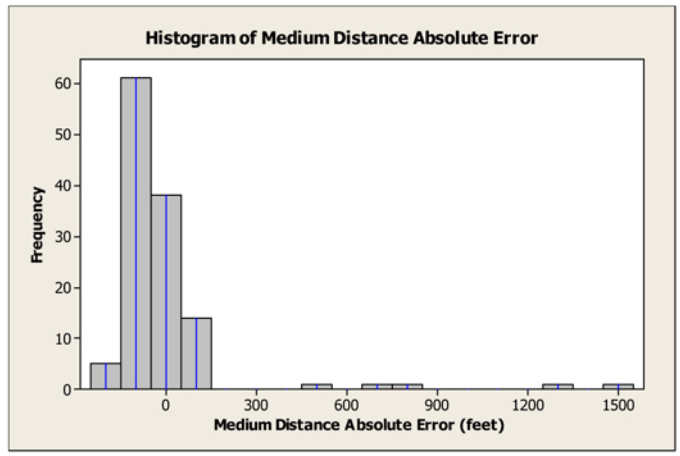

Figure 2. Histogram of absolute error for medium distances (148-211) feet

The second row of Table 1 shows that for medium distances, the standard deviation of the absolute error is 31 times the mean error! This huge ratio of the standard deviation to the mean is due to the several instances of extremely large overestimation error. Figure 2 gives the histogram for absolute error at medium distances. It has some similarity to the histogram for short distance errors in that there is a notable tendency to underestimate distances while there are still a number of subjects who dramatically overestimate a medium distance.

The subject with the worst error (#79) used “klicks” as a unit of measurement and estimated the distance as half of a klick; since a klick defined as a kilometer or 3280 feet, this estimate was converted to 1640 feet. The actual distance was 180 feet, resulting in an absolute error of 1460 feet or 811%. During the survey, this subject was then asked to estimate the distance using some other units. In response to this request, the subject estimated the distance as 230 feet for an absolute error of only 50 feet or 28%. It is notable that this subject's choice of “klicks” as comfortable unit of measurement may have been a factor in the distance measurement being very poor.

The second worst subject (#47), who also had the worst estimation error for short distance, gave an estimate of 1 “block”, a unit that could not be interpreted numerically. The second estimate provided by this subject was 500 yards which converted to 1500 feet. In this case the actual distance was 198 feet resulting in an absolute error of 1302 feet or 658%. In this case, the choice of “blocks” as a comfortable unit of measurement may not have been a factor in poor distance measurement, as the second estimate (in yards) was extremely poor. The choice of units for distance estimation will be a subject of future investigation.

The third row of Table 1 shows that for long distances, the standard deviation of the absolute error is more than 8 times the mean error. Again this ratio is due to the several instances of large overestimation error. Figure 3 gives the histogram for absolute error at long distances. This histogram has some similarities to the histograms for short and medium distances: there is a noticeable tendency for many subjects to underestimate while a few subjects greatly overestimate these distances. For long distances, the worst subject (#43) estimated the distance as 0.7 km which was converted to 2297 feet. For this case, the actual distance was 350 feet so the absolute error was 1947 feet or 556%.

