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Perceiving "Walk-on-able" Slopes

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Prospective control of walking and running requires perceiving sloping surfaces that can and cannot support these activities. Two experiments on slant perception were conducted, motivated by the notion of geographical slant rather than optical slant, and by an affordance based description of surface layout. In Experiment 1, participants standing on a horizontal surface (the ground) adjusted the inclination in the frontal plane of a large wooden platform at 0, 2, or 4 m from them until satisfied that it was at the maximal slope at which ordinary walking could be conducted. Subsequent to their judgments, the actual maximum of a "walk-on-able" slope was determined for each participant. In Experiment 2, participants adjusted the inclination of the visible platform to match the inclination of the right foot, which was occluded and resting against a small ramp inclined between 0° and 50° to the ground plane. They then judged the visible platform for its walk-on-ability and were subsequently tested for the maximal slope that each could in fact walk on in the ordinary manner. In both experiments, perception of the maximal slope that is walk-on-able conformed closely to the actual slope maximum permitting ordinary walking. The discussion of the results addresses limitations of previous slant perception research and underscores the importance of action-relevant measures to investigations of the perception of surface layout.

For a person, a horizontal, flat, extended, rigid surface affords support for standing, walking, and running. A vertical flat, extended, and rigid surface does not; it is a barrier to locomotion. Slopes between vertical and horizontal afford ordinary walking and running if they are not too steep. If they are too steep, then they afford a different style of locomoting, namely climbing, but then only if the surface is no longer strictly flat. It must have irregularities to be grasped

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and stood on. The significance of describing surface layout in terms relevant to locomotion was underscored by J. J. Gibson (1979/1986) and elaborated through the concept of affordances. An affordance description is crucial to the understanding of direct perception. As J. J. Gibson (1979/1986, p. 260) remarked:

> The direct perception of a distance is in terms of whether one can jump it. The direct perception of a mass is whether one can lift it. Indirect knowledge of the metric dimensions of the world is a far extreme from direct perception of the affordance dimensions of the environment. Nevertheless, they are both cut from the same cloth.

The focus of this article is the perception of slopes that can support ordinary walking. The investigation of surface slant perception has had a varied history, largely dominated by experimental procedures in which the behavioral consequences of a surface being sloped this way or that, with this degree of incline or that, have not been at issue. Traditionally, the focus has been on the constraining of metrical judgments of slant by particular, putatively pertinent, variables of visible surface layout under restrained viewing conditions. Roughly, the question has been: How much is that (display) sloped? The research reported here seeks to ground the study of slant perception in action-relevant measures. Roughly, the question posed is: Could you walk on that surface? To set the stage for this latter question, we overview briefly the conceptual basis, methods, and outcomes of prior research on slant perception.

STUDIES ON OPTICAL SLANT

In an early publication on the perception of surface layout, J. J. Gibson (1950) identified slant as a major phenomenal property. He defined slant in optical terms, as a surface's angular inclination to the line of regard, and hypothesized that the gradient of a surface's texture elements was the basis for slant perception. According to the texture gradient hypothesis, the density of surface elements (a function of their dispersion and their compression) was specific to distance, and the direction of the gradient was specific to the direction in which the surface sloped toward or away from the observer. In consequence, surface texture, surface orientation, and the manner of displaying a surface became the primary variables in studies designed to reveal the basis of slant perception.

A customary feature of research on slant perception has been the effort to eliminate indices of the direction and length of the perpendicular from the point of observation (the origin of the line of regard) that extends to the ground plane (Beck & Gibson, 1955; Braunstein, 1976; Epstein & Park, 1964; Flock, 1964, 1965; Freeman, 1965; J. J. Gibson, 1950; Gibson & Cornsweet, 1952; Perrone, 1980, 1982). The usual method has people view surfaces through the aperture in a reduction screen. Texture patterns presented on a rear projection screen, rather than real inclined surfaces, have tended to serve as the stimuli. Invariably, such studies have revealed that the reported apparent slant is not proportional to the geometrically predicted degree of surface inclination. Participants systematically underestimate the magnitudes of surface slant that stand in simple projective correspondence to the presented texture gradients (Flock, 1964).

