Perception, 2007, volume 36, pages 249 – 257

DOI:10.1068/p5449

Perceived slant: A dissociation between perception and action

Jessica K Witt, Dennis R Proffitt¶
Department of Psychology, University of Virginia, PO Box 400400, Charlottesville, VA 22904, USA;
e-mail: drp@virginia.edu
Received 1 April 2005, in revised form 17 February 2006

Abstract. Perceived slant is grossly overestimated, such that 5° hills look to be about 20°. However, overestimation is found only in visual and verbal measures of apparent slant; action measures are accurate. This dissociation is consistent with several lines of research that suggest that there exist two perceptual processes, one for visually guided actions and another for explicit awareness. However, studies in other contexts have shown that analogous effects can be the result of differences in the task demands associated with the responses themselves as opposed to the processes underlying the responses. Two experiments are reported in which these alternatives were tested. Our results are consistent with the hypothesis that two perceptual processes underlie the dissociation between explicit awareness and visuomotor assessments of perceived slant.

1 Introduction

There is currently a plethora of proposals for two distinct visual systems that guide actions over different extents of space and time. A common attribute of these proposals is that one process guides immediate actions whereas the other process aids in planning for the future. In this paper, we refer to the first process as being *visuomotor* and the second as being *explicit awareness*. We believe that these labels reflect some of the fundamental differences between the processes, and that they are consistent with accounts proposed by other researchers.

One of the earliest proposals for dissociable visual systems was made by Bridgeman et al (1979), who also used the term visuomotor, but referred to the system responsible for explicit awareness as the *cognitive* process. Jeannerod (1997) proposed a *pragmatic* process involved in sensorimotor transformations and a *semantic* process responsible for perceiving objects as meaningful units. More recently, Glover (2004) suggested that the distinction should be made in terms of stages of processing, with a *control* process for accurately guiding actions and a *planning* process that chooses and initiates the beginning of actions. Milner and Goodale (1995) related dissociable visual functions to two anatomically distinct visual pathways. They proposed that the dorsal visual stream was responsible for visuomotor guidance, termed the *how* pathway, and that the ventral stream was responsible for conscious visual pattern recognition and identification, termed the *what* pathway.

Evidence from patient populations supports the notion of distinct visuomotor and explicit awareness systems. Blindsight patients have no conscious awareness of objects in the area of their visual field to which they are blind, so they cannot spontaneously plan actions directed towards these objects. However, when they are encouraged to act on objects in their blind area, their actions are accurate (Perenin and Rossetti 1996; Rossetti 2000), which suggests that the visuomotor system is functional. In contrast, patients with optic ataxia have explicit awareness of their environments, and yet they are unable to grasp objects in effective ways (Perenin and Vighetto 1988). These patients have an intact explicit awareness and an impaired visuomotor system. This double dissociation suggests that explicit awareness is distinct from the visuomotor processes that guide actions effectively.

¶ Author to whom all correspondence should be addressed.

Normal populations also show patterns suggestive of two visual-processing systems. One line of research has employed visual illusions. Explicit perceptual tasks, such as visual matching, fall prey to such visual illusions as the Ebbinghaus and Müller-Lyer illusions. In contrast, actions that are guided by the visuomotor system, such as grasping or pointing, are immune to these illusions (eg Aglioti et al 1995; Otto-de Haart et al 1999). It is important to note, however, that this research is problematic for two reasons. The first criticism is that a different number of illusions affect each task. For the Müller-Lyer illusion, in which two lines are present, one illusion is the apparent lengthening of one line due to the outward tails while a second illusion is the apparent foreshortening of the other line due to the inward tails, so the apparent difference in explicit awareness tasks increases when both illusory lines are present. In contrast, the grasping task is only directed at one line, and thus can only be influenced by one illusion (Franz 2001; Franz et al 2000; Pavani et al 1999). The second criticism has to do with the responses themselves, and will be discussed later in this section.

