Title

A 3D Computer Simulation Test of the Leibowitz Hypothesis

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ABSTRACT

Do large objects appear to approach more slowly than smaller objects traveling at the same speed? If so then this might help explain the inordinately high accident rates involving large vehicles such as buses and trains. To test this, this study constructed an experiment using a 3D visual simulator in which different sized textured spheres approached at different speeds. We found that observers consistently judged the smaller sphere to be the faster, even in cases where the larger sphere was traveling at up to twice the speed of the smaller. Analysis of these results suggests that the brain relies upon the perceived rate of change of an object's visual angle, $d\theta/dt$, to determine how quickly an object is approaching.

INTRODUCTION

Rear-end collisions with buses and collisions with trains at railroad crossings occur at significantly higher rates than the corresponding cases involving only automobiles. This has long puzzled accident investigators, since one would expect the movements of larger objects to be more easily noticed and interpreted by motorists. In 1985, Leibowitz observed that large aircraft at airports appeared to move more slowly than smaller aircraft, even though the former were traveling much faster *(1)*. He went on to hypothesize that this misperception must in turn be caused by the way in which the brain processed and interpreted the visual information provided in this scenario. To our knowledge, Leibowitz' hypothesis has received only limited testing. A study by Cohn and Nguyen in 2002 studied a narrow aspect of this concept by looking at human perception of size increases *(2)*. Their conclusion that the initial approach of larger objects is seen slower or later than for smaller ones suggests that larger objects are perceived to move at slower speeds, thus offering credibility to Leibowitz's theory.

This study takes research in this area one step further by testing human perception of the relative speed of two comparable objects, distinguished only by size and speed at various times. Our goal was to lend further support to Leibowitz's theory that people perceive larger objects to travel slower than smaller ones. The use of 3D visual simulators to assess perceptions of roadway safety has been tested in studies looking at construction work zones safety *(3)*. The results indicate that the vision model-based tool can assess the relative conspicuity of individual elements of a roadway or roadside scene. It holds potential value in virtual prototyping of work-zone sight lines, colors, and placement of hazard warning cues, which can have significant implications along railroad crossings.

METHODOLOGY

We constructed a two alternative forced choice (2AFC) experiment consisting of two sequential time epochs. In one of the epochs, chosen at random, a five foot diameter sphere approached the observer at eye level, traveling at 35 mph (56.35 km/h). In the other epoch, a ten foot diameter sphere approached at one of the speeds given in Table 1. The observer's task was to indicate by pressing a button which epoch contained the faster approaching sphere. An experiment consisted of 270 such trials. The number of times that the ten foot diameter sphere assumed each approach speed (also selected randomly) is also indicated in Table 1. (As we explain later, we were able to run fewer trials for the slower approach speeds while maintaining approximately equal measurement errors.)

Speed in mph (km/h)	**# Trials (Out of 270)**
25 (40.25)	40
35 (56.35)	40
45 (72.45)	40
55 (88.55)	50
65 (104.65)	50
75 (120.75)	50

TABLE 1: 10 ft Diameter Sphere Approach Speeds

A faceted white sphere was constructed using OpenGL (10 longitudinal slices, 10 lateral slices, with a black wire-frame coinciding with the edges formed by the slices). It was presented against a black ground plane and horizon. The ground plane was delineated with yellow longitudinal lines 5 feet (1.53 meters) apart. Twenty white, 6 feet (1.83 meters) high, .25 feet (.076 meters) diameter cylinders were randomly placed throughout the ground plane (but not in the path of the approaching sphere) to give the observer a sense of perspective and proportion. The scene was presented on a projection-based virtual reality (VR) system (see Figure 1). The viewer, seated in front of the projection screen, wears stereo shutter glasses and a six-degrees-of-freedom head-tracking device.

As the viewer moves his or her head, the correct stereoscopic perspective projections are calculated for each eye and presented. The scene was presented with a frame rate in excess of 60 Hz (resulting in a greater than 30 Hz frame rate for each eye.) A frame from one such presentation is shown in Figure 1. Each time epoch started with the sphere 6.5 seconds away from the observer, and ended with the sphere 0.25 seconds away, so that it remained in view for 6.25 sec. Since tests of this type are fatiguing, the experiment was divided into four segments of approximately 67 trials each to give test subjects a chance to rest in between. Subjects can also stop and rest within a segment if necessary.