The need to account for the systematic underestimation of slants led to much theorizing by those working within the paradigm (e.g., Flock's, 1964, "optical theta" hypothesis; Freeman's, 1965, "perspective theory"; Braunstein's, 1976, "perspective ratio" hypothesis). Generally, underestimation of slant has been attributed to the tendency of judgments to conform to the slant of the reduction screen or to the texture of the back projection screen (Epstein & Park, 1964). The focus of these studies of slant perception became underestimation and the "frontal tendency hypothesis" rather than the perception of surface layout. It is important to note that all such theories are intended to account for putative perceptual deficiencies that arise when slant judgments are made solely on the basis of two-dimensional displays viewed monocularly to eliminate "extraneous cues" such as linear perspective. Generally speaking, these theories have not been successful.

Three general criticisms may be levied at the research on optic slant perception. One criticism is directed at the window methodology, one is directed at the specifying capability of texture gradients, and one is directed at the notion that the slant of a surface away from the perpendicular to the line of sight is a variable of which the environment is composed. All three criticisms were made by J. J. Gibson (e.g., 1970/1982, 1979/1986), but others have been of similar voice. To begin with, displaying a texture inside an aperture or window does not delimit the impression of slant. Perceiving the occluded edge of the window dictates that one's impression will be that the surface is slanted in relation to the surface with the window (J. J. Gibson, 1979/1986). As Perrone (1980, 1982) argued, the occluding edge is informative about the perpendicular from the line of regard to the textured stimulus; it provides the basis for a ground plane judgment where none is wanted and implicates a surface layout that differs from that intended by the experimenter. Perrone (1980, 1982) provided a projective-trigonometric model that accounted for the reported systematic underestimation of slant on the basis of the magnitude of the discrepancy between the surface angle suggested by the texture gradient and that suggested by the window's occluding edge.

The second criticism is aimed at the notion of texture gradients. Regardless of the limitations of the reduction screen/window methodology, is the texture gradient up to the task of being unique and specific to optical slant? Many simple demonstrations suggested that it is not (Marr, 1982; Stevens, 1979). Possible measurements on an arrangement of texture elements include their sizes, their separations, their density, and their density gradient. The preceding variables can be so configured (in a picture) as to support an impression of optical slant. If size, separation, and density are removed as variables, however, leaving only the density gradient, then an impression of optical slant is absent (Marr, 1982; Stevens, 1979). Marr (1982) suggested that optical slant is not measured directly, but rather an estimate of relative depth is made from the sizes of the texture elements, and possibly brightness changes, and slant is then inferred from these prior measures. The latter would be an unwelcome conclusion from J. J. Gibson's (1979/1986) view, if it were taken to be the solution to an apparently fundamental aspect of perceiving surface layout.

The third criticism suggests, however, that the nature of the problem of slant perception leading to Marr's (1982) conclusion is ill-conceived. Optical slant is not a variable of which the environment is composed and optical slant perception is not an elemental impression from which other surface-layout impressions are compounded (J. J. Gibson, 1970/1982, 1979/1986). This latter criticism leads to the revision of the notion of slant that is the starting point for the present research.

GEOGRAPHICAL OR GRAVITATIONAL SLANT AND THE AFFORDANCE PERSPECTIVE

Early in the study of slant perception, J. J. Gibson appreciated the contribution of the observer's awareness of his or her orientation relative to the ground plane. He contrasted optical slant, the kind addressed in the experiments reviewed earlier, with gravitational or geographical slant (J. J. Gibson, 1979/1986, Gibson & Cornsweet, 1952). Whereas the optical slant of the displays in the slant perception experiments reviewed earlier is defined (and measured) relative to the frontal plane perpendicular to the line of sight (J. J. Gibson, 1979/1986, p. 166), geographical slant is defined relative to the surface of the earth. (For more general considerations, optical slant is taken to be the angle between the line of regard and the environmental surface at the point of intersection of the two; consequently, the optical slant of a given plane in the environment will vary as a function of line of regard; Kaushall, 1976.) Unlike optical slant, geographical slant has immediate relevance for action.

As remarked, J. J. Gibson came to emphasize the analysis of environmental surface layout in terms of those properties that, in the right combination relative to a particular animal, afford support for some activity. To elaborate on the earlier example, four properties must co-occur at the scale commensurate with a person's particular biomechanical constraints if the surfaces of the local environment are to afford upright posture and locomotion, namely: (a) nearly flat, rather than convex or concave; (b) sufficiently extended, relative to the size of the person; (c) rigid, relative to the weight of the person; (d) nearly horizontal. J. J. Gibson termed such a set of environmental properties taken with reference to a particular animal an affordance of the local environment (J. J. Gibson, 1979/1986). Accordingly, we chose to study geographical slant qua an affordance for locomotion—rather than the appearance of optical slant under the conditions of reduced vision—as more revealing of the basis for the perception of surface inclination.