Another line of research on normal populations has found visual-processing dissociations in perceiving spatial layout in natural environments. Proffitt et al (1995) demonstrated that the perceived slant of hills was greatly overestimated in explicit awareness, but that an action measure was accurate. They used two types of explicit awareness measures—verbal reports and a visual matching task. Participants verbally estimated how steep hills were in degrees. For the visual matching task, they positioned a cross-section on a disk to match the slant of the hill (see figure 2a). A visually guided action provided an action measure of perceived slant (see figure 1). Participants placed their hands on a board and, without looking at their hands, attempted to tilt the board to be the same slant as the observed hill. Participants set the orientation of the board accurately both for shallow and for steep hills. However, both verbal reports and the perceptual matching task revealed large overestimations of perceived slant. For example, 5° hills were estimated to be about 20°.

One interpretation of these results is that the palm-board measure is driven by visuomotor processes and thus is accurate, whereas verbal and visual measures are driven by explicit awareness, which is susceptible to illusions and exaggerations of the environment. Consistent with the interpretation of a dissociation, previous studies demonstrated that verbal and visual measures, but not the haptic board measure, were strongly influenced by the participants' physiological state. Participants' verbal reports and visual matching adjustments indicated that hills appeared steeper when participants were encumbered, tired, of low physical fitness, elderly, and in declining health. However, none of these factors influenced the palm-board adjustments (Bhalla and Proffitt 1999). That the responses are independently influenced by different manipulations is consistent with an account of two dissociable perceptual processes.(1)

It is, however, possible that the apparent dissociation between the different measures of slant is due, not to a dissociation in underlying processes, but rather to differences in their inherent task demands. It is the purpose of the experiments reported in this paper to investigate this possibility.

(1) These patterns of results strongly suggest that the palm-board adjustments are driven by a visuomotor process. The palm-board task shares many characteristics with other types of tasks that are thought to be under visuomotor control; however, it does not share all of the characteristics of these putative visuomotor tasks. To date, no one has defined a set of characteristics that would be necessary and sufficient for a task to be considered a visuomotor task. Moreover, it may be that there is no set of common characteristics that are applicable across all types of actions. So even though the palm-board task shares some characteristics with actions such as drawing (Daprati and Gentilucci 1997) and pincer estimates (Haffenden and Goodale 1998, 2000), which are influenced by visual illusions, the pattern of results discussed earlier shows that the palm-board task is dissociable from the explicit awareness measures in a manner that suggests a visuomotor/explicit awareness distinction.

Vishton et al (1999) showed how inherent task demands could account for apparent dissociations found between visuomotor and explicit awareness measures used in studies of geometrical illusions. Explicit awareness of illusory figures has typically been assessed by having participants make relative magnitude estimations in which one dimension in an array is compared with another. For example, in studies of the Müller-Lyer illusion, participants would judge which of two lines was longer (Otto-de Hart et al 1999). Similarly, in the case of the Ebbinghaus illusion, participants would judge which of two circles was larger (Algioti et al 1995). Unlike these relative magnitude judgments, which required a comparison between two objects, the action measures employed in these illusion studies were directed at a single object. Using their thumb and index finger, participants would grasp either the line in the Müller-Lyer figure or the central circle in the Ebbinghaus display. Thus, the action measures were absolute in the sense that they did not require that the extent of one object be matched or compared to that of another.

In their investigation of the horizontal – vertical illusion, Vishton et al (1999) showed that both visual matching and action tasks showed evidence of the illusion only when they required relative judgments; absolute judgments of both kinds were unaffected by the illusion. In the relative-matching task, participants estimated the size of a vertical line relative to a horizontal one. Perceived length of the vertical line was influenced by the horizontal line. However, when participants estimated the length of the vertical line in millimeters, their judgment was not influenced by the presence of the horizontal line. Similarly, when participants reached to only one of the lines, which is an absolute grasping task, grip aperture was unaffected by the other line. However, when participants had to reach to both lines at the same time—by reaching with their thumb, forefinger, and middle finger—grip scaling was influenced by the vertical – horizontal illusion. On the basis of these results, Vishton et al argued that, for the horizontal – vertical illusion, the dissociation is between relative versus absolute judgments rather than between visual and action measures.

The tasks used to measure perceived slant also differed with respect to this distinction between relative and absolute judgments, thereby raising the possibility that the dissociation found was not due to differences between the explicit awareness and visuomotor systems but rather due to differential task demands. Both the verbal and visual matching tasks required comparing the orientation of the hill to that of the horizontal ground plane, and, thus, both are relative measures. The haptic task required adjusting a board's orientation without having to relate it to the horizontal, and therefore, in accord with Vishton et al's distinction, it was an absolute measure. The difference in perceived slant between the two estimates could be due to distinct perceptual processes or, alternatively, to the relative versus absolute demands of the tasks.

