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Perception of visual inclination in a real and simulated urban environment

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Abstract. The perceived inclination of slopes is generally overestimated. We claim that overestimation depends on the use of impoverished stimuli and on the distance between the observer and an inclined surface. In experiment 1, participants reported the perceived inclination of a set of urban roads from two different viewing distances. Observers did not overestimate the perceived inclination of slopes when they saw roads from the shorter viewing distances, whereas they slightly overestimated the perceived inclination of slopes from the farther distance. In experiment 2, participants reported the perceived inclination of a set of stereoscopic slides representing the same urban roads as in experiment 1. Here, observers did not overestimate the perceived inclination of slopes when the projected stereoscopic image contained horizontal disparity and simulated the shorter viewing distance; while they revealed a slight overestimation from the farther distance. We found always overestimation when the binocular image did not contain horizontal disparity, independently from the viewing distance. In conclusion, slopes are overestimated when (a) horizontal disparity is absent, and (b) the viewing distance is increased.

1 Introduction

The inclination overestimation effect, which is defined as the inclination of a surface appearing to lie further away from the horizontal plane than the real inclined surface (figure 1), was observed in several studies.[1] Jastrow, who reported observers' errors in reproducing angles, observed and recorded this effect for the first time in 1893.

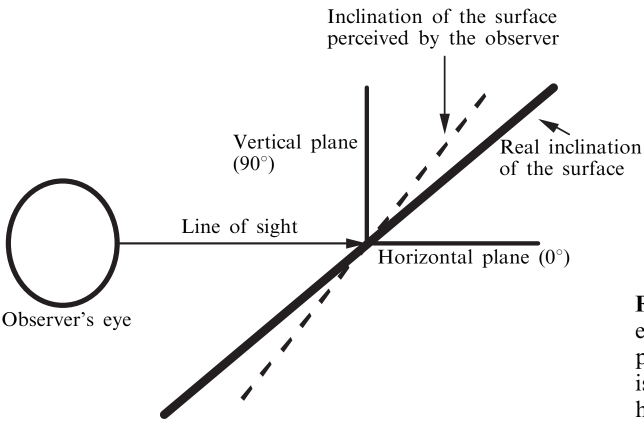

Figure 1. Visual inclination overestimation effect. Side view. The perceived inclination of the surface is overestimated compared to the horizontal plane.

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[1] Some researchers (Perrone 1980, 1982; Perrone and Wenderoth 1991) used the term visual slant underestimation instead of overestimation because their frame of reference was the vertical plane (or frontoparallel plane). In the present research, we refer to overestimation since we used the horizontal plane (or ground level) as our reference plane.

After Jastrow, the results of many other studies investigating the role of various cues to depth, showed that observers' judgment of the perceived inclination of a selected surface was generally overestimated (Braunstein 1968; Clark et al 1955, 1956; Epstein and Mountford 1963; Eriksson 1964; Flock 1964; Gibson 1950; Gibson and Cornsweet 1952; Kraft and Winnick 1967).

Many researchers suggested that cues to flatness contained in the experimental stimuli might cause the observer to overestimate the inclination of a surface (Gibson 1950; Gibson and Cornsweet 1952; Woodworth and Schlosberg 1954). Among the cues to flatness, which have been identified, is the frame surrounding the inclined surface and the visible texture on which the inclined surface is projected. Furthermore, the reduction screen through which the inclined surface is seen, although not a cue to flatness itself, can cause the surface to be perceived as flattened (Eby and Braunstein 1995; Perrone 1980, 1982; Perrone and Wenderoth 1991). One way to eliminate such artificial cues was to use real inclined surfaces as stimuli, and Gruber and Clark (1956) attempted to do so by using pieces of cardboard presented at various inclinations. Despite this, the inclination of these surfaces was still overestimated and we suppose this was a result of the lack of binocular disparity caused by the observer's monocular viewing of the stimuli.