Unlike past studies of optical slant that require participants to make an absolute judgment as to the degree of surface slant, the present study requires participants to make a judgment as to the potential for a functional interaction—the surface's affordance. This is accomplished by the systematic manipulation of property (d) while the other three are held constant. Specifically, our study is intended to assess how accurately people can perceive the maximal departure from the horizontal ground plane—the maximum geographical slant—that is scaleable by comfortable walking while maintaining normal upright posture. By this we mean to restrict participants to walking at the rate they could most easily maintain on level ground, measurable as their preferred steady-state stride frequency. Additionally, compensatory changes in the configuration of their limbs (e.g., walking on their toes to shift the center of gravity forward) are excluded. If perception for the control of action is based on perceiving affordances, then participants' perceptual judgments regarding slant scaleability should correspond closely to the actual dynamics of their performance.

EXPERIMENT 1

Can a person perceive the maximum slope of a surface negotiable by normal walking? A number of experiments suggest that surfaces are perceived in terms of the activities they will support, for example, the "climb-ability" of stairs (Mark, 1987; Mark & Vogele, 1988; Warren, 1984), the "pass-through-ability" of apertures (Warren & Whang, 1987), and the "sit-on-ability" of raised surfaces (Mark, 1987; Mark & Vogele, 1988). Of special relevance to present concerns is research demonstrating that very young children (mean age 14 months) perceive a walkway as supporting different actions as a function of the degree and direction of its slope. The slopes the toddlers tried to walk up were steeper than the slopes that they tried to walk down; and whereas they hesitated and haptically explored prefatory to locomoting on downward slopes, they did neither prefatory to locomoting on upward slopes (Adolph, Gibson, & Eppler, 1990).

Importantly, the aforementioned studies reveal that perception of the compatibility of the local surface layout with some intended activity is scaled to the constraints on performance imposed by the biomechanics of the relevant effector ensemble. For example, Warren's (1984) investigation of stair climbing demonstrated that the ratio of lower leg length to riser height with a value of .89 demarcated the boundary between those stairs perceived as climbable and those perceived as unclimbable—a value that agreed with the ratio of .88 predicted by a biomechanical model of the task. A reasonable inference, therefore, from these experimental investigations of affordance perception is that a person should be able to perceive the maximum "walk-on-able" slope.

Method

Participants. Six undergraduates participated in partial fulfillment of requirements for an introductory psychology course.

Apparatus. The apparatus is shown in Figure 1. It consisted of a plywood platform 4.3 m long and 1.23 m wide, raised approximately 5.8 cm above the laboratory floor. This platform was connected on its underside by hinges to a plywood ramp that measured 2.46 m × 1.23 m such that in combination a continuous surface of support 6.76 m in length was provided. The angle of inclination of the hinged ramp could be adjusted by means of a rope and pulley arrangement to any value in the range of 0° to 87° by one of the experimenters. The experimenter adjusting the inclination of the ramp was concealed from the student's view by a 2.46 m tall gray metal cabinet that served as a partition. The platform and ramp were surrounded by floor-to-ceiling curtains of uniform texture and color providing a homogeneously bounded viewing corridor. The ramp was used exclusively for viewing and was not designed to support a participant's weight. Participants did not attempt to scale this adjustable ramp.

A second ramp measuring 2.15 m × 1.23 m was constructed of building studs and 1.36 cm flooring plywood. This ramp was manually supported and designed to bear a participant's weight. This ramp was used to obtain measures of each

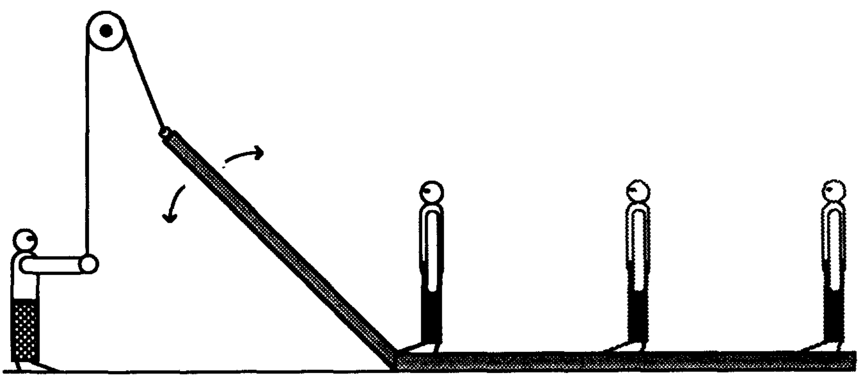

FIGURE 1 Apparatus in Experiment 1.

participant's maximum climbable ramp angle of inclination. The color and texture of the surface of this second ramp was virtually identical to that of the hinged ramp as both were constructed from carefully matched plywood sheets.

