http://doi.org/10.34074/rere.00218

Article

SLIPPERY SLOPES IN VIRTUAL ENVIRONMENTS. TESTING AN EXPERIMENTAL DESIGN FOR SLANT ESTIMATIONS IN THE REAL WORLD AND 3-D COMPUTER GENERATED ENVIRONMENTS

Barnaby Pace

ABSTRACT

Over the last 70 years, there have been numerous studies undertaken in an attempt to explain slant perception and underestimation. Research has shown that the optical slant is being viewed at a lesser value than that of the geographical slant counterpart. In other words, there is a lack of correspondence between what is being perceived and what is actually being presented. In order to understand the problem fully a number of terms need to be explained, such as optical vs geographical slant. The optical slant is the slanted surface that is perceived by an individual, whereas the geographical slant is the physical slanted surface within a real environment. For example, the geographical slant for this paper is approximately 45°, if it is being held in a normal reading position, whereas the optical slant is 0° to the reader (based on an example in Gibson, 1950a). This phenomenon of slant underestimation has been shown repeatedly throughout the literature, a summary of which will be presented here. One of the more important findings is that as the geographical angle increases so too does the level of underestimation, as illustrated in Perrone (1981). This paper outlines an experimental design for testing slant perception estimations in the real world and computer generated environments.

THE EARLY RESEARCH

In the early 1950s Gibson and colleagues (Gibson, 1950a, 150b, Gibson & Cornsweet, 1952) conducted a number of experiments on the perception of slanted surfaces, partly in response to solving aviation problems encountered during World War II (Gibson, 1979). Although there had been previous research conducted on the perception of slants, it was Gibson's work that formed the foundation for numerous later experimental research projections. Gibson's 1950 experimental research provided definitions for determining what a visual surface was (Gibson, 1950b), and in doing so provided the necessary information for defining the qualities needed for a visual surface to be considered a slant, although this was later revised in his 1972 test. In addition to this was the concept of regular and irregular patterns in regard to slant perception, which provided the basis for his experimental hypothesis. This is the prediction that the "irregular texture would yield judgment of slant less consistent than the judgment obtained with the regular texture" (Gibson, 1950b, p. 377). Through this hypothesis, Gibson was able to determine a direct correspondence between the textual density and slant perceived, stating that "as the gradient of the density of texture of a projected image is increased by the experimenter, the slant of the surface perceived increasing correspondingly" (Gibson, 1950b, pp. 383). Further support for Gibson's 1950 hypothesis was given through his collaborative work with researcher J. Cornsweet. Although the 1952 hypothesis (Gibson & Cornsweet, 1952) was based on the concept of optical and geographical slants, it also incorporated the previously mentioned textual density and slant perception relationship. The results obtained tended to indicate absolute thresholds for the observer for both types of slants mentioned in their hypothesis, primarily optical and geographical.

The continuation of Gibson's research can be seen in the writing of Howard Flock. Flock's 1964 research on monocular slant perception primarily concentrates on motionless situations from both the point of the stimulus and the observer in order to lessen the effect of motion parallax as mentioned by Gibson (1950a, 1979). Flock (1964) described a slant as a collection of 'like elements', such as grass, which make up a visual surface or plane. Through this definition, he proposed an optical theta as a method for the calculation of slant angles. In addition to this Flock also proposed 2 postulates and 4 criteria in order to determine the quality and quantity of the 'like elements' in the slanted surface. As Freeman (1965) pointed out, a total of 13 criteria and assumptions are involved in Flock's psychophysical theory of the optical slant, thereby making the whole process very complicated. Flock's (1965) later work provided further evidence in support of the original findings, primarily in response to Freeman's (1965) writing, which strongly criticised the data and method given.

COMPUTER GENERATED SLANTS

It was Braunstein (1968) who first started to use computerised images in order to test the previously mentioned theories of slant perception. The stimuli used were a number of motion-picture sequences projected on a translucent screen through the use of a motion projector showing 24 frames per second, The sequences were comprised of computer-generated images in the form of approximately 750 white dots with a black background, which had been translated into X and Y coordinated on the plane rotated around these axes. With the addition of a Z-axis, perpendicular to the line of sight, a three-dimensional effect was achieved. Prior to this, Braunstein (1966) had used a similar method in order to test depth perception. Braunstein (1968) concluded that textual gradients appear to be insufficient as a source of slant information (Perrone, 1981). In addition to this, the data showed large amounts of underestimations compared to similar studies (Perrone, 1981).