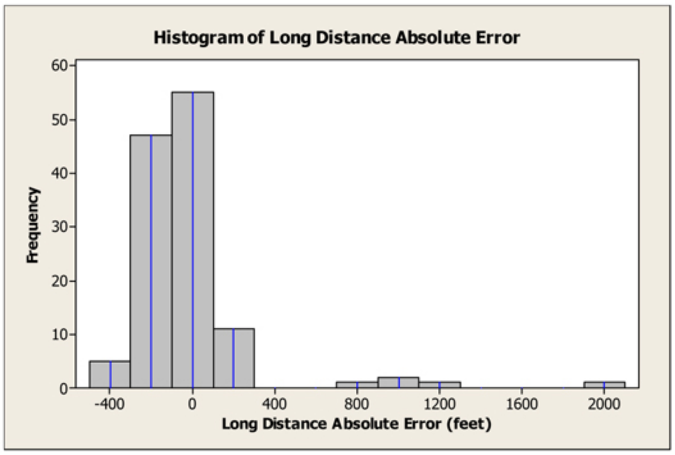

Figure 3. Histogram of absolute error for long distances (330-383) feet

The distributions of absolute error for short, medium and long distances are compared in Figures 4a and 4b below. Figure 4a presents the data using the same scale for the abscissa; Figure 4b presents the data using the same scale for the ordinate. It is noted that the absolute error distributions for medium and long distances are not nearly as concentrated about an error of zero feet as the some of the following figures might suggest. That is an artifact caused by the few very large errors whose inclusion on the histograms effectively compresses the scale near the origin.

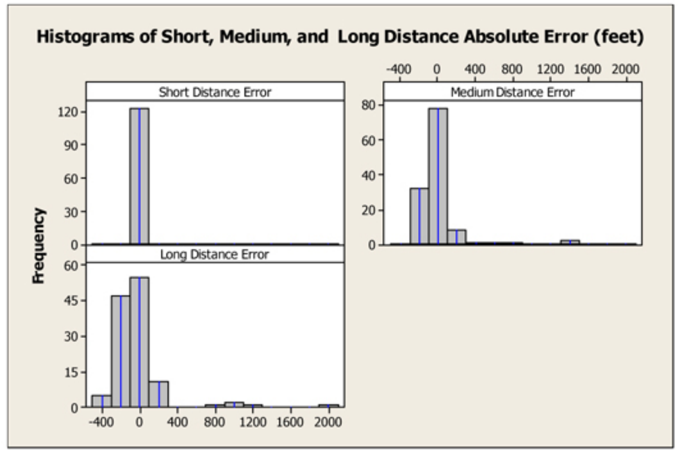

Figure 4a. Histograms of absolute error for short, medium, and long distances; same abscissa scale

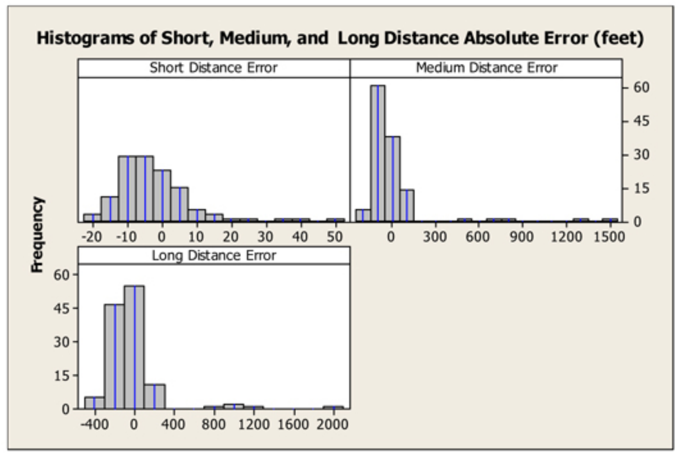

Figure 4b. Histograms of absolute error for short, medium, and long distances; same ordinate scale

PERCENT ERROR

Instead of using the absolute error for much of the analysis that follows, the percent error, calculated as [(estimated - actual)/actual], was used so that the error distributions can be more readily compared for different distances estimated. It will be seen that the distribution of the percent error has the same kind of "positive skew" as the absolute error. Positive skew means that the tail of the distribution stretches out to the right, but not to the left.