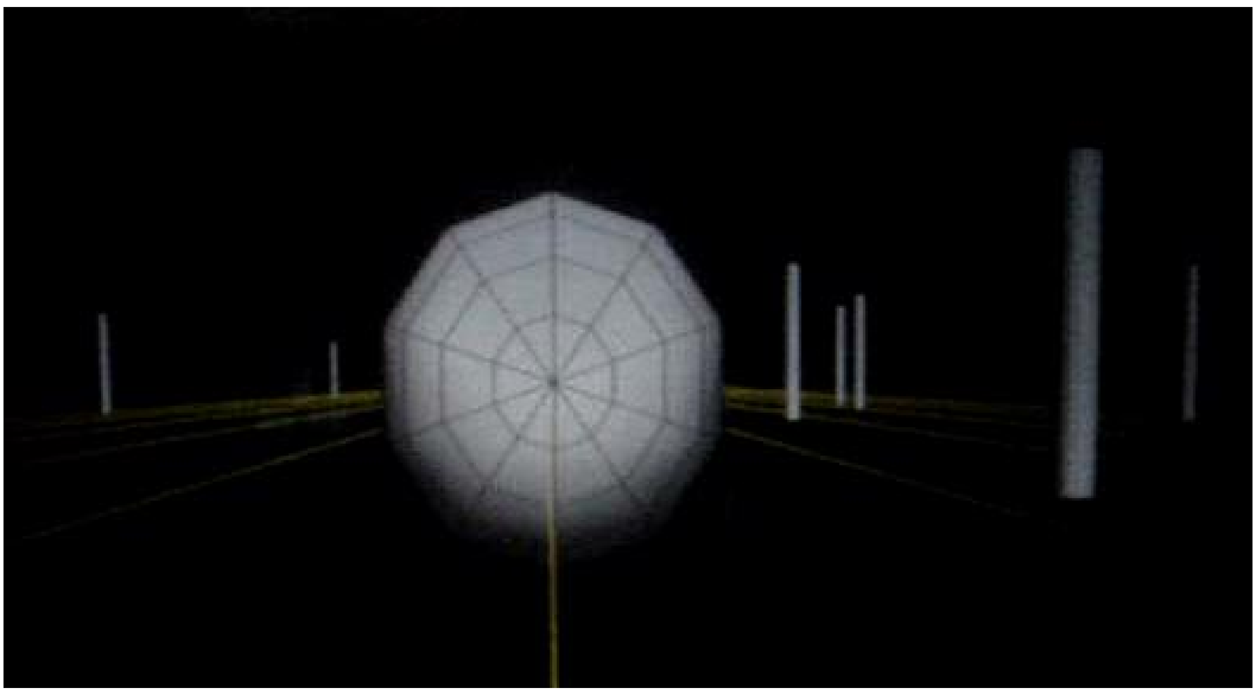

FIGURE 1: Visual Scene

Four visual cues are available to the observer in judging the faster of the two approaching spheres: monocular image expansion, binocular cues deriving from stereopsis, texture dilation, and reference to the static cylindrical posts and ground plane lines. Even though we have included binocular effects in these experiments, we do not expect them to play much, if any, role in this task. Since such effects are not noticeable at distances greater than approximately 30 feet (9.15 meters), this information will not be available to observers until the final 0.33 sec of a

(6.25 seconds) 35 mph approach, and only the final 0.02 seconds of a 75 mph (121 km/h) approach. It seems highly unlikely that the brain would be able to utilize such a small quantity of information, occurring at the very end of the presentation. Here we allow the sphere to come within .25 seconds of the observer before occluding it. In practical applications where decisions would have to be made 2 to 4 seconds before collision, binocular cues would be entirely unavailable.

FINDINGS

We tested the ability of five males (labeled S1 to S5, ranging in age from the early 20's to the mid 50's, with corrected normal eyesight) to identify the faster of two, different sized approaching spheres. The results of these tests are summarized in Table 2, which shows the total number of trials n (across all subjects) that were conducted for each large-sphere speed (V_{10}), the proportion of times P_5 that subjects judged the smaller diameter sphere to be the faster, and the standard error (SE) of the measurement, given by.