Braunstein and Payne (1969) continued with the concepts and ideas mentioned in Braunstein's 1968 work using similar computer-generated images as stimuli. This time three experiments were carried out. Experiment one consisted of images of computer-generated slanted surfaces of regular patterns projected in a similar manner to those in Braunstein's 1968 work. Here the subjects were presented with two stimuli slants at once, one being present in either eye. They were then asked to indicate which of the two had the greater slant. In addition to this, the participants were to show the greatest degree of slant presented to them by tilting a demonstration plane. Experiment two contained computer-generated line images rather than dots as in experiment one. Experiment three consisted of irregular dotted patterns in order to test different types of texture on the perception of slanted surfaces, as had been suggested by Gibson (1950b).

The continuation of computer-generated stimuli can be seen in the computer simulation produced by Clocksin (1980). Clocksin devised a computer simulation that used an optical flow pattern as discussed by Gibson (1979) to detect slanted surfaces. The simulation uses a number of equations as well as additional information to produce a slant value for each of the receptors in the visual field that have been activated as its output. Once this has been achieved additional calculations can be performed to determine information such as the absolute surface slant and degree of slant. This can then be compared with the results obtained from participants for further analysis. An example of this shows the levels of inaccuracy given by both the computer program and human participants. It should be noted that this simulation is also able to perform similar tasks with edge perception.

SLANT UNDERESTIMATION

One of the common findings in the research on slant perception is underestimation by the participants as seen in the work by Braunstein (1968). Perrone (1980) proposed a mathematical model for the estimation of slant perception, as a part of his Ph.D. thesis (Perron, 1980). This model contains two options in order to allow for variation in the information presented in the visual field, such as the orientation of the surface regarding the direction of the true perpendicular and the surface plane. The model has been tested against Gibson's (1950b) findings, showing that the predicted result obtained for a backward slant using the model's second option matches closely to those shown in Gibson's data, provided that we take the equation $y = x - v$ where $v = 12^\circ$, into consideration. Similarly, the results for the forward slant are of equal comparison, with the aid of the equation. Perrone also compared the model against Smith's (1959) data in order to test for generality. This comparison produced similar findings between the model and data already obtained. The only difference between the model/Gibson and the model/Smith comparison was that in Smith's case the second option was expected to have either *a* or *ø* as estimates due to the fact that the slants shown did not fill the entire field of view.

Perrone's (1982) later writing provided a critical evaluation of his previous work and proposed a modified version of the model mentioned above. Perrone's (1982) general model contains two proposals based on the correct assessment of the true straight-ahead direction and the perceived straight-ahead direction. The two important parameters to be taken into consideration in the model are firstly, the projected length of the image and secondly, the angle of convergence of the sides of the image in question (Perrone & Wenderoth, 1991). The model stated that if the true straight-ahead direction is used in the calculation of the slant, then underestimations will occur due to the fact that only half of the visual surface is being taken into consideration, whereas if the perceived straight-ahead direction is used then the whole visual surface will be calculated, therefore producing more accurate results. In addition, Perrone (1981) also comments on the use of different apertures (circular and rectangular) in the presentation of slant surfaces, stating that different calculations need to be taken into consideration depending on the aperture used. An example of this is that the slant of the circle is more accurately perceived than the slant of rectangles (pp. 11). Once again, the model was tested against a number of previous studies (Gibson, 1950b, Smith, 1959), producing favourable results.

FURTHER RESEARCH

Research in this area has continued to develop. Johansson and Börjesson (1989) proposed the development of a new theory for visual space perceptions, which at the base level takes into consideration wide-angle recording of slanted surfaces. The theory is to form three-dimensional metrical specifications for visual slant information with the use of information from the optical flow patterns, similar to the concepts mentioned by Smith and Snowden (1994) in their text. The authors claim that their "theory is capable of explaining real-life slant perception" (Johansson & Börjesson, 1989, pp.249), as well as the assumption that their model's processor is consistent with neurophysiological capability. The conclusion drawn by Johansson and Börjesson, after conducting three experiments to test their model are: firstly, that the visual system is sensitive to wide-angle optical flow information, and secondly that their model is in accordance with these findings. Later Börjesson (1994) worked independently on the optic sphere theory as a method for determining slanted surfaces. The method behind the theory involves the "extrapolation of the projected arc to a great circle on the optic sphere" (Börjesson, 1994, pp.267), this is then compared to the point of no change in order to make the slant judgment.