Design. There were three points of observation: 0, 2, and 4 m from the base of the ramp. The initial ramp slant was either 0° or 60°. Each student made three judgments from each point of observation for both initial ramp slant values for a total of 18 trials. Trials were fully randomized.

Procedure. On each trial, the participant's task was to indicate when the ramp was at the limit of being walk-on-able. The participant was instructed that designating a surface walk-on-able meant that one could walk up the ramp comfortably, at an ordinary pace, while maintaining upright posture and making full "flat-footed" contact (from the plantar complex to the posterior of the heel) as normally occurs when walking on level ground. Additionally, the participant was instructed that "going up on the toes," a compensatory maneuver that would keep the participant's center of gravity over his or her base of support on an incline, was not allowed. In accord with the method of adjustment, the slant was initially presented at either 0° or 60° to the participant. The latter value was selected as it exceeds the steepest walk-on-able slant while meeting the criteria of the experimental task by more than 20°. The participant then instructed the experimenter to raise or lower the ramp until satisfied that it was at the slant corresponding to the maximum walk-on-able value. The participant was free to vary the ramp slant as much as needed and could take as much time as needed to arrive at his or her decision. A trial typically took several minutes (more than one, and less than four). Following the conclusion of a trial, the ramp was occluded with the curtain (in order to permit the unseen adjustment to the new initial slant), and the participant was instructed to move to another point of observation, if the next trial required it.

On completion of the 18 trials, the participant's actual maximal walk-on-able slant was measured for the conditions of each point of observation. This measurement procedure involved three stages. First, the participant was seated and requested to dorsi-flex the right foot to its maximum. This value was used to provide a preliminary slant for the weight-bearing ramp. Second, from the 4 m point of observation, the participant was instructed to walk at a self-selected comfortable pace ("one you could sustain for long periods if you had to"). This walking speed was measured on five separate occasions and a mean value determined. Third, the ramp was set at an angle determined by the previously determined maximum of dorsal flexion and, from a given observation point, say 4 m, the participant walked to the ramp at the established speed. (The participant was timed; if he or she deviated from the previously established mean pace, the measurement trial was repeated. This timing was conducted, obviously, for only the 2 m and 4 m approaches.) The participant proceeded to walk up the ramp for a maximum of three steps. The manner in which he or she did so was carefully monitored. On each side of the ramp was an experimenter who looked to see whether or not the participant was forced to go up on the toes to maintain upright posture. If he or she did not, then the ramp was raised and the trial repeated. As a rule, the slant equal to maximum stationary dorsal flexion was always climbable, so ramp raising from that value was always the case. Stage three was repeated five times for each point of observation.

Results and Discussion

For each participant, the mean perceived maximum walk-on-able slant was calculated (from the data of the six trials) for each observation position. An analysis of variance (ANOVA) revealed that the distance of the place of observation was not significant, $F < 1$: at 0 m, perceived maximum slant equaled 26.8 cm at 0 m, 26.7 cm at 2 m, and 27.1 cm at 4 m. The 18 data points for the six participants are presented in Figure 2, regressed linearly against the six actual maxima; the data averaged over observation distance for each participant are presented with actual maximum slope in Table 1. For all participants, the 18 judgments were close and consistent. All responses fell within a 12° range, and the standard deviations never exceeded 3.55°. The mean perceived maximum ramp angle and the actual maximum ramp angle never differed by more than 5.11° (Participant 4) and the difference was as small as .61° (Participant 1). The conclusion to be drawn is that the maximum surface slant permitting ascent by ordinary locomotion is perceptible to a degree of accuracy appropriate for successful action.

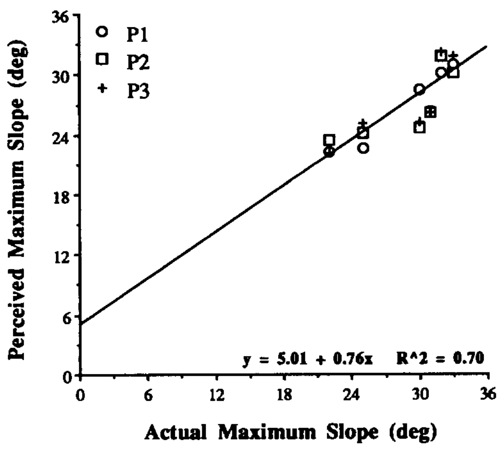

FIGURE 2 Mean judgments of the maximum slope of a ramp that could be scaled, as a function of the empirically determined maximum, in Experiment 1.

