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Does a monocularly presented size-contrast illusion influence grip aperture?

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Abstract—The present study tested the idea that if subjects rely more on scene-based pictorial cues when binocular cues are not available, then both their perceptual judgements and their grasp might be influenced by pictorial illusions such as the Ebbinghaus (Titchener) Circles Illusion under monocular viewing conditions. Under binocular viewing conditions, subjects were always able to scale their grip accurately to the true size of the target disc and were unaffected by the illusion. Under monocular viewing, however, subjects appeared to be influenced by the illusion. Thus, when confronted with physically different target discs displayed on backgrounds that made them appear equivalent in size, subjects treated the two discs as equivalent—even when picking them up. These results, combined with earlier work from our laboratory suggests that binocular information plays a critical role in normal human prehension but when this information is not available the visuomotor system is able to "fall back" on the remaining monocular cues, which can cause the visuomotor system to be more susceptible to pictorial illusions. © 1998 Elsevier Science Ltd. All rights reserved

Key Words: monocular; binocular; illusion; grasping; pictorial cues.

Introduction

Recent work shows our perception of object features such as size can be at odds with the computations generated by our visuomotor system. Aglioti *et al.* [1], for example, demonstrated that the calibration of grip aperture during grasping is remarkably insensitive to the pictorial cues that produce the Ebbinghaus Circles (or Titchener) Illusion. Thus, even though subjects' perception of the relative size of two discs was affected by the background against which the target discs for grasp were displayed, the scaling of their grip aperture (measured in flight) was largely determined by the true size of the discs. Similar dissociations between visuomotor control and perceptual report have been observed with the horizontal–vertical illusion [12] and the Müller-Lyer illusion [3]. But why should the perception of object size be so susceptible to pictorial illusions of the kind just described while visuomotor control is not?

Perceptual mechanisms make use of the entire visual array; thus, the relations between objects in the array play a crucial role in scene interpretation. *Pictorial cues*, like interposition, familiar size and perspective, provide some of the most important information about the nature of objects and their relations in the scene. These pictorial cues can, if cleverly arranged, create the illusion that objects are bigger or smaller than they really are, often by providing incorrect information about the apparent relative distance of elements in the array [2, 4]. For perception, however, such illusions are of little consequence. In contrast, if the execution of a goal-directed action such as manual prehension, which must be calibrated with respect to the true metrics of the situation, falls prey to such illusions, it will fail. For this reason, the control systems which mediate such actions, are likely to ignore the available pictorial cues and make use of cues that are based entirely on the goal object itself. For example, the correct grip aperture during manual prehension can be reliably computed from the retinal image size of the goal object, if that image is properly calibrated with an accurate estimate of object distance. One reliable source of distance information for the calibration of reaching and grasping is binocular vision. Servos *et al.* [11] demonstrated that grasping movements made under monocular viewing were less "efficient" than those performed under binocular viewing conditions, achieving lower peak velocities and showing prolonged periods of deceleration

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during the closing phase of the grasp. But even though this shows that binocular vision plays a significant role in prehension, the subjects were still able to pick up the goal objects with little difficulty when binocular vision was denied, suggesting that the available monocular cues were sufficient to calibrate their grasp.

It is possible that subjects may be able to use learned pictorial information from the goal object itself, or the scene in which it is embedded, to help calibrate their reaching and grasping movements when binocular vision is not available. In fact, recently our laboratory has found that individuals with visual form agnosia, who are unable to perceive many of the pictorial cues present in visual scenes, are much more disadvantaged in the control of their grasp when binocular information is removed than are normal observers [5]. The fact that these individuals scaled their grasp much less accurately under the monocular viewing condition, despite showing normal binocular grasping, suggests that the visuomotor system "prefers" to use binocular information but can fall back on pictorial cues under monocular viewing conditions.

If subjects do indeed rely more on scene-based pictorial cues when binocular cues are not available, then under monocular viewing conditions, both their perceptual judgements and their grasp might be influenced by pictorial illusions such as the Ebbinghaus (Titchener) Circles Illusion. The present experiment was designed to test this possibility.