This kind of skew would be expected after considering the process of distance estimation. That is, if the actual distance to an object is 200 feet, and the subject estimates that to be 100 feet, the percent error is −50%; if the subject would estimate the distance to be 300 feet, the error is +50%. If the subject would instead estimate the distance as 400 feet, the error would be +100%. Even a subject who was completely incompetent at distance estimation would not exhibit an error

Table 2. Descriptive statistics for percent error for short, medium, and long distances

	Mean	Standard deviation	Maximum under-estimation	25th percentile	Median (50th percentile)	75th percentile	Maximum over-estimation
Short (22-30) ft	– 11.2%	40.8%	– 81%	– 35%	– 20%	8%	178%
Medium (148-211) ft	– 5.3%	118.9%	– 95%	–59%	– 33%	1%	811%
Long (330-383) ft	– 9.2%	82.3%	– 96%	–52%	– 18%	8%	556%

of −100%, since that corresponds to an estimate of zero feet. Regardless of the distance estimated, the bound for under-estimation error is −100%. On the other hand, as larger distances are estimated, there is increased likelihood of large over-estimation error, which has already been observed to exceed +100%. This is the reason why the distributions of both absolute and percent errors in distance tend to have positive skew and why the skew is more accentuated at larger distances.

The percent distance estimation errors for short, medium and long distances were calculated and some descriptive statistics are provided in Table 2 below. Of course these percentages behave in much the same way as the absolute errors, although they are somewhat easier to interpret in some cases. The general tendency to underestimate distances is seen in the persistent negative values for the mean errors (which range from about −5% to −11%) and the median errors (which range from −18% to −33%). Standard deviations are still very large compared to the mean, ranging from 3.6 times the mean to 22 times the mean. The maximum errors observed in either direction are exceedingly large, as well, which contributes to these large standard deviations.

<table 2 here>

The histograms of percent error are compared in Figure 5 below which now uses the same scale for each histogram. Some similarities in the error distributions are evident, as all three distributions exhibit positive skew. Also, there is a pronounced tendency for subjects to underestimate distances, as can be seen from the number of observations with negative percent error.

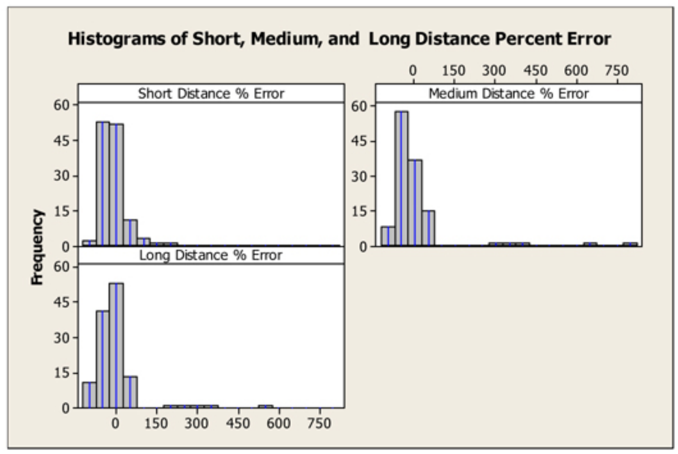

Figure 5. Histograms percent error short, medium, and long distances; same abscissa and ordinate scales

Sometimes the "bell-shaped" curve (i.e., a Gaussian or normal distribution) is found to describe variation in observed data, particularly when those data represent errors. This was not the case for the errors in distance estimation. In Figure 6 below, overlaid on each histogram is a Gaussian distribution with its parameters (the mean and standard deviation) estimated from the observed data for that particular distance range.

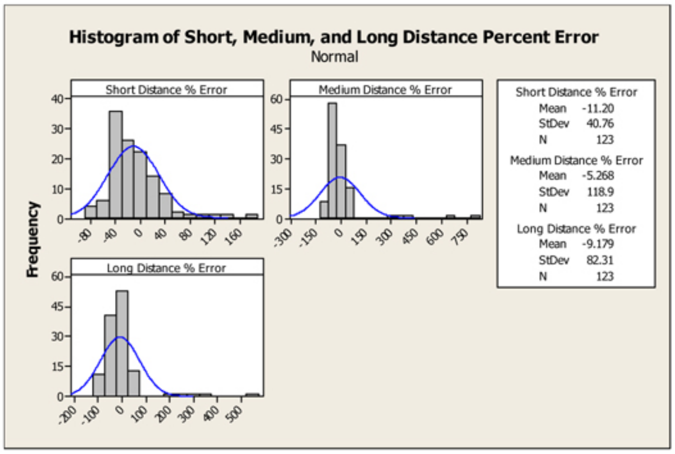

Figure 6. Histograms of percent error for short (22-30 feet), medium (148-211 feet), and long (330-383 feet) distances with different abscissa and ordinate scales, and normal fit

These fits are not acceptable. The standard goodness of fit test using the Anderson-Darling statistic was used to evaluate the fit quantitatively, and in each case it showed an exceedingly small probability (less than 0.5%) that the observed data could be samples from a Gaussian distribution.

