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Searching for invariance: Geographical and optical slant

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ABSTRACT

When we move through rigid environments, surface orientations of static objects do not appear to change. Most studies have investigated the perception of optical slant which is dependent on the perspective of the observer. We investigated the perception of geographical slant, which is invariant across different viewing perspectives, and compared it to optical slant. In Experiment 1, participants viewed a 3D triangular target surface with triangular phosphorescent texture elements presented at eye level at one of 5 slants from 0° to 90°, at 0° or 40° tilt. Participants turned around to adjust a 2D line or a 3D surface to match the slant of the target surface. In Experiment 2, the difference between optical and geographical slant was increased by changing the height of the surface to be judged. In Experiment 3, target surfaces were rotated by 50° (± 25°) and viewed in both a dark and lighted room. In Experiment 1, the overall pattern of judgments exhibited only slight differences between response measures. In Experiment 2, slant judgments were slightly overestimated when the surface was at a low height and at 0° tilt. We compared optical slants of the surfaces to geographical slants. While sometimes inaccurate, participants' slant judgments remained invariant across changes in viewing perspective. In Experiment 3, judgments were the same in the dark and lighted conditions. There was no effect of target motion on judgments, although variability decreased. We conclude that participants' judgments were predicted by geographical slant, not optical slant.

1. Introduction

Numerous investigations of the perception of slant have studied optical slant primarily (Braunstein & Payne, 1969; Koenderink & van Doorn, 1976; Norman, Todd, Norman, Clayton, & McBride, 2006, Norman, Todd, & Phillips, 1995; Perrone, 1982; Phillips, 1970; Stevens, 1983; Todd, Thaler, & Dijkstra, 2005; van Ee & Erkelens, 1996; van Ee, van Dam, & Erkelens, 2002). Optical slant is egocentric and is defined as the angle between the surface normal and the line of sight (Todd & Perotti, 1999). Any change to the viewer's position or the surface's position yields changes in a surface's optical slant, even though the orientation of the surface to the surroundings does not change. A single large scale surface has multiple optical slant values at different points across the surface. For example, if an observer stands at one end of a long table, the closest end has a very different optical slant value than the middle of the table or the opposite end. However, the orientation of different portions of the table's surface are generally perceived and judged to be the same, that is, the surface is flat and level. In addition, when navigating through a static environment, people do not perceive rigid surfaces as constantly changing in orientation. If optical slant was used to inform us about the slant of surfaces in the world, the experience would be chaotic and disorienting.

Fortunately, perception of the slant of rigid surfaces remains stable with changes in viewer position (e.g., a flat table continues to appear flat no matter where the observer is). Without this stability, interaction with our environment would be incredibly difficult. The instability of optical slant makes it less likely that we use it to inform us about the slant of surfaces. Sedgwick and Levy (1985) suggest that it would be more efficient for the visual system to rely on geographical slant rather than continuously update itself with fluctuating optical slants. Geographical slant is the slant of a surface relative to gravity which remains stable with changes in a viewer's position. Therefore, investigating the perception of geographical slant may be a more ecological approach to understanding human perception of surface orientation.

Perception of the slant of large-scale surfaces has been studied extensively (Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Proffitt, Creem, & Zosh, 2001; Stefanucci, Proffitt, Clore, & Parekh, 2008). Much of this research has concluded that the perception of the slant of large-scale surfaces (e.g., hills and ramps) depends on extraneous factors such as glucose levels (Schnall, Zadra, & Proffitt, 2010) and social support (Schnall, Harber, Stefanucci, & Proffitt, 2008). Therefore they assumed constancy across the large surfaces while suggesting that judgment accuracy reflects states of the perceiver/actor as much as the actual slant of the surface. In general, studies have focused on the relative

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accuracy of slant perception or the lack thereof. Durgin, Li, and Hajnal (2010) conducted a study investigating the tendency to overestimate the slant of small-scale surfaces in near visual space. They had participants judge geographical slants by verbal estimation and a free-hand matching task. They found that there was a bias in the estimation of geographical slant: participants showed a tendency to perceive slanted surfaces to be steeper than they actually were. Durgin et al. also used a two alternative forced choice paradigm and a psychometric staircase procedure to calculate the point of bisection (i.e., the equidistant point between vertical and horizontal) perceived by their participants. On each trial, participants would be shown a single slanted surface and would indicate whether the slant was closer to vertical or horizontal. On average, the equidistant point between horizontal and vertical was 34°. The current investigation is focused on determining whether or not there is constancy of slant judgments across different viewing perspectives rather than whether those slant judgments are accurate. Smaller scale surfaces have fewer different optical slant values that are almost equivalent to each other. Optical slant can be manipulated easily using smaller surfaces by changing viewing perspective. Thus, optical slant can be compared to geographical slant at each viewing perspective. The current study uses small-scale surfaces in near space for this reason.