Method

Experiment 1

Subjects Fifteen right-handed subjects (5 males, 10 females; mean age = 23.8 years) with normal or corrected-to-normal vision participated in the experiment, for which they were paid. Subjects were strongly right-handed, as determined by a modified version of the Edinburgh handedness inventory [8]. All subjects had stereoscopic vision in the normal range with assessed stereoacuity of 40″ of arc or better as determined by the Randot Stereotest (Stereo Optical, Chicago, U.S.A.).

Apparatus. The target discs and background arrays were the same as those used by Aglioti *et al.* [1]. Target discs were constructed of 3 mm thick white plastic with a thin black line drawn around the circumference on their top surface. The discs ranged in size from 27–31 mm (in 1 mm steps). During presentation, two discs were positioned on a Ebbinghaus circles display, one disc in the centre of a circular array of 11 small circles (each 10 mm in diameter) and the other in an array of 5 large circles (each 58 mm in diameter). The overall diameter of the array of small circles (through the centre of circles) was 47 mm; the overall diameter of the array of large circles was 110 mm. The centres of the two arrays were 120 mm apart. The entire display was mounted on a turntable so that the left/right position of the arrays could be easily changed.

Procedure. At the beginning of the test session, subjects were given the handedness questionnaire and tested for eye dominance (viewing preference). During the testing, subjects stood in front of the table on which the Ebbinghaus circles display was placed. During a pre-test phase, subjects were systematically tested with different pairs of discs in order to establish which pairs would be reliably judged as equivalent in size. During the testing we used two types of trials under both binocular and monocular (with subjects wearing an eye-patch) viewing conditions. In the first type, which was repeated 16 times, the large disc was placed in the array of large circles and the small disc in the array of small circles, to create the illusion that the discs were in fact the same size (Fig. 1A). The second type of trial, in which two discs of the same size were used to create the illusion that the discs were different sizes, was subdivided into two further types—each repeated 8 times—in which both discs were either small or large (Fig. 1B). The left/right position of the arrays was counterbalanced throughout. At the begin-

A

B

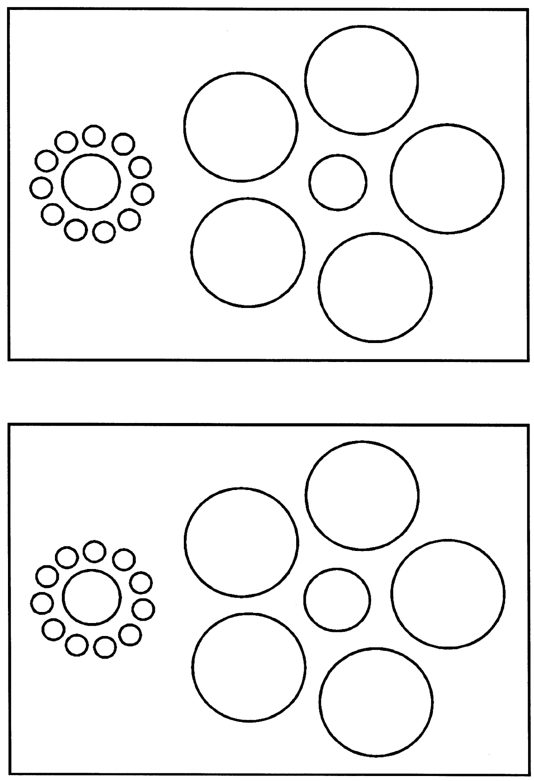

Fig. 1. The Ebbinghaus (Titchener) Circles Illusion. **A** The standard version of the illusion. The target circles in the centre of the two annuli appear to be different in size even though they are physically identical. People typically report that the circle surrounded by the annulus of smaller circles appears to be larger than the circle surrounded by the annulus of larger circles. **B** A version of the illusion in which the target circle in array of larger circles is physically larger than the other target circle. The two targets should now appear to be identical in size.

ning of each trial, subjects placed the tips of their index finger and thumb of their right hand on a start button positioned on the table at their midline about 60 mm from the centre of each of the discs. The display on each trial was arranged while subjects had their eyes closed and the room lights were extinguished. The experimenter initiated the start of a trial by signalling the computer to activate an overhead lamp which remained on for 3.5 s. The subjects were instructed that on each trial they were to pick up the disc on the left if they thought the discs were the same size, and the disc on the right if they thought the discs were different. These instructions were counterbalanced.