When it can be concluded that data follow a Gaussian distribution, it is common practice to estimate certain probability intervals for the underlying random variable, X, using the sample mean and standard deviation. For instance, the probability that X is greater than the mean plus three standard deviations is estimated to be about 0.00135 or 0.135%. When the fit of the Gaussian distribution is very poor, this sort of estimation procedure is prone to error; that was found to be the case here. For a survey of 123 people whose responses fit the Gaussian distribution, one would not expect to observe a single error exceeding the mean plus three standard deviations. Only when the survey has a much larger number of respondents, such as 1,000, would a single such observation be likely to occur. In actuality, though, for the current survey of 123 respondents, such large errors (greater than the mean plus three standard deviations) were observed three times each for short and medium distances and four times for the long distance, far more often than one would expect from Gaussian data.

The relatively high frequency of extremely large estimation errors invited an analysis of these observations. Standard procedures for the identification of "outliers" were employed and the results are presented next.

OUTLIERS

The existence of outlier respondents was investigated using the "box plot" routines in the statistical software package MINITAB. Box plots are widely accepted procedures for the identification of outliers and discussions are available in many respected texts (e.g., Montgomery and Runger, 1999, or Johnson, 2005).

Box plots (or "box and whisker" plots) provide a visual depiction of the empirical probability distribution function. They are of particular use when the distribution may be nonsymmetric, or skewed, and thus may not follow the Gaussian distribution. The plots indicate the location of three observed quartiles (the 25th percentile, 50th percentile or median, and the 75th percentile), along with the minimum and maximum observed values. The "box" extends from the 25th percentile to the 75th percentile; the length of the box is called the "interquartile range", while the box width (in the horizontal direction) has no significance. The location of the median is denoted as a horizontal line through the interior of the box. Additional lines or "whiskers" can extend up to 1.5 times the interquartile range in either direction; they begin at the edge of the box and stop at the smallest (and largest) observed data within that limit. Observed data that lie beyond these whiskers, but at a distance less than three times the interquartile range from the edge of the box, are designated as "outliers." Observed data that lie beyond three times the interquartile range from the edge of the box are often called "extreme outliers."

The box plot for short distance percent error is given below in Figure 7 and will be discussed in some detail, as an example. In this box plot the 25th percentile of the distribution is at −35% estimation error, the lower boundary of the box. The median is at −20%, which is the horizontal line in the box interior; the 75th percentile is at +8%, the upper boundary of the box. The interquartile range is 43%, the vertical dimension of the box representing the location of 50% of the data points.

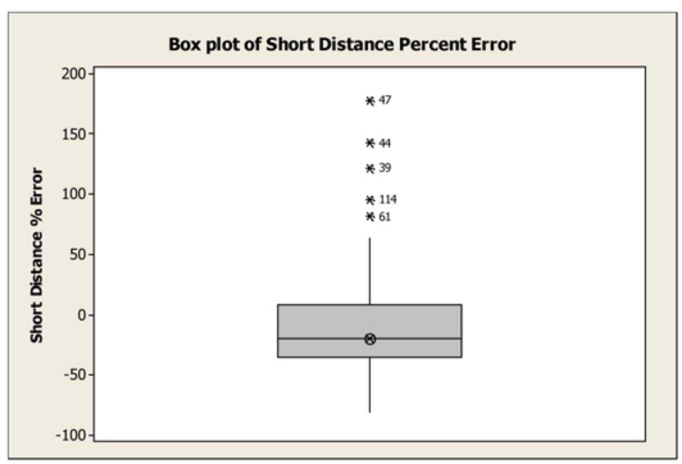

Figure 7. Box plot for percent error for short distances (22-30 feet)