The response measure that has been used most frequently in studies of geographical slant perception is the palm board (Coleman & Durgin, 2014). The palm board is typically placed at waist level, and is out of the participants' sight. Participants place their hand on it to adjust the board to be parallel to the angle of the target surface they are observing. Gibson (1950) began using a palm board to provide participants with a non-verbal method to estimate slant. Proffitt et al. (1995) found that participants tended to overestimate geographical slant when making verbal estimates or adjusting an angle on a disk to match the cross-section of the inclination of the hill, but when using the palm board, they were more accurate. Witt and Proffitt (2007) conducted a study directly comparing slant judgments of large scale hills using three response measures: a palm board, a relative visual matching task, and an absolute visual matching task. They found that judgments made with the palm board were significantly more accurate than the other tasks and were not significantly different from the actual slope of the hill. Witt and Proffitt concluded that judgments made with the palm board were accurate because the measure did not require explicit perceptual awareness but instead relied on visuomotor control, which they posit to be separate processes. Durgin, Hajnal, Li, Tonge, and Stigliani (2010) conducted several experiments investigating the accuracy and reliability of palm boards. They found that judgments of slants in near space made with palm boards were consistently underestimated compared to a free-hand measure. Coleman and Durgin (2014) found that there is a systematic bias for haptic perception of surface orientation. Participants would underestimate the slant angles when the palm board was set at a lower height (aligned with the participant's navel) and overestimate slant angles when the palm board was higher (at eye level).

The primary purpose of the current study was to investigate whether perceived slant remains invariant under changes in viewing perspective. In Experiment 1, the surfaces were presented at either 0° tilt or 40° tilt. Geographical tilt is defined here as the amount of rotation around a vertical axis through the surface. For a slanted surface presented at 0° tilt, the surface would be slanted directly away from the observer. If that surface was presented at 90° tilt, the observer would see the slanted surface edge on. The optical slant for this surface would be very different in both cases, while the geographical slant would remain the same. Geographical slant is unaffected by changes in tilt while optical slant varies. Fig. 1 shows optical slant values plotted against geographical slant values. The solid thin line represents the relationship between optical and geographical slant when the target surface was at eye level and 0° tilt. In this case, optical and geographical slant are equivalent. The dashed thin line corresponds to the condition in which the target surface was presented at eye level at 40° tilt. In this case,

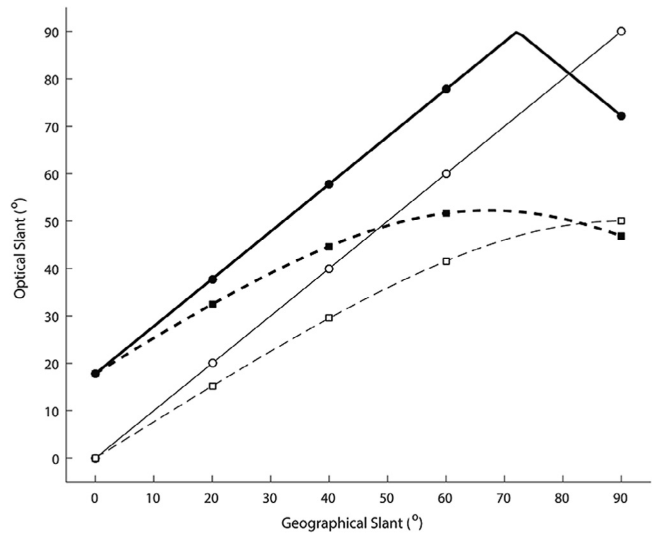

Fig. 1. Transformed optical slant values are plotted against corresponding geographical slant values for each condition. Optical slant values were linearly transformed so that 0° and 90° optical slant would correspond to 0° and 90° geographical slant. Optical slants were computed continuously for corresponding geographical slants from 0° to 90° presented at and below eye level at 0° and 40° tilt. Points on the functions correspond to geographical slant values presented to participants in the study. The solid lines and circles indicate surfaces presented at tilt 0° and the dashed lines and squares indicate those presented at tilt 40°. The thin lines and open shapes indicate surfaces presented at eye level (Experiment 1) and the thick lines and closed shapes indicate surfaces presented below eye level (Experiment 2).

optical slant varies with the same geographical slant values. In Experiment 2, the surfaces were presented at 0° and 40° tilt again, but at a lower eye height to amplify the difference between geographical and optical slant. The solid thick line corresponds to target surfaces presented at 0° tilt below eye level and the dashed thick line corresponds to target surfaces presented at 40° tilt below eye level. Again, optical slant varies. For the same unchanging set of geographical slants, optical slant changes dramatically across the different viewing conditions (for 5 geographical slants there are 18 different optical slants). If participants perceive optical slant, then their judgments of geographical slant should reflect these differences.

Given the controversial nature of the palm board, we used two visually guided response measures: an adjustable 3D surface that participants controlled and matched to the perceived geographical slant and a 2D line viewed on a computer screen and adjusted to match the perceived geographical slant. The participant sat between the response measure and target surface so they could not be viewed simultaneously. Durgin and Li (2011) found a bias to overestimate the slant of 2D lines, which would prove problematic for using a line task as a dependent measure. A secondary purpose of Experiment 1 was to determine whether adjusting a 2D line would yield the same results as adjusting a 3D surface.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Ten adults ranging in age from 20 to 30 (two males) participated in this experiment. All participants had normal or corrected-to-normal vision and passed a stereo fly test (Stereo Optical Co., Inc.) measuring stereo acuity. Participants were required to identify a target circle with a disparity of 80 s of arc in order to participate in the study. All participants gave written informed consent prior to taking part in the study. Research was conducted in accordance with the Code of Ethics of the