To test these possibilities, we measured perceived slant and compared the (absolute) haptic task and the previous (relative) visual matching to an absolute visual matching task.[2] If the differences in the original studies were due to differences between the explicit awareness and visuomotor systems, then performance on the absolute visual

[2] In some sense, it is an oxymoron to say that a matching task is absolute as, by definition, one thing is being compared to another. In this context, what we mean by 'absolute' is that the judgment is of the absolute slant of the hill and not the slant of the hill relative to something else. This is analogous to the distinction that Vishton et al (1999) made in their experiments. As they state in their footnote 1, 'absolute' referred to when the response was directed at only one line and 'relative' referred to when the response was directed at both lines. They found an effect of the vertical – horizontal illusion when the judgment was of one line relative to the other, and no effect when the judgment was of one line by itself regardless of whether the measure was an action measure or not. Like Vishton et al, we used different types of matching tasks, one which evoked a relative judgment (a judgment of the slant of the hill relative to the horizontal ground plane), and one that evoked an absolute judgment (a judgment of the slant of the hill in and of itself). For expositional purposes, we labeled these the relative visual matching task and the absolute visual matching task, respectively.

matching task should be the same as performance on the relative visual matching task. However, if the differences in the original studies were due to the reference frame of the measures used, then performance on the absolute visual matching task should be as accurate as performance on the haptic task.

2 Experiment 1: Hills viewed straight on

We measured perceived slant with three types of measures. Two were visual matching tasks, one relative and the other absolute, and the third was the absolute haptic adjustment task. For the relative visual matching task, participants indicated the apparent orientation of the hill relative to the horizontal, whereas the absolute visual matching task required that they respond to the orientation of the hill without having to relate it to the horizontal.

2.1 *Method*

2.1.1 *Participants.* Thirty-five students (ten female, twenty-five male) at the University of Virginia volunteered for the experiment. They were asked if they would like to participate as they were passing the hill. All gave informed consent.

2.1.2 *Stimuli.* Two hills were viewed from the bottom. One hill had an incline of 22° and the other of 31°, as measured by a Suunto clinometer. The hills had a fairly uniform and even surface.

2.1.3 *Apparatus and procedure.* Three types of measurements were used: an absolute haptic measure, a relative visual matching measure, and an absolute visual matching measure. The first two had been used in previous hill experiments (Proffitt et al 1995). For the haptic task, participants tilted a palm-board with their hands to match the slant of the hill (see figure 1). They rested their hands on an adjustable board, which could be angled to be parallel to the hill. A protractor was attached to the side of the board so that the experimenter could measure the estimated angle. Participants could not see the protractor and were not allowed to look at their hands while performing the task. The board was attached to a tripod, which was set slightly above waist level.

For the relative visual matching task, participants adjusted the angle of a cross-section on a flat disk (see figure 2a). For the absolute visual matching task, participants

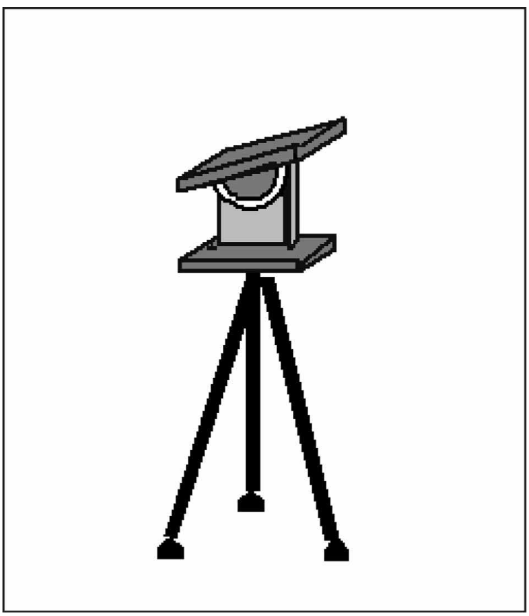

Figure 1. Apparatus for the haptic task. Participants positioned their hand on the top of the board and tilted it until it matched the slant of the hill.