In natural viewing, we perceive hills, roads, mountains, etc from a variety of depth cues; yet, despite this complexity, experiments are generally conducted with impoverished and artificial stimuli, such as figure outlines, random-dot patterns, and isolated textures. There are only a few studies in which the inclination of a surface has been measured in more ecological conditions, but in those studies, the slopes were also generally overestimated (Davies et al 1996; Kammann 1967; Kinsella-Shaw et al 1992; Proffitt et al 1995). The first to use real hills for studying the perceived inclination of surfaces was Kammann (1967); more recently, Proffitt et al (1995), Bhalla and Proffitt (1999), and Proffitt et al (2001) systematically measured the inclination of a set of many hills from the ground plane. They measured the inclinations of those slopes by various methods. Participants provided verbal responses, performed a visual matching task, and adjusted a palm board. The results showed that verbal and visual judgments reflected large overestimation of the actual inclinations. Haptic approach was far more accurate than the other two methods.

In the present work, we suggest that the study of the perceived inclination of objects should start from 'natural' stimuli (as Proffitt et al did), and move to the study of 'quasi-natural' stimuli which simulated 'natural' stimuli within a more controlled context. The advantage of using quasi-natural stimuli is that they do not contain cues to flatness and allow for the control and the systematic manipulation of the cues to inclination in complex scenes. Following this reasoning we conducted two experiments using both natural and quasi-natural stimuli.

2 Experiment 1. Natural stimuli

We measured the accuracy of observers in adjusting the inclination of a rotating paddle to natural inclinations; to do this, we took the observers in front of real inclined urban roads. The measure of accuracy (Ono 1993) was the mean of the point of subjective equality (PSE) compared with the point of objective equality (POE). In this experiment, we expected a good level of accuracy, since the whole range of cues to depth was present and none of the natural complexity was lost, as was the case when using artificial stimuli.

We also decided to manipulate the viewing distance, since it has been found quite recently that geographical inclination leads to overestimation with increasing viewing distances (Creem-Regehr et al 2004; Feresin and Agostini 2004). We suggest that, even with natural stimuli, layout perception is not very accurate at larger distances.

Perhaps there is a natural limit in the available information itself; indeed stereopsis becomes a useful cue since it falls off rapidly when distance between the observer and the perceived object is increased. This is why we used a small cross, at a fixed distance from the observer (4 and 6 m), as a fixation point on each inclined road. It is known that 6 m is already a distance at which stereopsis becomes inefficient as a cue to depth. Using this constraint we were certain that all the observers made their judgments while looking at exactly the same point on the inclined road.

2.1 *Method*

2.1.1 *Observers.* A group of twenty-two observers participated in this experiment. All were volunteers and unaware of the aim of the research.

2.1.2 *Stimuli.* We measured the inclination from the horizontal (0°) of three urban roads: 4°, 10°, 16°, by means of a geologist's clinometer. This experiment was conducted in daylight in an urban environment with roads, buildings, parked cars, trees, etc. Moreover, the roads were viewed binocularly by the observers. We are aware that the inclinations tested ranged from 4° to 16°, and so cover only a small portion of the range from 0° to 90°. Indeed, it was not easy to meet a road constantly inclined more than 16° from the horizontal in an urban environment (the authors can assure the reader that urban roads in Trieste are often very difficult to climb even by car!).

2.1.3 *Apparatus.* The observers reported their haptic judgments by using a rotating paddle mounted on an adjustable table (figure 2). The rotating palm paddle was connected to an electronic protractor (Emaco Angle Star Protractor System, Montréal, Québec, Canada) with an accuracy of 0.1°, and to a visual display. We carried this apparatus with us to conduct the experiment outside the laboratory.