Buckley, Frisby, and Blake (1996) proposed an Ideal Observer theory, an ideal observer being a "theoretical perfect observer whose sensory and perceptual system works without error" (Reber, 1995, pp. 354) in order to solve the problem of poor slant perception. The authors used binocular viewing methods rather than monocular viewing due to better performance, which matches Perrone's statement that "Binocular viewing led to more accurate estimates of slant than did monocular viewing" (1981, pp.1 0). Buckley, Frisby, and Blake's findings showed a failure in the effect of density on the perception of a slanted surface, concluding that compression of the textured surface itself influences the judgments made. Compression has been stated as the ratio of width to length of each individual element contained on the slanted surface.

Pierce and Howard's (1997) research tested the perception of a textured surface in regard to the disparity of the horizontal, vertical, and overall size, plus the interactions between various types of patterns. The findings from these two experiments showed that for the horizontal size disparity condition (even though the full visual field surface was given) the predicted values for the levels of disparity were 2%, and that underestimation of disparities were 4% and 8% for the 10° and 20° stimuli. Similar results were also achieved for the half visual field surface. The researchers concluded that these results may be due to the conflict between disparity and other visual information such as distance cues. Vertical size disparity contained slant information opposite to that of the horizontal size disparity. Finally, for overall size disparity, the full visual field surface appears as a lesser version of the horizontal size disparity, therefore the conclusion is that horizontal size disparity provides most of the information used by the observer in the perception of slanted surfaces.

Andersen, Braunstein, and Saidpour (1998) took Braunstein's earlier work (1966, 1968, Braunstein & Payne, 1969) one step further into a more realistic three-dimensional environment. Andersen and his colleagues performed five experiments on both depth and slant perception in a three-dimensional environment specified by texture. The first experiment was primarily concerned with depth, with the other four being dedicated to slanted surfaces. Experiment Two investigated the judgment of a slant with two planes at either 40° or 80° comprising different line texture patterns. The mean results obtained showed judgments of 19.2° for the 40° condition and 56.2° for the 80° condition, thereby showing consistency with the previously mentioned results. Experiment Three was identical to Experiment Two but with only one plane being presented. The mean collected under this condition was a close match to that of Experiment Two, being 14.5° and 53.5° respectively. In experiment Four, the judgment with a simple plane oriented vertically was conducted in a similar manner to that of the previous two experiments, with the mean results of 12.0° and 48.4° being obtained. Finally, the fifth experiment involved two planes being oriented vertically. Under this condition, there is a slight increase in accuracy for the 40° slant from the previous experiment to 20.1°, whereas the 80° slant remains fairly similar to that in Experiment Four at 47.4°. One of the conclusions drawn by Andersen Braunstein, and Saidpour is that accuracy of a judgment is greater for surfaces close to the planes (slants of 80°) than for the slanted surfaces close to the frontal plane (40° slants) (Andersen, Braunstein & Saidpour, 1998, pp. 1087).

THIS STUDY

The experimental research undertaken within this paper is a continuation of Braunstein and colleague's work on slant perception with the aid of computer-generated images taking into consideration the foundation research conducted by Gibson (1950a, 1950b, Gibson & Cornsweet, 1952) and the research findings on underestimation as shown by Perrone (1980, 1981, 1982). The experiment to be outlined in this study involves the estimation of naturally occurring slanted surfaces by observers, similar to the slanted surfaces used in Bhalla and Proffitt's 1999 work. The collected data isl then compared with the findings of previous research as outlined above.

Braunstein's work (1968, Braunstein & Payne, 1969) used regular and irregular patterns of dots which, although they can represent depth and texture cues are not an accurate representation of real-world environments, partly due to the limitations of the technology available to him. His later work with Andersen and Saidpour (Andersen, Braunstein & Saidpour, 1998) integrated slightly more realistic computer-generated images in the form of wooden floorboards, but was still not a true representation of the natural environment in which the observers function. The aim of the present research is to allow for a comparison between the perception of computer-generated slants and those found in the real world. The purpose of this is to test for the degree of correlation between the two environments (real and computer-generated) in order to ensure that simulated programmes, such as those used by pilots, are an accurate representation of the real environment in which we function. If the findings fail to show a significant level of correlation between the two, then further research will be needed in order to isolate the necessary elements for the simulations to be more realistic. Such elements may include the quality of the display on which the stimuli are presented, taking into consideration things such as resolution, levels of colour hues, and brightness.