TABLE 1
Perceived and Actual Maximum Slope for Each Participant in Experiment 1 (in Degrees)

Participant	*Perceived*	*Actual*
1	31.4 ± 1.9	32
2	31.0 ± 3.6	33
3	26.2 ± 3.3	30
4	25.9 ± 2.9	31
5	23.8 ± 2.5	25
6	22.7 ± 2.0	22

EXPERIMENT 2

There has been a great deal of research aimed at comparing judgments of stimuli by vision and by touch (e.g., Jones, 1983). For example, investigations have been directed at determining the correspondence between judgments across modalities of absolute magnitudes of some stimulus object property, such as linear extent or angle of separation. The emphases in these experiments has tended to be on (a) how the modalities differ with respect to a given perception and (b) the issue of how the "sense data" made available by the different modalities are integrated. In Experiment 2, haptic and visual contacts with slanted surfaces are compared. The concern, however, is not with the differences or integrability of the data of the two senses, but with the mutual subservience of the haptic and visual perceptual systems to the detecting of information specific to action-relevant properties.

Investigations of intersensory equivalence or integration have rarely been directed at judgments about stimulus properties with implications for action in the context of the experiment. In Experiment 2, the participant was asked to indicate when an adjustable visible ramp was parallel to a small enclosed (occluded) ramp upon which his or her foot rested. This experimental task assessed the ability to match the inclination of a distal surface perceived visually with the inclination of a surface underfoot that is perceived haptically and that is part of the current surface layout supporting upright standing. By juxtaposing what is seen with what is felt, the present experiment mimics a most prominent feature of ordinary perceiving in the service of action. Perceiving the affordance of a given surface for the prospective control of action always takes place in the context of an ongoing act that is supported by the realized affordances of other surfaces. Thus, perceiving whether a given sloped surface is walk-on-able is an activity that most usually occurs in the context of standing on a surface that is sloped to this or that degree and in this or that direction. The observer ordinarily perceives what transformations of posture a surface will permit from the perspective of a current posture or postural transformation made possible by the available surface layout. The present experiment may be viewed as providing a line of inquiry convergent with that initiated by Mark, Balliett, Craver, Douglas, and Fox (1990), which underscored the critical role played by the observer's exploratory activities in the successful perception of affordances (see E. J. Gibson, 1988; E. J. Gibson et al., 1987). Where subtle postural transformations are prohibited, with a consequent restriction on subtle variations in type and degree of exploratory maneuvers, affordance perception suffers and even fails.

A further question posed to a participant in Experiment 2 was whether he or she could walk up a ramp set at the angle they selected in the first task while maintaining upright posture. The second question is intended to reveal ability to perceive whether or not a given visible slant will support upright locomotion when a perceptually parallel geographical slant is available. Specifically, the second task in Experiment 2 assesses the accuracy of judgments of the walk-on-ability of a visible ramp previously judged to be parallel with the supporting surface of the visually occluded foot ramp. This was done to demonstrate that participants could in fact judge accurately whether or not the performatory context provided by the perceptually parallel geographical and visual slants met the requirements for upright locomotion.

Method

Participants. Three undergraduate students, two graduate students, and one member of the faculty at the University of Connecticut served as participants.

Apparatus. The apparatus of Experiment 1 was used together with a small enclosed ramp onto which the right foot could be placed at a particular inclination to the ground (see Figure 3). The foot ramp was enclosed in a box

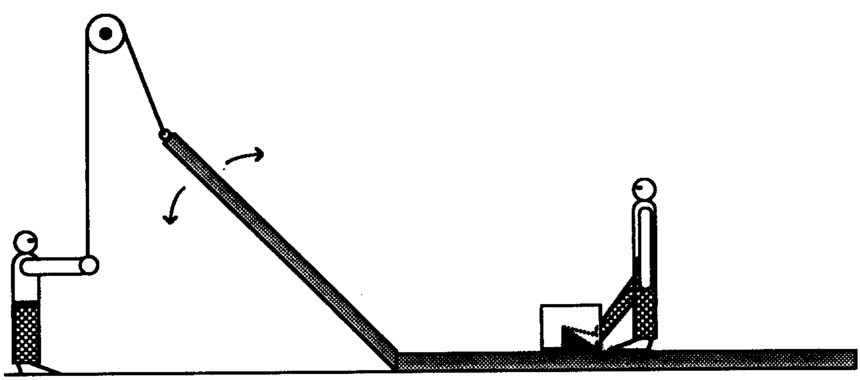

FIGURE 3 Apparatus in Experiment 2.

consisting of two side walls, a back wall, and a top wall. The opening at the front permitted insertion of the foot. Foot placement was such that the weight of the body was on the back (left) foot. The top and side walls prevented the participant from seeing the foot's angle of inclination to the ground plane.