The whisker extends downward to −81%, which is the most negative percent error observed that was not an outlier. The upper whisker extends to the maximum observed value (+64%) in the data that was not an outlier. Three survey respondents (#61, #114, #39) had large (positive) over-estimation errors that were classified as "outliers." Two more respondents (#44 and #47) met the criterion for "extreme outliers" with their extraordinarily large errors. There were no negative errors that qualified for being an outlier.

The box plot for percent error at medium distances is given in Figure 8. All five outliers met the criterion for "extreme outliers", since they were so very large. The propensity for such huge errors in over-estimation is truly remarkable.

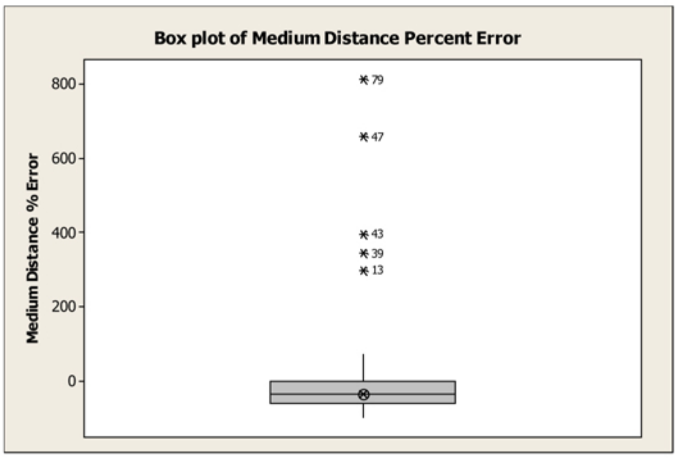

Figure 8. Box plot of percent error for medium distances (148-211 feet)

The box plot for percent error at long distances is given in Figure 9. Just as was the case for medium distances, all the outliers met the criterion for "extreme outliers."

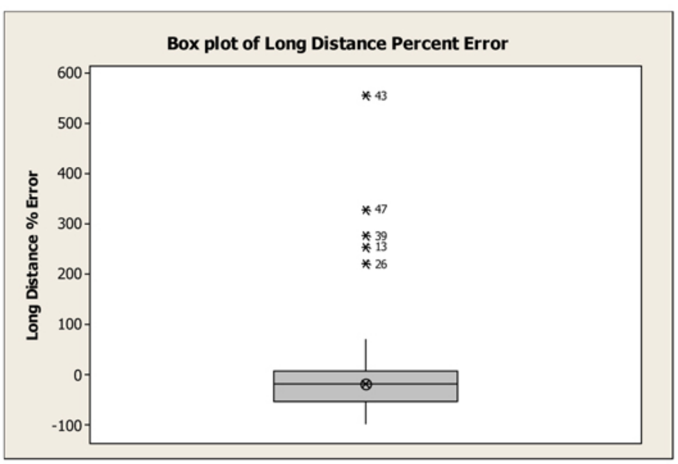

Figure 9. Box plot of percent error for long distances (330-383 feet)

Of the 123 respondents used in the analysis, nine people were identified as giving responses that were outliers or extreme outliers; there were 15 total outlier responses. Table 3 provides data for the survey respondents who were outliers for at least one distance.

Although the general tendency of survey respondents was to underestimate differences, all of the outlier respondents overestimated distance for the reasons given in the earlier discussion of percent error. In some cases, the outlier errors were dramatic, from 82% to 178% for short distances, 300% to 811% for medium distances and 221% to 556% for long distances.