METHODOLOGY

Hypothesis

Drawing on the literature the following hypothesis is to be tested: there will be a significant level of correlation between the underestimations made by participants in the computer-generated environment and overestimations made in the real world. If this hypothesis is true, then it can be stated that computer-generated environments are accurate representations of the real world. If the hypothesis is rejected then the reverse statement can be made, that computer-generated environments are poor representations of the real world and therefore caution is needed when using such stimuli in training equipment such as flight simulators.

Subjects

Six volunteer participants included 5 males and 1 female ranging between 20 and 22 years of age.

Stimulus

Four external, real-world, slanted surfaces located on the University of Waikato campus were used as the stimulus for this experiment. Two surfaces slanted at 11°, one at 4°, and one at 18° (Note that a ±1° margin of error is to be taken into consideration. This is due to the inconsistencies found in naturally occurring surfaces.) (Figure 1) The calculation of the slanted surfaces is given under Procedure.

Figure 1 – Stimulus one - 11° (top left), Stimulus two - 4° (top right), Stimulus three - 18° (bottom left), Stimulus four - 11° (bottom right).

Apparatus

The participants viewed the stimulus binocularly through a circular shaped aperture (diameter of 20cm, a circumference of 62.83cm (2.d.p.)) constructed from cardboard. This was utilised in order to remove depth cues, such as horizon line) which could be used in the determination of the degree of slant by the observer, viewing angle is therefore 14.9°. A chair was provided in order to minimise body and head movement, thereby reducing the effects of motion on the perception of the slanted surface.

A tilt pad, similar to that described in Bhalla and Proffitt's 1999 research, ranging from 0 to 45 degrees was used to record the degree of slant perceived by the observer in both phases of the experiment. The tilt pad operates on a pivot system, allowing the user to move the pad backward and forwards 45 degrees, although for this experiment only the backward 45 degrees were needed as all slanted surfaces presented were of a forward-slanting nature.

Procedure

Four slanted surfaces located on the grounds of the University of Waikato with the degree of slant measured using 0° as ground level as used in Bhalla and Proffitt's (1999) experiment. In order to increase the accuracy of the degree of surface slants, nine measurements (X1- X9) were taken in a 3x3 matrix with a pre-set distance (d) between each. The mean of the measurements was used to provide the slant of the surface being measured. This process was then repeated by a second individual to order to ensure the reliability of the original calculations.

Participants were seated by the researcher to view the stimulus. The chair was positioned on a flat surface (0° to 1°) either on concrete or hard soil. Once the participants were in position the researcher instructed them to look through the circular aperture at the stimulus. The participants were asked by the researcher to manually adjust the tilt pad (which was attached to the chair) in order to indicate the degree of slant being presented to them as they perceived it. The title pad allowed the participants to provide a non-verbal indication of the perceived degree of slant. Once the participant removed their hand from the tilt pad, the degree of slant indicated was recorded.

Once the experimental data was collected from all participants, the mean degree of misestimation, if any, was calculated. Once these calculations had been undertaken, comparisons between the data collected in previous findings, such as those commented on in Bhalla and Proffitt's (1999) research, were checked for consistency. In order to test the hypothesis, the results obtained within this study were compared to findings of previous research which used computer-generated images such as Braunstein's 1968 and 1969 works.

RESULTS

The results obtained indicate the same trend as shown by Braunstein and colleagues (Braunstein, 1968; Braunstein & Payne, 1969; Andersen, Braunstein & Saidpour, 1998), and as such provides support for the hypothesis that there is a strong relationship between the underestimations made by participants with computer-generated slanted surfaces and the overestimations made in the real world.

The mean results show an overestimation of 12.6° for the first stimuli (11°) with a mean of 23.6°. Stimulus two (4°) produced an overestimation level of 5° from a mean of 9°. The third stimulus showed a mean estimate of 31.3° with an overestimation of 13.3°. The fourth stimulus (11°) showed an overestimation of 6.8° from the perceived mean of 17.8°. Stimulus one and four (both 11°) fail to show a correlation in overestimation which will be examined in the discussion sections.