Design. There was one point of observation at 4 m from the base of the ramp. The occluded foot ramp assumed slants of 10° to 40° in 5° increments and an additional, outlying value of 50° to yield a total of eight angles. The latter inclination was in considerable excess of slants adjudged and determined to be walk-on-able in Experiment 1. The visible ramp was inclined at either 0° or 60°. These constituted the initial surface slopes, with increases or decreases, respectively, under the participant's control. Each participant made five judgments for each of the eight slants of the occluded foot ramp for both initial slant values of the visible ramp for a total of 80 trials. Conditions were fully randomized.

Procedure. At the beginning of each trial, the foot ramp was set at a specified angle and the participant placed his or her foot into the box containing the foot ramp. Following the placement of the foot, the curtain was opened and the large ramp at a given initial inclination (0° or 60°) was revealed. The first task on a given trial (as defined by a particular value of foot inclination in combination with an initial slant value of the visible ramp) was to match the visible ramp inclination with the foot inclination. The participant did this by instructing the experimenter to lower or raise the visible ramp until its slant matched the inclination of the foot. The participant was allowed as much variation and time as needed to reach and fine tune his or her decision. The second task was to judge whether or not the visible surface at this inclination matching the foot inclination was in fact walk-on-able under the restrictions identified in Experiment 1. On the average, each trial lasted 1 to 2 min. The experiment took approximately $1\frac{1}{2}$ hr to complete.

In a separate session, the actual maximum of walk-on-able slopes was determined for each participant in the same manner as identified in Experiment 1.

Results and Discussion

How well could a participant match the inclination of the visible surface to the inclination of the foot? The challenge in designing the experiment was to constrain participants to make their judgments of a visible surface slant with reference to the performatory context determined by the geographical slant. The latter has specific implications for the locomotory work to be done. In other words, the emphasis was on the perception of the action-relevant property of the surface inclination of a potential locomotor path. Table 2 reports the mean of the visible slopes set by each participant to match the felt inclination of the occluded right foot, together with the corresponding r^2 of the linear regression.

TABLE 2
Mean of the Visible Slope (in Degrees) as a Function of Inclination (in Degrees) of Occluded Right Foot for Each Participant in Experiment 2 Together with the r^2 of the Linear Regression

	Participant					
Inclination	*1*	*2*	*3*	*4*	*5*	*6*
10	10.5	10.5	10.5	17.3	11.8	19.8
15	19.3	13.3	14.0	19.3	13.5	23.3
20	31.0	23.0	20.8	25.3	17.8	31.8
25	30.8	25.3	27.8	29.3	17.3	35.0
30	35.3	33.3	30.5	32.3	25.0	40.8
35	41.8	36.8	38.5	37.3	30.3	39.5
40	47.8	39.3	39.0	39.5	31.3	43.5
50	49.8	45.5	42.8	43.5	40.5	43.8
r^2	0.93	0.97	0.95	0.98	0.97	0.86

As can be seen, the visible ramp was so adjusted as to provide a close match to the felt angle of the foot; for all six participants, the obtained r^2 was significant beyond the .01 level. Figure 4 presents the linear regression of the average inclination of the visible ramp against the angle of foot inclination. Apparently, participants were able to perceive the inclination of the visible ramp sufficiently well to know when it was not at the inclination of the foot and to be able to adjust it until it was.