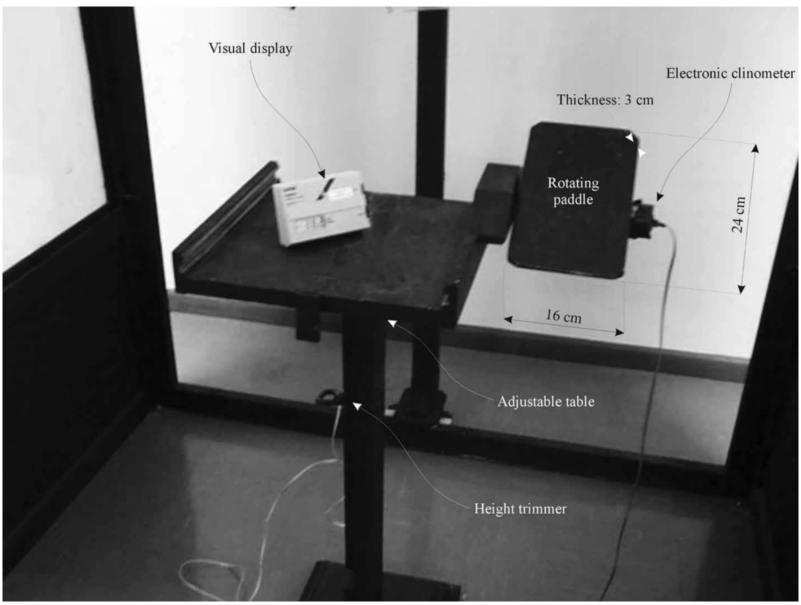

Figure 2. Rotating paddle and electronic clinometer.

2.1.4 *Procedure.* The observer was asked to stand at the base of the selected road and to fixate a small cross (40×40 cm) made from cardboard and placed at the centre of the road. The variable 'distance' had two levels: 4 m and 6 m measured from the observer's eye and the fixation point (the centre of the cross).

From each distance, the observer judged the inclinations of the selected roads (4°, 10°, 16°). 3 settings were presented in pseudo-random order, and each setting was presented 8 times, leading to a total of 24 trials for each observer for the 2 distances—a total of 48 trials.

The task performed by the observers was a 'visual-kinesthetic' task; that is the perceived kinesthetic inclination of the manual paddle was compared with a set of real inclinations (ie the set of urban roads). After every trial the experimenter recorded the observer's setting from the visual display.

The method we used is called the 'paddle method' (figure 3) and it was used for the first time by Gibson in 1950 and then by many other researchers (Bhalla and Proffitt 1999; Carrozzo and Lacquaniti 1994; Feresin et al 1998; Howard and Kaneko 1994; Ohmi 1993; Proffitt et al 1995, 2001).

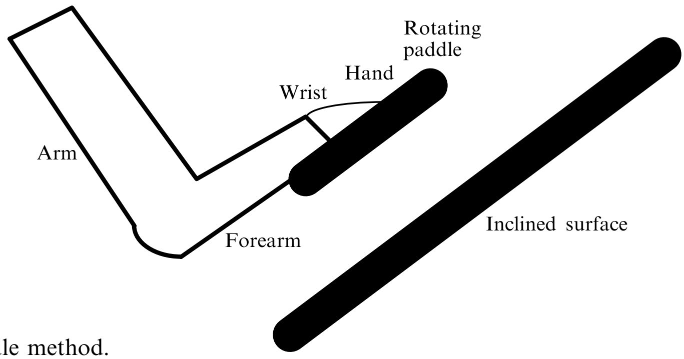

Figure 3. Paddle method.

In 1998, Feresin, Agostini, and Negrin-Saviolo tested the validity of the paddle (also called haptic or visual-kinesthetic method). In three conditions, they evaluated the hand-paddle method for indicating perceived inclination. The main result emerging from that research was that the use of the paddle method involves a wrist rotational bias due to the position of the subject's forearm while performing a kinesthetic task. The underestimation found in the first condition nearly disappeared on giving the subject a kinesthetic feedback concerning the veridical inclination of the paddle which compensated the rotational bias.

In that paper, the authors emphasised that, when subjects were asked to perform a kinesthetic task by rotating a manual paddle, they spontaneously used three anchors: the perceived 0°, 45°, and 90°. They also assumed that training the subjects to consciously use these anchors reduces data variability since it prevents the use of uncontrolled strategies. Finally, these results showed that, in a visual-kinesthetic task, an inclined line was matched correctly when subjects had previously been trained in the kinesthetic domain. This suggests that an uncontrolled use of the intersensory method could involve a motor problem and the presence of heterogeneous strategies rather than a visual misperception.

Because of these results, in the present work the paddle was set by the experimenter to the horizontal plane before each trial in order to ensure anchoring during the experiment. In this way it is possible to separate the kinesthetic outcome from the visual outcome, and be certain the method being used is a valid one.(2)

We trained the subjects to pay attention to the motor deficiency of the wrist and to use the horizontal anchor as a reference point before setting the paddle to the perceived inclination of the urban road. Furthermore, we were careful to avoid a possible muscular limitation due to the position of the forearm also in the horizontal

(2) While performing the task, all observers used the objective horizontal anchor and the 45° subjective anchor.

position of the paddle. After the subject had chosen the most comfortable position, which remained constant during all the trials, the experimenter taped the hand to the paddle. The tape did not interfere with the free movement of the wrist. This was done to prevent movements of the fingers, which could have influenced the inclination response of the wrist. The paddle was not a weight on the hand, and there was no change in any of the limb's eigenvectors (Pagano and Turvey 1995).