Table 1. Mean results for participants' responses to slanted surfaces and degree of misestimation

STIMULUS	MEAN (DEGREES)	DEGREE OF MISESTIMATION (±)	
Stimulus 1 - 11°	23.6°	+12.6°	Overestimation
Stimulus 2 - 4°	9°	+5°	Overestimation
Stimulus 3 -18°	31.3°	+13.3°	Overestimation
Stimulus 4 - 11°	17.8°	+6.8°	Overestimation

Comparison between Proffitt's 1995 findings and those in this experiment indicate a similar trend although being just outside the pre-set margin of error (Table 2). The variation in overestimation levels for a surface of the same slant could be influenced by a number of environmental variables that are explored within the discussion. Due to the nature of the slanted surfaces portrayed in the computer-generated environments a clear comparison cannot be drawn between those found in Braunstein and colleagues (Braunstein, 1968; Braunstein & Payne, 1969; Andersen, Braunstein & Saidpour, 1998) and those shown in this study. Therefore, the hypothesis can only be supported by the trends shown and not by the degree of correlation between all the sets of data involved.

Table 2. Comparison to Proffitt's 1995 Findings

STIMULI	CURRENT FINDINGS (° DIFFERENCE)	PROFFITT (1995)
4° (Stimulus 4)	9° (+5°)	7.7° (+3.7°)

DISCUSSION

The aim of this pilot study was to test the hypothesis and demonstrate a correlation between the misperception made of slanted surfaces found in both the real work and those generated in computer virtual environments, such as can be in found in flight and driving simulators. Although this experiment provided further evidence in support of Proffitt's (1995) findings, it did not give adequate evidence to support the aim of due to the nature of slanted surfaces found in computer-generated environments. The smallest slant given in computer-generated environments 20° (Andersen et al., 1999) and the largest slant given in this study was 18°, due to the location. The steepest slope found on the University of Waikato campus grounds is 18°. Gibson's 1950b experiment did provide a 10° slant that could be used as another comparison for the two 11° surfaces, as it is then in the margin of error ±1°, although this stimulus itself is not computer-generated. An ideal experimental comparison would therefore use computer-generated surfaces to match those being used in the real world. This would allow the researcher to test for variables such as the impact the monitor (resolution, brightness and depth (3-D soft and hardware)) has on the perception of the slants being portrayed. As well as the mismatch of surface slant a number of other variables need to be reviewed, such as the texture of the is being viewed.

The texture of the surface being perceived is another important consideration. Variables, such as the length of the grass in the areas being viewed need to be taken into consideration when analysing the data from different slants. An example of this can be seen in stimuli three and four (Figures 1c and 1d). On viewing we are able to see that the grass in both stimuli three and four is uneven (irregular) in nature as compared to stimuli one and two, therefore giving the observer misleading information in regards to the density of the surface's texture. The time of day and shadow pattern produced also gave the observer misleading information on the textural density of the surface. As stimulus four (11°) the shadow laying at the top of the slanted surface produces the impression of a flatter surface that is actually present, which may explain why the observers perceived this slant at a lesser angle when compared to stimulus one (11°). If this is the case, then general weather patterns and the amount of light present in viewing the stimulus will also need to be taken into consideration. In order to overcome this problem, experimental conditions need to be matched as closely as possible between participants in order to achieve interparticipant consistency.

As well as the large number of external variables which the experimental design, in this case, was unable to account for, a number of other experimental problems occurred. The first of these was the method by which the slant estimations were given by the observer. The tilt pad, as used in Proffitt's 1999 research, had a number of limitations. Firstly, the highest level of degree that can be shown is 45° and although the greatest slant given was only 18° the observer's perception of this slant, as shown in the data, ranges from 16° to 50°. This limitation forced the participants to give a verbal response as to the estimation of the slant being presented to them. In order to avoid this problem in future research, a number of modifications need to be made to the tilt pad. Firstly, by extending the height of the lag bracket between the base and the tilt pad to allow for greater movement, and secondly, extending outward the bracket to the 'protractor' is foxed, to avoid contact with other parts of the tilt pad frame.

In addition to this, the tilt pad also tended to produce results closer to the physical slant than previous research would suggest (Gibson, 1950b, Braunstein, 1968). Proffitt's (1995) and Bhalla and Proffitt's (1999) research indicated a similar trend, showing comparisons between the tactile and verbal responses. If, in fact, there is a relationship between the improved slant judgments and tactile responses this could prove to be a valuable aid for pilots when navigating at low levels, and an area for further research. In addition to the design faults in the tilt pad, the size of the aperture also needs to be re-calculated if the experiment is to be re-tested. In this experiment, the aperture had a circumference of 62.83cm which, in hindsight, was too small and thus restricting the field of view and removing a large portion of the textured surface. This restriction limited the amount of depth information the observer was able to acquire from the textured surface which, as Gibson (1950b) identified, is one of the key sources of depth information.