How well did a participant judge the walk-on-able nature of a given visible ramp inclination set to match the given angle of the foot? He or she produced a matching slope of the visible ramp 10 times for each foot inclination and on each occasion judged whether on not the given slope could be walked up in the

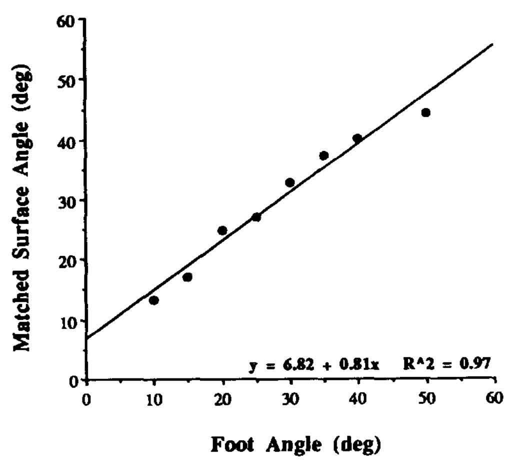

FIGURE 4 The linear regression of the average inclination of the visible ramp against the actual angle of inclination of the occluded (right) foot.

ordinary manner. The correctness of a participant's judgments could be determined by comparing each of them to the actual maximum walk-on-able slope for that person. It was possible, therefore, to express the 10 judgments by each participant at each foot inclination as a "per cent correct" measure. Figure 5 plots the relation of this measure to angle of foot inclination for each of the six participants. Inspection of Figure 5 reveals that judgments of walk-on-ability were least accurate for the slope adjusted to fit the foot angle closest to that

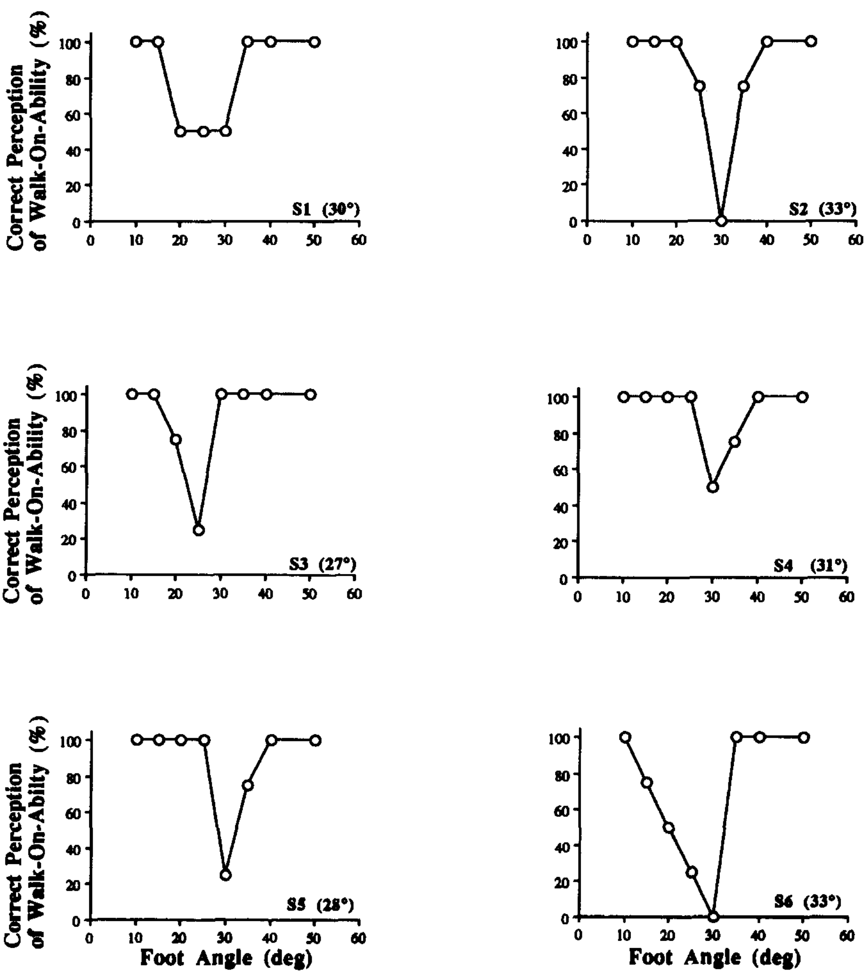

FIGURE 5 A "per cent correct" measure of walk-on-able judgments for the visible slopes as a function of the actual angle of inclination of the occluded (right) foot, for each of the six participanrs in Experiment 2. The number in parentheses in each panel is the actual maximum walk-on-able angle, as measured for each participant.

corresponding to the actual maximum slope inclination. Judgments of the visible slopes adjusted to fit an inclination of the foot less than or greater than the actual maximum were perceived, respectively, as "walk-on-able" and "not walk-on-able" with a high level of accuracy. In evaluating this result it is important to underline that the right foot's posture was not dictated by the demands of preserving upright stance. The forward right foot rested on the foot ramp, with the weight borne by the left foot in the rear. For different foot slopes, the position of the body's center of mass relative to the placement of the feet was the same. That is, an inclination of the foot ramp that exceeded the slope of walk-on-able surfaces was not accompanied by any especially severe difficulties in standing. In short, the participant was not judging the visible surface simply according to the degree of difficulty that he or she had in standing at the place of observation.