2.2 *Results*

A within-subjects ANOVA performed on the differences between the paddle settings (PSE) and the real inclination values (POE), revealed no significant difference among the three levels of inclination. In contrast with this, we found a statistically significant effect for the variable 'distance' ($F_{1,21} = 5.23$, $p < 0.05$).

The results are presented in figure 4. As the graph shows, the observers were very accurate and showed no overestimation of the perceived inclinations when the distance between the observer and the fixation point was 4 m, as revealed by a one-group *t* test performed on each inclination. When the distance was 6 m, we found a statistically significant effect for 4° ($t_{21} = -2.36$, $p < 0.05$), 6° ($t_{21} = -3.20$, $p < 0.005$), and close to significance for 10° surface inclination with a probability lower than 0.07.

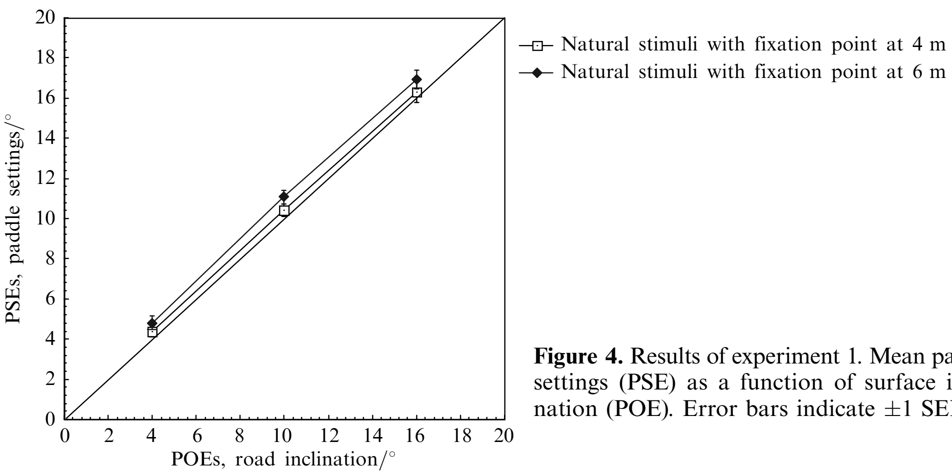

Figure 4. Results of experiment 1. Mean paddle settings (PSE) as a function of surface inclination (POE). Error bars indicate ±1 SEM.

These findings indicate that, when the whole range of cues to depth is present, observers are very accurate in their perception of slopes. However, the perceived inclination seems to depend on the distance between the observer and the fixation point, with our data showing an overestimation for the 6 m condition.

3 Experiment 2. Quasi-natural stimuli

We measured the accuracy of each observer's adjustment of the rotating paddle to different visual inclinations in two conditions. Once again, the measure of accuracy was the mean of the point of subjective equality (PSE) as compared to the point of objective equality (POE).

There were three independent variables: inclination, depth cues, and distance.

(i) There were three levels of inclination: 4°, 10°, 16°;
(ii) There were two levels of depth cues: disparity-present condition (images representing inclined roads with horizontal disparity), and disparity-absent condition (images representing inclined roads without horizontal disparity);
(iii) There were two levels of distance: 4 m and 6 m.

We expected an increase in accuracy in the disparity-present condition, because many static depth cues were present in the image. We expected a decrease in accuracy in the disparity-absent condition, since in this condition there was a lack of one essential binocular cue, disparity. Instead of adding cues to depth, as has usually been done in past experiments on depth perception, we removed horizontal disparity.

We also expected a decrease in accuracy in the 6 m condition, an overestimation of the perceived inclination as observed in our first experiment. In this case too, stereopsis becomes a usefulness cue since it falls off rapidly when the distance is increased.