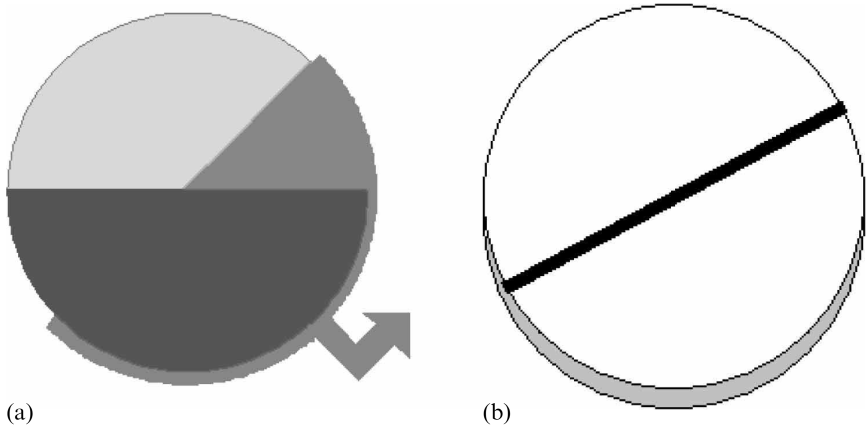

Figure 2. The two disks that were used in the perceptual matching task. (a) The relative matching disk. Participants positioned the cross-section of the disk to match the slant of the hill. (b) The absolute matching disk. Participants turned the disk so that the line across the disk was at the same angle as the hill.

turned a disk so that the diagonal line painted on the disk matched the slant of the hill (see figure 2b). On both matching tasks, a protractor was attached to the back of the disk so that the experimenter could record the estimated angle. For the absolute matching task, a weighted needle hung down vertically from the center and pointed to the angle on the protractor.

Participants viewed only one hill (22°, $n = 16$; 31°, $n = 19$). Each participant completed all three types of measurements, which were counterbalanced across participants. Hills were viewed head-on; thus, participants viewed the pitch orientation of the hills. Participants were not allowed to turn either of the matching disks so that the angle on the disk would be parallel to the hill viewed in cross-section (the roll orientation). No feedback was given during the experiment.

2.2 *Results and discussion*

Perceived slant was measured with three types of tasks (see figure 3). As is apparent from the graph, both measures of explicit awareness showed overestimation, whereas the

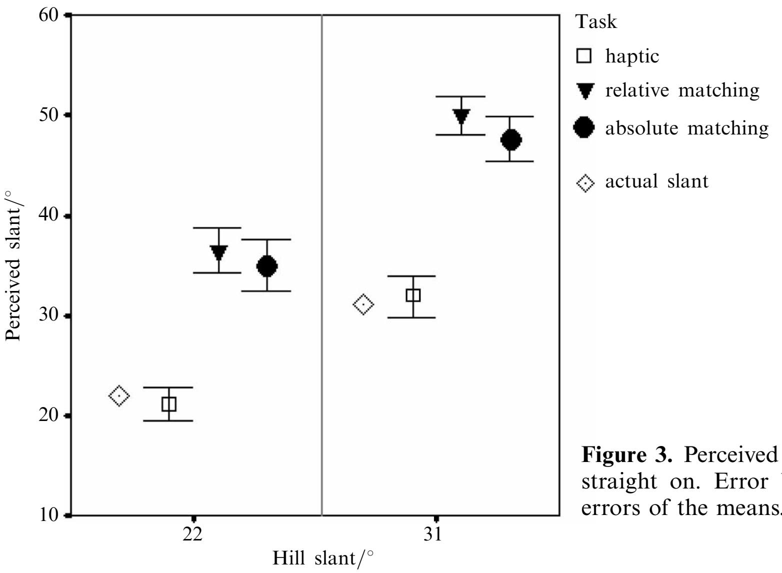

Figure 3. Perceived slant of hills viewed straight on. Error bars depict standard errors of the means.