Of the nine respondents noted as outliers, two were male police officers and five were non-police females. Five of the outlier respondents were less than 25 years in age. The common chi-square test for independence was separately carried out for gender, age and police to see if they were related to the occurrence of outliers. The results showed that none of these factors had any statistically significant effect on the likelihood of a randomly chosen subject exhibiting estimation response that would be classified as an "outlier."

<table 3 here>

GENDER, AGE, AND POLICE

Box plots categorized by the gender of the survey respondent are provided in Figure 10 for short distance percent error. One could note from the box plot that the median error of male respondents is closer to zero than females' median error. This might lead one to conclude that males exhibit more accurate distance estimation.

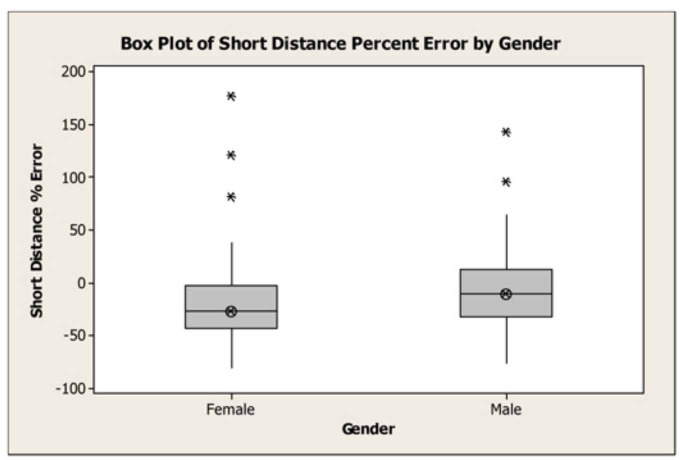

Figure 10. Box plot of percent error by gender for short distances (22-30 feet)

The usual approach of analysis of variance has been applied to these data, and the hypothesis that the mean error of males is less than that of females was rejected. The reason is that

Table 3. Data on respondents with estimation error classified as "Outlier" (O = outlier, XO = extreme outlier)

ID #	Gender	Age >25?	Police?	Short distance outlier	Medium distance outlier	Long distance outlier
13	F	No	No		XO (300%)	XO (255%)
26	M	No	No			XO (221%)
39	F	Yes	No	O (122%)	XO (344%)	XO (277%)
43	F	Yes	No		XO (397%)	XO (556%)
44	M	No	No	XO (143%)		
47	F	Yes	No	XO (178%)	XO (658%)	XO (329%)
61	F	No	No	O (82%)		
79	M	No	Yes		XO (811%)	
114	M	Yes	Yes	O (96%)		

Table 4. Median percent estimation errors by Gender, Age, and Police ("ss" = statistically significant difference; "ns = not statistically significant)

		Median error Short distance	Median error Medium distance	Median error Long distance
Gender	F	–26% ss	–41% ss	–43% ss
	M	–11% ss	–25% ss	–14% ss
Age >25?	Yes	–11% ss	–29% ns	–15% ns
	No	–29% ss	–34% ns	–22% ns
Police?	No	–21% ns	–27% ns	–19% ns
	Yes	–14% ns	–33% ns	–17% ns

the presence of outliers distorts both the sample mean and sample standard deviation to the point where the potential statistical significance of the observed difference in mean errors is lost. In addition, it is very likely that the normality assumption for the error terms that is made in analysis of variance is severely violated.

The same situation was found to be true for the gender differences for medium and long distances: when the outliers are included in the data, the statistical significance of differences in mean error for males and females is lost. In another paper, Strauss and Carnahan (2009) show that these differences turn out to be statistically significant when the 9 outlier subjects are removed from the data set. Once that had been done, it was found that for all distances, it was statistically significant that the mean error of males was less than half of the mean error of females.