3.1 *Method*

3.1.1 *Observers.* A second group of twenty-four undergraduate and graduate psychology students of the University of Trieste participated in this experiment. All were volunteers and unaware of the aim of the research.

3.1.2 *Stimuli.* We took two sets of four pairs of slides of the roads that were used as stimuli in the first experiment. The first set of slides was taken with two parallel cameras, simulating human interocular distance (6.4 cm) and showing, when projected, most depth cues, including binocular disparity. It is known that any camera has a particular field of view that is determined by the focal length of its lens and the size of the film used. The observer's natural field of view of experiment 1 matches the field of view of the camera; otherwise there is a systematic compression or expansion of the optically specified virtual space of the image. Indeed, on taking the shots, we used normal lens ($f = 1.8$, film size = 50 mm) which perfectly simulated the observer's field of view in a natural condition. It is possible to compare the retinal images of the quasi-natural stimuli with the retinal images of the real urban scenes.

The first set of slides (disparity present condition) was taken with two parallel cameras, simulating human interocular distance (6.4 cm). This means that we assumed a cyclopean eye (or visual egocentre (Howard and Templeton 1964, page 283) midway between the left and right eye (eye height 1.70 m). The two cameras were positioned to the left and to the right, respectively, of the cyclopean eye. It is known that objects on the visual axes of the two eyes, when in symmetrical convergence, are judged to be in the median plane of the head (law of cyclopean projection).

The second set of slides was taken with one camera only and therefore, when projected, was lacking the binocular disparity cue. In both conditions, the cameras were placed in the same positions as those occupied by the observer in the first experiment (ie 4 m and 6 m from the point of fixation). The point of fixation of the cameras was the same small cross that was used in the first experiment.

3.1.3 *Apparatus.* The second experiment was conducted in one of the laboratories at the Department of Psychology of the University of Trieste in which there is a full-field stereoscope. This stereoscope was arranged in the form of a cubic frame with two big screens of translucent plastic and two semisilvered mirrors hanging from the frame (figure 5).

By means of this stereoscope we were able to eliminate the problem of flattening in four ways. First, there was no visible frame of reference; second, there was no reduction screen; third, the viewing condition was binocular instead of monocular (unlike some experiments described in the literature); and, finally, the texture of the screen on which the inclined surface was projected was not visible. This is why the stimuli presented by means of this apparatus were named 'quasi-natural'.

Inside the stereoscope, the adjustable table on which the rotating paddle was mounted was the same as that used in the first experiment (figure 2). The rotating palm paddle was connected to an electronic protractor with an accuracy of 0.1° and to a visual display. To the right and the left of the stereoscope a pair of slide projectors was mounted at a distance of 150 cm. These projectors were used to project the slides onto the screens of the stereoscope. They were provided with a particular lens (Kodak Ektapro Select, 36 mm, $f = 2.8$) able to magnify a projected image even over the small distance between the projector and the screen.

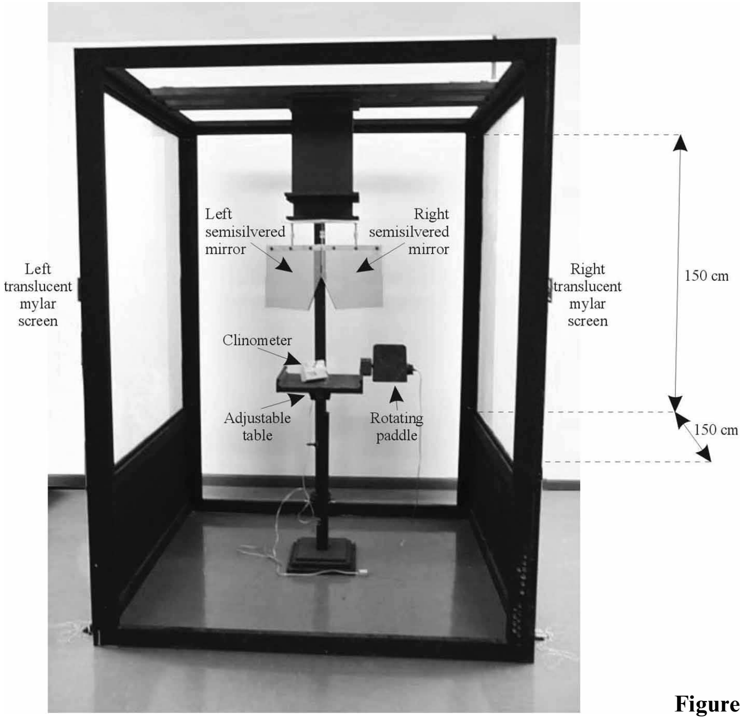

Figure 5. Full-field stereoscope.