haptic task was accurate. To confirm, we ran a repeated-measures ANOVA with type of estimate as a within-subjects variable and hill angle as a between-subjects variable. The effect of hill was significant ($F_{1,33} = 27.79$, $p < 0.01$), and type of estimate was significant ($F_{2,32} = 53.92$, $p < 0.01$). Planned contrasts revealed that the haptic estimate was significantly lower than the relative visual matching estimate ($F_{1,33} = 106.02$, $p < 0.01$) and the absolute visual matching estimate ($F_{1,33} = 52.93$, $p < 0.01$). The matching estimates did not differ significantly from each other ($F_{1,33} = 2.98$, $p > 0.09$). The interaction between hill and type of estimate was not significant ($p > 0.6$). t-Tests showed that the haptic measure did not differ significantly from the actual slant of the hills (ps > 0.6) and that both visual matching measures were significantly greater than the actual slant of the hills (ps < 0.01). These results support the notion that there is a distinction between the processes responsible for explicit perceptual awareness and for visuomotor behavior, and thus, that the previous effects were not due to artifacts of the different task demands inherent in making relative versus absolute judgments.

3 Experiment 2: Hills viewed from the side

In experiment 1 we indicated that hills are overestimated in explicit awareness but not for the processes that guide visuomotor actions. These results suggest that the reference frame used in the task does not influence estimates of perceived slant. Hills are also overestimated when viewed from the side (Proffitt et al 2001). In the second experiment, we tested whether an absolute visual matching task would be accurate when participants viewed the cross-section of the hills. In this task, participants could actually hold up the absolute disk and match each end of the diagonal line to the incline of the hills viewed in cross-section (see figure 4). If there is perceptual overestimation of hills viewed from the side, then the absolute matching task should still show overestimation even though it may seem trivially easy to match the line accurately with the hill.

3.1 *Method*

3.1.1 *Participants.* Thirty-five students (twenty-four female, eleven male) at the University of Virginia volunteered for the experiment. They were asked if they would like to participate as they were passing the hill. All gave informed consent.

3.1.2 *Stimuli.* We used the same 31° hill as was used in experiment 1. Participants stood in the same place and viewed the hill from one of two directions. In one direction, the hill had an incline of 26° and in the other direction, of 31° as measured by a Suunto clinometer. The hills had a fairly uniform and even surface. The 26° hill was viewed such that the hill slanted up from the perceiver's left side to his/her right side, and the 31° hill was viewed such that the hill slanted up from the perceiver's right side to his/her left side.

3.1.3 *Apparatus and procedure.* The same three measurements as in experiment 1 were used, and order was counterbalanced. Participants estimated the slant of only one hill (26°, $n = 18$; 31°, $n = 17$). Participants stood at the base of the hill and viewed the hill from the side. Figure 4 shows how the participants stood and their viewpoint of the hill. A cone was placed on top of the hill, and participants estimated the slant from the base of the hill to the cone. The cone was offset from the top of the hill directly in front of the participants by roughly 3 m. The haptic measure was directly to their side as in experiment 1, making the board tilt perpendicular to the hill. Participants were instructed to hold the disks directly in front of them. They were not given feedback during the experiment.

Figure 4. Participants could perform accurately by aligning the disk with the hill's incline viewed in cross-section. However, they do not do this, and instead they grossly overestimate the hill's slant when using this measure.

3.2 *Results and discussion*

Estimates of perceived slant on hills viewed from the side are presented in figure 5. We ran a repeated-measures ANOVA with type of measure as a within-subjects variable and hill angle as a between-subjects variable. As the graph indicates, there was a significant effect of hill ($F_{1,33} = 12.01$, $p < 0.01$) and a significant effect of type of measure ($F_{2,32} = 42.80$, $p < 0.01$). Planned contrasts revealed that the haptic measure was significantly lower than the relative visual matching task ($F_{1,33} = 68.89$, $p < 0.01$) and the