In order to attempt to validate the gender hypothesis in the presence of outliers, the nonparametric (or distribution-free) Kruskall-Wallis test was employed (see Montgomery and Runger, 1999, or Johnson, 2005). This test is based upon the ranks (relative sizes) of the observations rather than their actual numerical value, and is thus relatively robust to the presence of outliers in skewed distributions. The test does not require that the underlying distributions are normal, but does require them to have similar shape; Figure 10 is an indication that this assumption is met. A drawback to such nonparametric tests is that they can be less sensitive than analysis of variance in detecting statistical significance. Nonetheless, the Kruskall-Wallis test showed statistically significant differences between females and males with regard to short, medium and long distance estimation errors. The median errors were larger for females than males, for all distances estimated. The median errors by gender are provided in Table 4 below, along with the categorizations by age and also whether the respondent was police.

<table 4 here>

Subjects whose age is greater than 25 were observed to have lower median distance estimation error that those who were younger. For medium and long distances, these differences were found to be statistically insignificant. In the case of short distances, the median error for older subjects was − 11% while the median error for younger subjects was − 29%. The Kruskall-Wallis test indicated this difference is statistically significant, with older subjects performing better at estimating short distances.

The same nonparametric procedure was used to test the hypothesis for whether distance estimation errors for police were lower than those of non-police. The differences were found to be statistically insignificant for all distances. It is possible to further categorize police subjects into "police trainees" and "police officers". Unfortunately, all but one of the "police officers" were over 25 years of age, which could cause any effects to be confounded with age.

CAR LENGTH ESTIMATION

Each survey respondent estimated the length of an average car in the United States; if the participant asked, that car was described as a 2002 Ford Taurus (which is 16 feet long). The median errors in estimating car length are provided in Table 5 below, along with categorizations by gender, age, and whether the respondent was police.

The Kruskal-Wallis test was used to investigate the relationship of these potential factors to car length estimation error. The observed tendencies for males and also for older subjects to have lower error were statistically significant. Whether or not the respondent was police did not have a significant effect.

Table 5. Median percent car length estimation errors by Gender, Age, and Police ("ss" = statistically significant difference; "ns = not statistically significant)

		Median Error car length
Gender	F	–37.5% ss
	M	–25.0% ss
Age >25?	Yes	–25.0% ss
	No	–37.5% ss
Police?	No	–32.8% ns
	Yes	–25.0% ns

There were seven outliers identified and their data are provided in Table 6.

Table 6. Data on respondents with vehicle length estimation error classified as "Outlier" (O = outlier, XO = extreme outlier)

ID #	Gender	Age >25?	Police?	Error
35	M	Yes	No	O (37.5%)
54	F	No	No	XO (525%)
62	M	Yes	No	O (37.5%)
71	M	Yes	Yes	O (56.25%)
86	F	Yes	Yes	O (43.75%)
118	F	Yes	Yes	XO (87.5%)
119	F	Yes	Yes	O (37.5%)

Chi-square tests for independence were carried out separately for gender, age and police to see if they were related to the occurrence of outliers in vehicle length estimation. None of these factors showed a statistically significant effect on the likelihood of a randomly chosen subject exhibiting a response that would be classified as an "outlier" for vehicle length estimation error. It is noted that the statistical test for age was weakened since there was only one young respondent who was an outlier.

SUMMARY/CONCLUSIONS

There was a tendency for survey respondents to underestimate distances to objects. For short distances the median percent error was − 20%; for medium distances the median error was − 33%; and for longer distance the median error was − 18%. The extremes in performance among individuals were extremely large, with errors ranging from − 96% to + 811%. The distribution of error did not conform to a Gaussian (normal) distribution for any of the distances because of the skew of the observed error distribution towards large positive errors which represent over-estimation. Box plots were used to identify nine respondents who produced 15 "outlier" error estimates which were vastly different from the rest of the data. Statistical tests for independence indicated that the tendency for an error estimate to be an outlier was not influenced by gender, age, or whether the subject was a police officer. Nonparametric statistical methods were used to compare the median error of males to females; the female subjects' distance estimation error was larger, in a statistically significant way.

Survey respondents were asked to estimate the length of an average car. There were seven respondents who produced outlier responses to this question. The tendency to be an outlier was not related to gender, age or whether the subject was a police officer. Nonparametric methods indicated that males and also older subjects had lower error, while it did not matter whether the subject was a police officer.