The movements of the hand and fingers during grasping were tracked by conventional optoelectronic recording. Three 8 mm diameter infrared light-emitting diodes (IREDS) were attached with small pieces of cloth adhesive tape to the radius at the wrist, the ulnar border of the thumbnail and the distal portion of the index fingertip of the subject's right hand. The tape allowed complete freedom of movement of the hand and fingers. The position of each IRED was tracked with a two infrared-sensitive camera system (WATSMART, Northern Digital, Waterloo, Canada) at a sampling rate of 100 Hz. The 3-dimensional co-ordinates of the IREDs were stored by the WATSMART's data acquisition unit and later filtered off-line (with a low pass second-order Butterworth filter with a 7 Hz cut-off). The maximum grip aperture (the maximum vectored distance between the thumb and index finger IREDs) on each trial was reconstructed off-line at the end of the experiment.

Planned comparisons were performed as paired *t*-tests, using Bonferroni corrections to adjust the error rate for the number of tests performed.

Experiment 2

Subjects. Twelve right-handed subjects (6 males, 6 females; mean age = 25.5 years) with normal or corrected-to-normal vision participated in the experiment, for which they were paid. Subjects were strongly right-handed, as determined by a modified version of the Edinburgh handedness inventory [8]. All subjects had stereoscopic vision in the normal range with assessed stereoacuity of 40″ of arc or better as determined by the Randot Stereotest (Stereo Optical, Chicago, U.S.A.).

Apparatus and procedure. The apparatus and procedure were similar to that used in Experiment 1. There were only two changes. The first was that the Titchener