Taking the aforementioned factors into consideration, with the addition of computer-generated slanted surfaces matching the degree of the naturally occurring surfaces, the experiment could be re-run to produce favourable results based on the data trends shown in this experiment. In addition, this research has suggested several other issues which could also be addressed in future experiments, such as an investigation into whether the level of accuracy between tactile and verbal responses could prove valuable in several areas, particularly military applications. A study of the effects of shadowing on depth, as well as slant perception, would add to the understanding and comparison of both computer-generated and real-world situations. Gender differences, although unrelated to the hypothesis for this experiment, may produce interesting results taking into consideration differences in spatial abilities. Due to the limited sample size used in this experiment, no pattern to support such an idea was shown. Some of these issues show a higher level of real work and day-to-day implications than others. All of them, though, would add to the growing pool of knowledge about human perception of our environment and how we navigate within it.

Barnaby Pace is an experienced human factors specialist and engineering psychologist working and researching how individuals perceive and move within virtually created environments such as flight and driving simulators. Barnaby hold's Masters' qualifications in Psychology and Engineering as well as a Ph.D. in Education. He is currently working as a Principal Advisor for Waka Kotahi New Zealand Transport Agency Research and Evaluation group.

REFERENCES

01 Andersen, G. J., Braunstein, M. L., & Saidpour, A., (1998). The perception of depth and slant from texture in three-dimensional scenes. *Perception, 27*, 1087-1106

02 Bhalla, M., & Proffitt, D. R., (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1076-1096

03 Börjesson, E., (1994). *The Optic Sphere Theory as a Slant Determining Mechanism*. Cited in Jansson, G, Bergestron, S. S. & Epstein, W., (Eds). (1994). *Perceiving Events and Objects*. Lawrence Erlbaum Associate Publishers.

04 Braunstein, M. L., (1966). Sensitivity of the observer to transformations of the visual field. *Journal of Experimental Psychology, 72*, 683-687.

05 Braunstein, M. L., (1968). Motion and texture as sources of slant information. *Journal of Experimental Psychology, 78*, 247-253.

06 Braunstein, M. L., & Payne, J. W., (1969). Perspective and form ratio as determinants of relative slant judgments. *Journal of Experimental Psychology, 81*, 584-590.

07 Clocksin, W. F., (1980). Perception of surface slant and edge labels from optical flow: A computational approach. *Perception, 9*, 253-269.

08 Flock, H. R., (1964). A possible optical basis for monocular slant perception. *Psychological Review, 71*, 380-391.

09 Freeman, R. B., (1965). Ecological optical and visual slant. *Psychological Review, 72*, 501-504.

10 Gibson, J. J., (1950a). *The Perception of the Visual World*. Boston: Houghton Mifflin.

11 Gibson, J. J., (1950b). The perception of visual surfaces. *American Journal of Psychology. 63*, 367-384.

12 Gibson, J. J., (1972). *The Ecological Approach to Visual Perception*. Boston, MA.

13 Gibson, J. J., & Cornsweet, J., (1952). The perceived slant of visual surfaces – optics and geographical. *Journal of Experiment Psychology, 44*, 11-15.

14 Johansson, G., & Börjesson, E., (1989). Toward a new theory of vision studies in wide-angle space perception. *Ecological Psychology, 1*, 301-331.

15 Perrone, J. A., (1980). Slant underestimation A model based on the size of the viewing aperture. *Perception, 9*, 285-302.

16 Perrone, J. A., (1981). *Visual Slant Underestimation*. PhD thesis, University of Canterbury, New Zealand.

17 Perrone, J. A., & Wenderoth, P., (1991). Visual Slant Underestimation. In Ellis, S. R., Kaiser, M. K., & Grunwald, A. J. (Eds.). *Pictorial Communication in Virtual and Real Environments*. 496-503, Taylor & Francis.

18 Pierce, B. J., & Howard, I. P., (1997). Type of size disparity and the perception of surface slant. *Perception, 26*, 1503-1517.

19 Smith, A. H., (1959). Outline convergence verse closure in the perception of slant. P*erceptual and Motor Skills, 9*, 259-266.

20 Smith, A. H., & Snowden, R. S., (1994). *Visual Detection of Motion*. Harcourt Bruce and Company.