GENERAL DISCUSSION

The results of the two experiments reported in the present article indicate that a person's perception of a sloping surface is systematically constrained by the actual dynamics of walking up inclines. In both experiments, a person's perception was consistent with the biomechanical constraints on the activity to be conducted. In our general discussion we comment on the range of conceptual issues that need addressing for a thorough account of slope perception in the service of activity.

Most research on the perception of slant has been constrained by the interpretation of slant as the orientation of a surface relative to the frontal plane perpendicular to the line of sight, as determined by the viewing conditions imposed on the observer. That is, the kind of slant studied has been a restricted version of optical slant. It has not been geographical slant, where the focus is on a surface's inclination relative to the surface of the earth. Whereas optical slant implies absolute measures, geographical slant implies relative measures (J. J. Gibson, 1979/1986). With respect to the question of the information contained in the optic array specific to slant, the emphasis on geographical slant directs attention away from the optical consequences of a single-surface texture gradient to the optical consequences of the surrounding layout of surfaces with their full variation of convexities, concavities, and occlusions. The specification of a given surface's inclination must be sought in the field qualities of the optic array. Our interpretation, from this field perspective, is that the optical intensity distribution generated by a single surface's texture will prove to be an inappropriate optical property. Without committing to any current field formulation of the optic array (e.g., Dodwell, 1983; Koenderink, 1986; Lappin, 1990; Waxman & Ullman, 1985), a survey of the classes of field quantities advanced to date, especially as defined for the transforming array (the optical flow field), suggests that the appropriate property will be considerably richer mathematically than the notion of a gradient in one dimension.

Compounding the difficulty of identifying the informational support for geographical slant perception is the fact that the perception of geographical slant is frequently with respect to the locomotion possibilities that sloped surfaces do or do not afford. By definition, the affordance concept demands that optical analyses reveal the availability of information about the observer-as-actor concurrent with information about the surface layout, such that the propriospecific information contextualizes (e.g., sets the scale for) the exterospecific information. First attempts to satisfy this requirement focused on linear dimensions of the body such as leg length and eye height. A seminal paper by Lee (1974) identified that the velocity vectors of the optical flow field were expressible in units of the linear dimension defined by the height of the point of observation above the ground. Lee's (1974) mathematical analysis showed how this observer-specific scaling of the optical structure engendered by locomotion across the ground plane would contain observer-specific information about the heights of barriers and about the necessary timings of propulsions to effect successful leaps. The opening round of experimental analyses identified that perceptions of the affordances of climbable surfaces and walk-through-able apertures were open to rationalization in terms of critical values of leg length and shoulder width (Warren, 1984; Warren & Wang, 1987). In principle, these body dimensions are implicated in the optic array (both stationary and flowing), and coordinate with eye height, but the requisite mathematical analyses to prove these points to satisfaction remain to be done.

A second round of experimental investigation is now under way, and it is pressing the need for expanding the actor-anchored properties (that unify the surface layout properties comprising a given affordance) beyond linear anatomical dimensions.

Thus, Adolph et al. (1990) highlighted the locomotory coordination patterns executable by a neophyte walker, and Konczak, Meeuswen, and Cress (1992) demonstrated that the perception of climbable stairs is distinguished across age levels (approximately, 23 years vs. 71 years) in a manner comporting with joint flexibility and muscular strength as the scaling dimensions. Functional, dynamical aspects of the observer are naturally implicated in the theory of affordances (J. J. Gibson, 1979/1986; Turvey, Shaw, Reed, & Mace, 1981). It is plainly apparent, however, that appropriate characterizations of them (e.g., in terms of qualitative nonlinear dynamics applied in the style of Saltzman [1986; Saltzman & Kelso, 1987; Saltzman & Munhall, 1989]), and elaborating the mathematics of optical flow to incorporate them, pose formidable challenges.

By way of summary, we take our results to suggest that there is more to be learned from the study of geographical slant, where changes in the presented surfaces have real behavioral consequences, than from the study of optical slant. The long-accepted paradigms for the study of optical slant seem burdened with too many artificial constraints and with a contaminating element that provides information in conflict with the intended surface layout. The study of geographical slant avoids these pitfalls and holds out the promise of clean performance measures of perception informed by affordances. We take this methodological change to be a necessary first step toward uncovering the information that supports the direct perception of sloping surfaces.

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