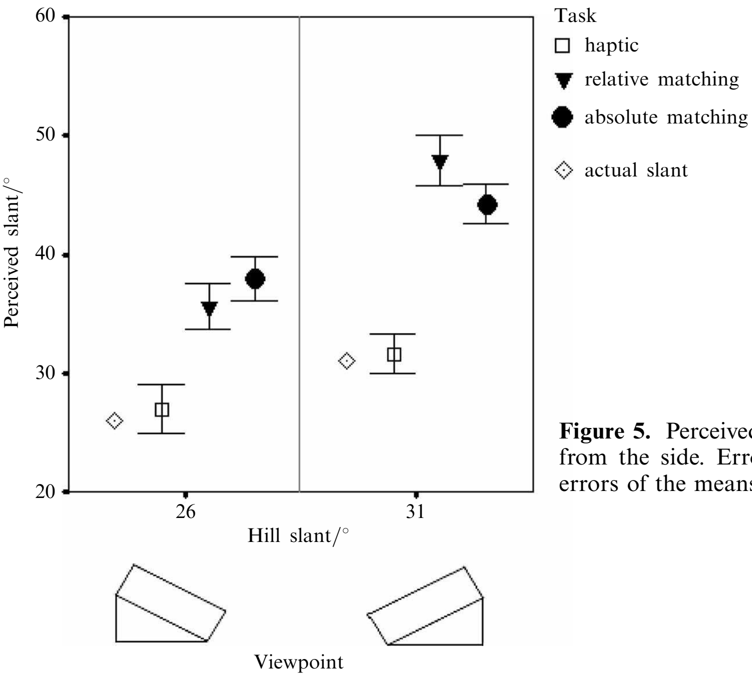

Figure 5. Perceived slant of hills viewed from the side. Error bars depict standard errors of the means.

absolute matching task ($F_{1,33} = 82.42$, $p < 0.01$). The two matching tasks did not differ significantly from each other ($F_{1,33} < 1$). The interaction between hill and type of estimate was significant ($F_{2,32} = 4.65$, $p < 0.05$). *t*-Tests revealed that the haptic measure was accurate (ps > 0.6) and both matching estimates were greater than the actual angle (ps < 0.01). Even when hills were viewed from the side and participants could directly line up the angle of the disk to the slant of the hill, they still overestimated slant. Overestimation occurs in explicit perceptual awareness and is independent of the reference frame of the response task and independent of viewpoint.

4 General discussion

In explicit awareness, hills appear to be much steeper than they actually are. Yet, when we ascend hills, we do so with ease and precision and show no evidence in our locomotor behavior that hills are perceptually overestimated. Such findings suggest a dissociation between explicit awareness and visuomotor behaviour.

One possible explanation is that there are two distinct perceptual processes, one for explicit awareness and the other for visuomotor control. Alternatively, Vishton et al (1999) argued that, in some cases, apparent dissociations may be due to different frames of reference evoked by the response measures. In previous experiments, one response measure evoked a relative frame of reference, which entails comparing one thing to another, whereas the other response measure evoked an absolute frame of reference.

In our experiments, we investigated whether the dissociations between measures of perceived slant were due to distinct perceptual processes or different reference frames. Our results demonstrated that both visual matching tasks showed overestimation, regardless of the frame of reference dictated by the measure. As in the previous experiments, the haptic task accurately matched the slant of the hill. These results suggest a dissociation in performance that may be explained by a theory of two distinct perceptual processes.

A possible advantage of having two types of perceptual processes is that each informs actions at different scales of time and distance. Previously, we proposed that visuomotor processes guide immediate behaviors, whereas explicit awareness promoted the planning of behaviors over longer extents of time and distance (Proffitt et al 1995). With respect to ascending hills, the visual control of locomotion is concerned with the precise accommodation of locomotion to the proximal layout of the ground. Accuracy and reliability are essential. However, in planning the rate of locomotion, explicit perceptual awareness must relate the physiological state of the body and the desired rate of energy expenditure to the extent and slant of the hill. Here, it is important to promote sensitivity to slant over the small range of angles that people can actually traverse. This differential sensitivity can be achieved through response compression.

Response compression means that perceptual sensitivity is inversely related to the magnitude of the stimulus. For example, in audition, a just-noticeable difference in amplitude is a function of background amplitude, with small differences being detectable only at small background amplitudes. In terms of a power function description of sensitivity, response compression means that the exponent is less than one. Response compression in perceived slant is adaptive because it means that perceivers are more sensitive to slight changes in incline within the range of slants that afford walking. Given that people are accurate in recognizing horizontal (0°) and vertical (90°) inclines, the psychophysical function for slant sensitivity is anchored at these points. Given these anchors, response compression results in overestimation because the function is a negatively decelerating one.

Thus, overestimation of slant promotes heightened sensitivity to the small slants that people can actually traverse. This heightened sensitivity to small changes in slant is advantageous for planning such actions as selecting walking speed so as to maintain an optimal rate of energy expenditure.