$$SE = \sqrt{\frac{P_s\,(1-P_s)}{n}}\,.$$

Since SE increases from zero at $P_s = 0$ to a maximum at $P_s = .5$ and then decreases to zero again at P_s=1.0, correspondingly more trials are required when $P_s \approx 5$ than when P_s is at either extreme to achieve the same standard error. From a series of pre-trials we determined that when V_{10} was low subjects would almost always judge the smaller sphere to be the faster ($P_s \approx 1$), hence we ran correspondingly fewer trials for the lower values for V_{10} than for the larger values. The final two columns show the difference ΔP_5 and its associated standard error, given by

$$(\Delta P_5)_C = (P_5)_C - (P_5)_{C-1}\,,$$

$$SE_{\Delta P} = \sqrt{\left(\frac{P_5(1-P_5)}{n}\right)_C + \left(\frac{P_5(1-P_5)}{n}\right)_{C-1}}\,,$$

where C is the Case. The 95% confidence intervals associated with the P are thus

$$CI_{95\%} = (\Delta P_5)_C \pm 1.96\,SE_{\Delta P}\,.$$

Since these confidence limits lie to the right of zero for every case except Case 1, we can state with 95% confidence that the differences ΔP_5 are statistically significant. Figure 2 plots P_5 as a function of V_{10}. Also shown are ± 1 SE bars.

Case	**V_{10} (mph)**	**V_5**	**n**	**n_5**	**P_5**	**SE**	**ΔP_5**	**$SE_{\Delta P}$**
1	25	35	198	188	0.949	0.016		
2	35	35	200	191	0.955	0.015	-0.006	0.021
3	45	35	197	164	0.832	0.027	0.123	0.030
4	55	35	236	164	0.695	0.030	0.138	0.040
5	65	35	237	119	0.502	0.032	0.330	0.044
6	75	35	199	95	0.477	0.035	0.218	0.048
Overall		1267	921	0.727	0.013			