The population of 123 respondents in this survey was not intended to be representative of the population in the United States. There was over-representation with respect to younger persons, because of the number of university students in the survey. Additionally, because of other objectives for this research, police officers and police trainees were sought out in order to evaluate their performance.

That being said, the analysis of categorized data provides quantitative information to characterize the likely distance estimation accuracy for a witness drawn from the population. It is quite likely that a witness will provide a distance estimate with a large error. For example Table 2 indicates that 25% of the survey subjects (1 in 4) had distance estimation errors of −35% to − 59%, depending on the distance. Table 2 also notes that nearly 75% of the survey subjects underestimate distance to varying extents. It also was found that nine of the 123 respondents (more than 7%) gave at least one estimate that was classified as an outlier, for at least one of the distance categories queried. These outliers, (though not frequent) are so inaccurate that they contain virtually no usable information. If the respondent is female, the median error is 1.6 to 3 times larger than if the respondent is a male, depending on the distance. However, females are no more likely to provide outlier estimates of distance than are males.

The purpose of the research is to provide probable ranges for distance estimation error that would be expected for witnesses. Experts may find this quantitative information to be useful in evaluating testimony and also in doing contingent calculations based on the range of possible error. It is not our intention to suggest that the results of this survey and analysis could be used to impugn any particular witness.

It is likely that further analysis of the effects of gender, age, occupation (including police status), and experience along with observed target information will provide some interesting results. From work that we have already completed, however, it seems clear that future analysis will need to proceed using the data set with outliers excluded in order to employ ANOVA - based procedures to explore main effects and interactions. The data used in this paper included those outliers.

REFERENCES

1. Andre J, and Rogers, S, (2006) Using Verbal and Blind-walking Estimates to Investigate the Two Visual Systems Hypothesis. Perception and Psychophysics, 68 (3), 353-361.

2. Gibson, J. J. The Perception of the Visual World, Houghton Mifflin, Boston, 1950.

3. Higashiyama, A. and Adachi, K. (2006) Perceived Size and Perceived Distance of Targets Viewed from Between the Legs: Evidence for Proprioceptive Theory, Vision Research, 46, 3961-3976.

4. Johnson, R. Probability and Statistics for Engineers, 7th ed., Pearson Prentice Hall, New Jersey, 2005.

5. Lappin, J.S., Shelton, A.L., and Rieser, J.J. (2006). Environmental Context Influences Visually Perceived Distance. Perception & Psychophysics, 68, 571-581.

6. MINITAB Statistical Software User's Guide, www.minitab.com.

7. Montgomery, D.C., and Runger, G. C., Applied Statistics and Probability for Engineers, 2nd ed., John Wiley and Sons, Inc., New York, 1999.

8. Sharrack, B. and Hughes, R.A.C. (1997). Reliability of Distance Estimation by Doctors and Patients: Cross Sectional Study. British Medical Journal, 315, 1652-1654.

9. Sinai, M.J., Ooi, T.L., and He Z.J. (1998). Terrain Influences the Accurate Judgment of Distance. Nature, 395, 497-500

10. Strauss M., and Carnahan, J. (2009). Distance Estimation Error in a Roadway Setting. The Police Journal. (Accepted for publication)

CONTACT INFORMATION

Correspondence should be directed to

Mark Strauss, PhD.
Ruhl Forensic Inc.
1210 Lancaster Drive
Champaign, IL 61821
or
mgstrauss@ruhl.com

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support of Ruhl Forensic Inc. for underwriting this research and to Nicholas Palkovic for his assistance in performing the survey and tabulating the results and to Dennis Ko for his assistance in processing data.

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. This process requires a minimum of three (3) reviews by industry experts.

ISSN 0148-7191

doi:10.4271/2010-01-0046

SAE Customer Service:
Tel: 877-606-7323 (inside USA and Canada)
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE Web Address: http://www.sae.org
Printed in USA

SAE International™