These findings support the notion that explicit perceptual awareness helps people plan future, intentional actions by representing the world in terms of their physiological potential as it relates to these actions (Bhalla and Proffitt 1999; Proffitt et al 1995, 2003; Witt et al 2004). Visuomotor processes promote accurate behavioral accommodations to the immediate surface layout. Thus, another distinction between the two perceptual processes is the timescale over which they operate. Explicit awareness supports long-term action planning, whereas visuomotor processes guide effective actions in the here and now.

Acknowledgments. This research was supported by NSF ITR/Carnegie Mellon grant 0121629 and ONR grant N000140110060 to the second author. The authors wish to thank Jeanine Stefanucci for her comments on an earlier draft and Steven Cholewiak for his help collecting data.

References

Aglioti S, DeSouza J F X, Goodale M, 1995 "Size-contrast illusions deceive the eye but not the hand" *Current Biology* **5** 679 – 685

Bhalla M, Proffitt D, 1999 "Visual-motor recalibration in geographical slant perception" *Journal of Experimental Psychology: Human Perception and Performance* **25** 1076 – 1096

Bridgeman B, Lewis S, Heit G, Nagle M, 1979 "Relationship between cognitive and motor systems of visual position perception" *Journal of Experimental Psychology: Human Perception and Performance* **5** 692 – 700

Daprati E, Gentilucci M, 1997 "Grasping an illusion" *Neuropsychologia* **35** 1577 – 1582

Franz V H, 2001 "Action does not resist visual illusions" *Trends in Cognitive Sciences* **5** 457 – 459

Franz V H, Gegenfurtner K R, Bülthoff H H, Fahle M, 2000 "Grasping visual illusions: No evidence for a dissociation between perception and action" *Psychological Science* **11** 20 – 25

Glover S, 2004 "Separate visual representations in the planning and control of action" *Behavioral and Brain Sciences* **27** 3 – 78

Haffenden A M, Goodale M A, 1998 "The effect of pictorial illusion on prehension and perception" *Journal of Cognitive Neuroscience* **10** 122 – 136

Haffenden A M, Goodale M A, 2000 "Independent effects of pictorial displays on perception and action" *Vision Research* **40** 1597 – 1607

Jeannerod M, 1997 *The Cognitive Neuroscience of Action* (Oxford: Blackwell)

Milner D A, Goodale M A, 1995 *The Visual Brain in Action* (Oxford: Oxford University Press)

Otto-de Haart E G, Carey D P, Milne A B, 1999 "More thoughts on perceiving and grasping the Müller-Lyer illusion" *Neuropsychologia* **37** 1437 – 1444

Pavani F, Boscagli I, Benvenuti F, Rabuffetti M, Farne A, 1999 "Are perception and action affected differently by the Titchener circles illusion?" *Experimental Brain Research* **127** 95 – 101

Perenin M T, Rossetti Y, 1996 "Grasping without form discrimination in a hemianopic field" *NeuroReport* **7** 793 – 797

Perenin M T, Vighetto A, 1988 "Optic ataxia: A specific disruption in visuomotor mechanisms. I. Different aspects of the deficit in reaching for objects" *Brain* **111** 643 – 674

Proffitt D R, Bhalla M, Gossweiler R, Midgett J, 1995 "Perceiving geographical slant" *Psychonomic Bulletin & Review* **2** 409 – 428

Proffitt D R, Creem S H, Zosh W D, 2001 "Seeing mountains in mole hills: Geographical-slant perception" *Psychological Science* **12** 418 – 423

Proffitt D R, Stefanucci J K, Banton T, Epstein W, 2003 "The role of effort in distance perception" *Psychological Science* **14** 106 – 113

Rossetti Y, 2000 "Implicit perception in action: short-lived motor representations of space", in *Finding Consciousness in the Brain* Ed. P G Grossenbacher (Amsterdam: John Benjamins) pp 131 – 179

Vishton P M, Rea J G, Cutting N E, Nuñez L N, 1999 "Comparing effects of the horizontal – vertical illusion on grip scaling and judgment: Relative versus absolute, not perception versus action" *Journal of Experimental Psychology: Human Perception and Performance* **25** 1659 – 1672

Witt J K, Proffitt D R, Epstein W, 2004 "Perceiving distance: A role of effort and intent" *Perception* **33** 577 – 590

ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 36 2007

www.perceptionweb.com