TABLE 2: Experimental Results

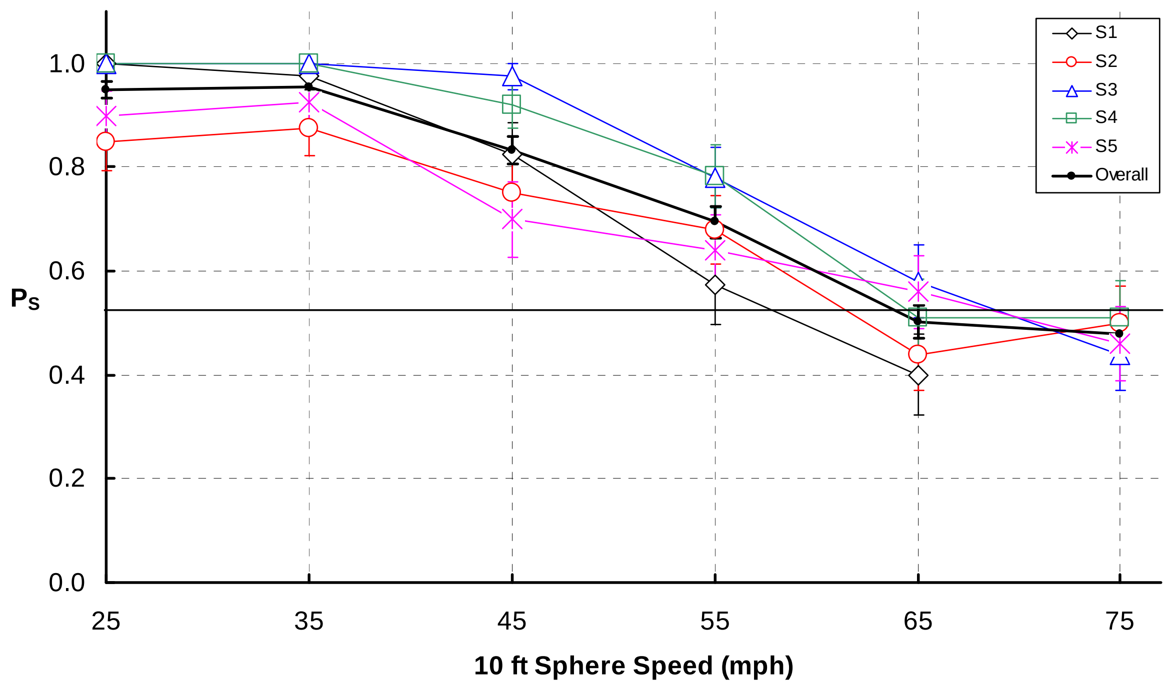

FIGURE 2: Experimental Results.
The results show that the average person displays a strong tendency to judge the smaller sphere as the faster, even when the actual approach speed of the larger sphere is 20 mph greater (V_{10} = 55 mph). Only when V_{10} reaches speeds of 65-75 mph (twice that of the smaller sphere) does the observer become unsure as to which is approaching faster ($P_5 \approx 0.5$). If we let z(t) be the distance from the observer to the sphere at any time t ($0 \leq t \leq 6.5$ sec). Then z(t) = V(6.5-t), where V = dz/dt is the approach velocity of the sphere. If r is the sphere's radius, then the visual angle θ_r that it subtends is

$$\theta_r(t) = 2\tan^{-1}\left(\frac{r}{z(t)}\right) = 2\tan^{-1}\left(\frac{r}{V(6.5-t)}\right)$$

while

$$\frac{d\theta_r}{dt} = \frac{r}{z^2 + r^2}V$$

These are plotted as functions of time in Figures 3.