3.1.4 *Procedure.* The observer was asked to stand at the centre of the cubic frame and then to observe the projected slides dichoptically through the semisilvered mirrors, to fixate the small binocular central cross, and to adjust the unseen rotating paddle with the palm of his/her hand until the kinesthetic perception was the same as the visual perception of the inclination of each stereoscopic image.

In order to obtain anchoring during the experiment (see Feresin et al 1998), the paddle was set by the experimenter to the horizontal plane before each trial. After each trial, the experimenter recorded the observer's setting from the visual display. The observer judged the inclinations of three stereoscopic images (4°, 10°, 16°). Each observer performed 96 trials, in pseudo-random order, consisting of the 3 settings, presented 8 times, for each of the 4 conditions.

The task performed by the observers was again a visual-kinesthetic task, in which the perceived kinesthetic inclination of the rotating manual paddle was compared with the actual set of inclinations of the roads presented (ie the set of projected slides representing the urban roads).

3.2 *Results*

The results are presented in figure 6. As the graphs show, the twenty-four observers were very accurate and showed no overestimation of the perceived inclinations in the disparity-present condition at the distance of 4 m. The observers were accurate and showed a slight overestimation of the perceived inclinations in the disparity-present condition at the distance of 6 m. They were less accurate in the disparity-absent condition, where they showed a consistent overestimation of the perceived inclination, both at the viewing distance of 4 m and at the viewing distance of 6 m.

A repeated-measures ANOVA performed on the differences between the paddle settings (PSE) and the real inclination values (POE) revealed a main effect of distance ($F_{1,23} = 55.4$, $p < 0.0001$) as well as depth cues ($F_{1,23} = 4.2$, $p < 0.05$). We found also a statistical difference for inclination ($F_{2,46} = 12$, $p < 0.0001$), and for the interaction

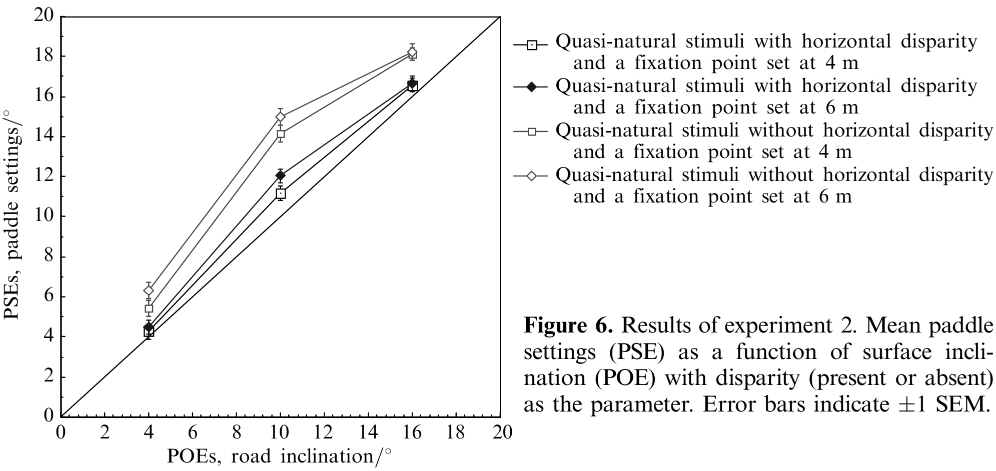

Figure 6. Results of experiment 2. Mean paddle settings (PSE) as a function of surface inclination (POE) with disparity (present or absent) as the parameter. Error bars indicate ±1 SEM.

distance × inclination ($F_{2,46} = 5.9$, $p < 0.005$). This interaction is due to a generally larger overestimation for the 10° level compared to the other 2 inclination levels. Furthermore, each PSE was compared to its corresponding POE by using a one-group *t* test. For both disparity-present and disparity-absent conditions, when the observers were at the distance of 4 m, we found a significant effect only for the 10° inclination (disparity-present: $t_{23} = -2.87$, $p < 0.01$; disparity-absent: $t_{23} = -3.7$, $p < 0.001$). When the observers were at the distance of 6 m independently from the level of the depth cues factor, all the *t* tests were significant, with a *p* value always lower than 0.001.