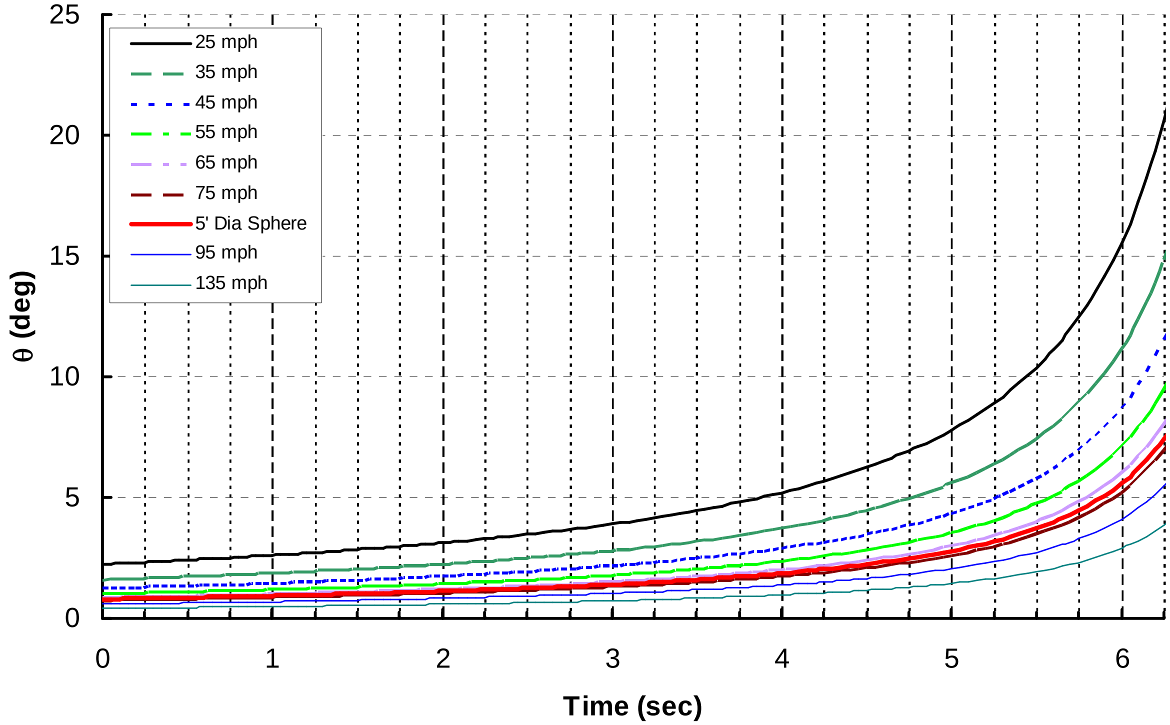

FIGURE 3a: θ vs. time

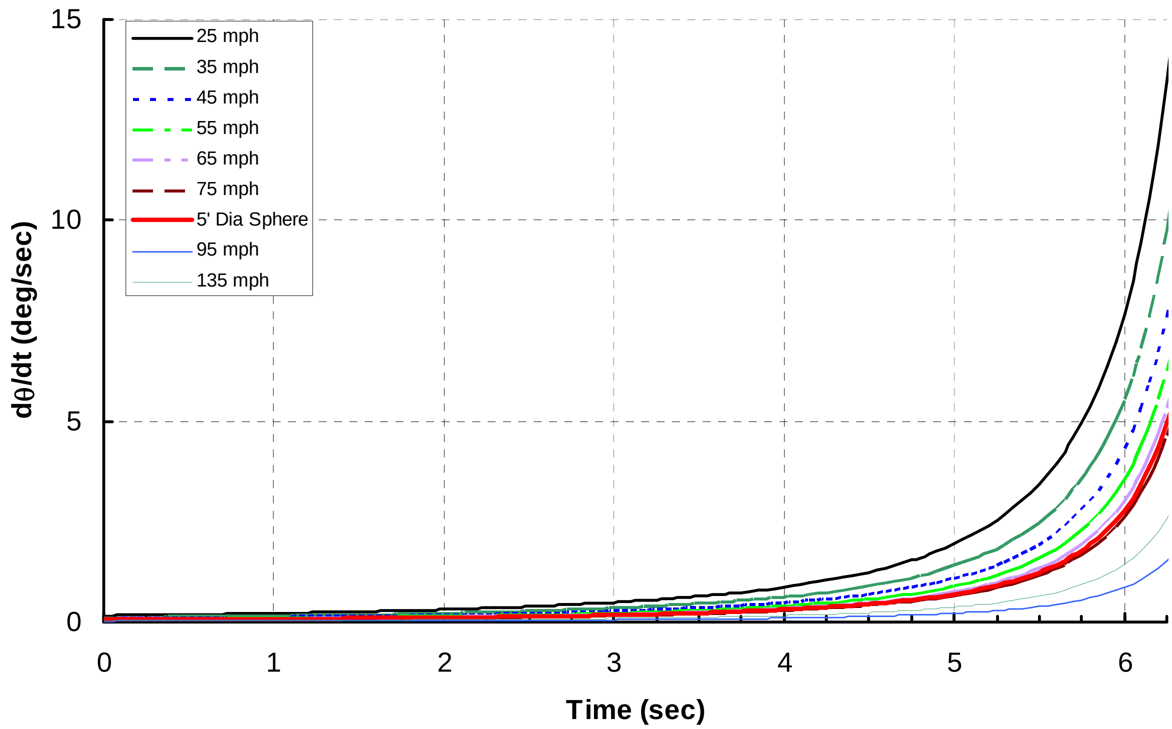

FIGURE 3b: dθ/dot vs. time

From these we see that for $V_{10} < 70$ mph ($= 2 V_5$), $\theta_{10} > \theta_5$ and $d\theta_{10}/dt > d\theta_5/dt$ for all t. For $V_{10} > 2 V_5$ the opposite holds, and for $V_{10} = 2 V_5$ the two sets of profiles coincide with one another. This final observation demonstrates the obvious fact that the monocular view of the smaller sphere's approach is exactly matched by that of a sphere twice as large, approaching twice as fast, from twice as far away. This, along with our experimental results, suggests that observers rely heavily on the monocular cues when making judgments about the speeds of approaching objects. In this case they could be relying exclusively on θ (i.e., comparing θ for various t), exclusively on $d\theta/dt$, or they could be using both in some combination.

If it is true that observers place heavy emphasis on monocular cues in performing this task, then it is easy to see why judgments about approaching objects are so unreliable. It is interesting to note that for $V_{10} < 2 V_5$ the brain judges the larger sphere to be approaching more slowly, even though its associated subtended angle and expansion rate are both *greater* than those associated with the smaller sphere.

We also note that compared with the final 2-3 seconds of the approach, the information provided in the first 3-4 seconds appears barely distinguishable in going from one speed to the next.

CONCLUSIONS

This study examines the perception of the speed of moving objects given their relative size. The results further lend credibility to Leibowitz's theory that bigger objects are perceived to move slower than smaller objects. In transportation safety research, the results can have implications on the design and improvement of rail crossings or signals at major traffic intersections.

While the design and testing of a computer model presented in this short study may yield reliable results, the research into Leibowitz's theory can advance much further if researchers empirically tested the validity of the concept. One area lacking and yet to be explored is the gauging of people's perceptions of actual moving vehicles of various sizes, such as the perception of fast approaching trains. Given that the safety implications involve the misjudgment of speeds by motorists and pedestrians at rail crossings, measuring whether there is significant discrepancy between movement by computer model simulations and actual physical objects would shed light on the future direction of related research.

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