These findings indicate that the observers were very accurate in their perception of the slopes in the disparity-present condition, but less so in the disparity-absent condition. The observers were also less accurate when the viewing distance became greater than 4 m. Thus, when people lack an important binocular cue, such as horizontal disparity, they show an increase in overestimating the perceived inclination of a surface.

The similarity between the results obtained here in the disparity-present condition and those of experiment 1 (natural stimuli) suggests that quasi-natural stimuli retain sufficient cues to simulate natural scenes.

4 Discussion

In the first experiment observers reported the perceived inclination of a set of urban roads from two different viewing distances. The results show that observers do not overestimate the perceived inclination of slopes when they see these urban roads from 4 m, whereas they slightly overestimate the perceived inclination of slopes viewed from 6 m.

The results of experiment 1 suggest that a real slope (in our study, an inclined road) is matched correctly by observers and not overestimated. This finding can be explained by the fact that our visual system is not biologically set to restricted viewing, to unnatural PC displays, and to impoverished stimuli, but is set to a complex environment characterised by shapes, colours, movements, etc. It seems reasonable to argue, therefore, that our system probably misperceives the amount of inclination of a slope when using viewing stimuli which lack one or more cues to depth, or stimuli which are too simple, such as figure outlines, random-dot patterns, isolated textures, or even photographs of natural slopes (Davies et al 1996; Huber and Davies 1999).

In our study we emphasise the importance of using natural stimuli when studying the perceived inclination of objects. This view is widely supported by researchers who agree that it is crucial to corroborate studies involving artificial displays with studies in natural conditions (Frisby et al 1996; Hecht et al 1999; Koenderink et al 2000; Proffitt et al 2001). We want to stress that it is also crucial to control the distance between the observer and the fixation point. This is the reason why we chose to manipulate this variable. The results of experiment 1 show an overestimation of the perceived inclination from a viewing distance of 6 m, which corroborates the idea that layout perception is not very accurate at larger distances even with natural stimuli.

In the second experiment, participants reported the perceived inclination of a projected set of slides representing the same urban roads as in experiment 1. The results show that observers do not overestimate the perceived inclination of slopes when the projected stereoscopic image contains horizontal disparity and simulates a 4 m viewing distance, while they reveal a slight overestimation when the simulated viewing distance is 6 m. In contrast to this, we always found overestimation when the projected binocular image did not contain horizontal disparity, independently from the viewing distance. Thus, when observers lack an important binocular cue, such as horizontal disparity, they show an increase in overestimating the perceived inclination of a surface. It is reasonable to conclude that visual inclination overestimation, generally found in many experimental works, seems to depend on the use of impoverished stimuli.

Our results have interesting implications for the general understanding of both the perception of spatial layout and the effects of various types of displays on that perception. We are not giving a methodological contribution by showing that the paddle method is a valid one. What we are trying to explain in the present work is something that has a theoretical significance, because it is connected with the substantial concept of *slant perception per se*. Every person is interested in understanding *slant per se*; even ordinary people who need to climb a natural ramp as an inclined road or an inclined hill. Moreover, the fact that there is an increase in overestimating the perceived inclination of a surface is very important also for people who do not have a proper binocular perception of depth: when they see an inclined road or a hill, they probably misperceive an inclined surface overestimating its inclination.

In conclusion, if we use the paddle method, combined with natural and quasi-natural stimuli, we obtain a good match between real and perceived inclination of slopes. Therefore, we would like to stress the importance of using natural stimuli when investigating the perception of objects, and comparing the results with those obtained in more controlled conditions, that is quasi-natural stimuli. We would like also to emphasise two things: (i) when we use quasi-natural stimuli it is possible to simulate natural scenes within a more controlled context in which the cues to inclination can be systematically manipulated, and (ii) it is appropriate to use quasi-natural stimuli instead of natural stimuli when it is difficult to investigate the perception of inclination in a strictly ecological environment.

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