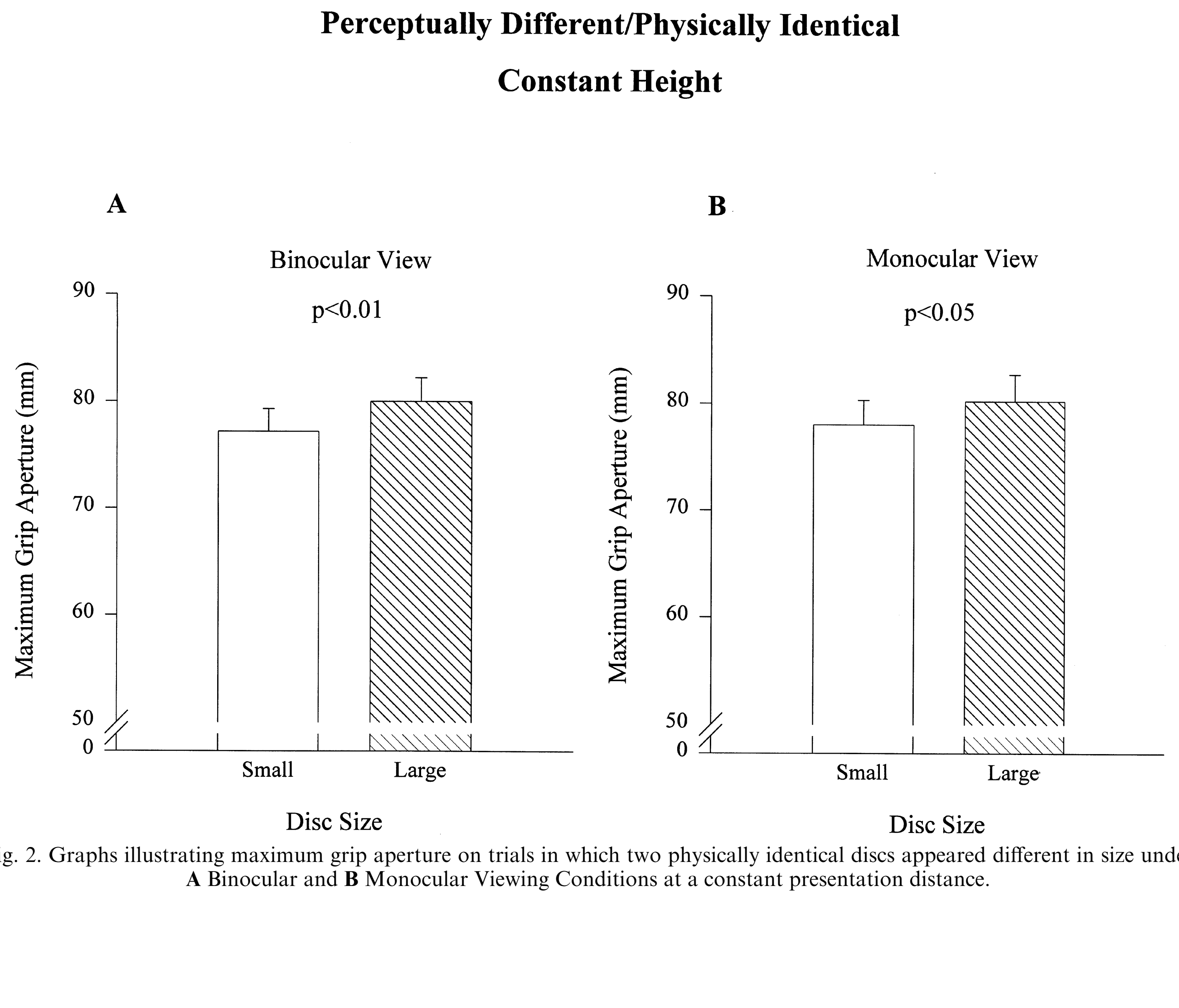

Fig. 2. Graphs illustrating maximum grip aperture on trials in which two physically identical discs appeared different in size under **A** Binocular and **B** Monocular Viewing Conditions at a constant presentation distance.

display was mounted on an adjustable platform which allowed for presentation height to be randomly varied from trial to trial (height was varied in 1 cm increments within a range of 10–14 cm from the surface of the table). The second was that the IREDs were now monitored by a new infrared sensitive camera system (OPTOTRAK) at a sampling rate of 100 Hz, positioned approximately 2 m from the subject. The 3-dimensional co-ordinates of the IREDs were stored by the OPTOTRAK's data acquisition unit and later filtered off-line (with a low pass second-order Butterworth filter with a 7 Hz cut-off).

Results

Experiment 1

Psychophysical testing carried out during practice trials allowed us to determine the difference in size between the two target discs that produced judgements of perceptual equivalence for each subject. The average difference was 2.6 mm, averaged across the 15 subjects we tested; in other words, for a pair of discs to be judged as equivalent on the illusion background, the disc centred in the annulus of the large circles had to be 2.6 mm larger on average than the disc centred in the annulus of the small circles. All the subjects remained sensitive to the size-contrast illusion throughout the testing. When an illusion background was present and the two discs were identical in size, the choice made by the subjects indicated that they thought the discs were different; on "illusion" trials in which the discs where physically different, they behaved as though the two discs were the same size.

There was a overall significant within subjects effect ($F(11) = 3.43$, $P < 0.001$). Under the binocular viewing condition, although subjects saw the illusion it did not influence their grip aperture, which was scaled to the true size of the target disc under both the perceptually different/physically identical($t(14) = 5.68$, $P < 0.01$) (Fig. 2A) and perceptually identical/physically different ($t(14) = 4.81$, $P < 0.001$) conditions (Fig. 3A). Under the monocular viewing condition, subjects did open their grip wider for the large disc during the perceptually different/physically identical conditions ($t(14) = 4.11$, $P < 0.01$) (Fig. 2B). In the perceptually identical/physically different condition, however, subjects did not

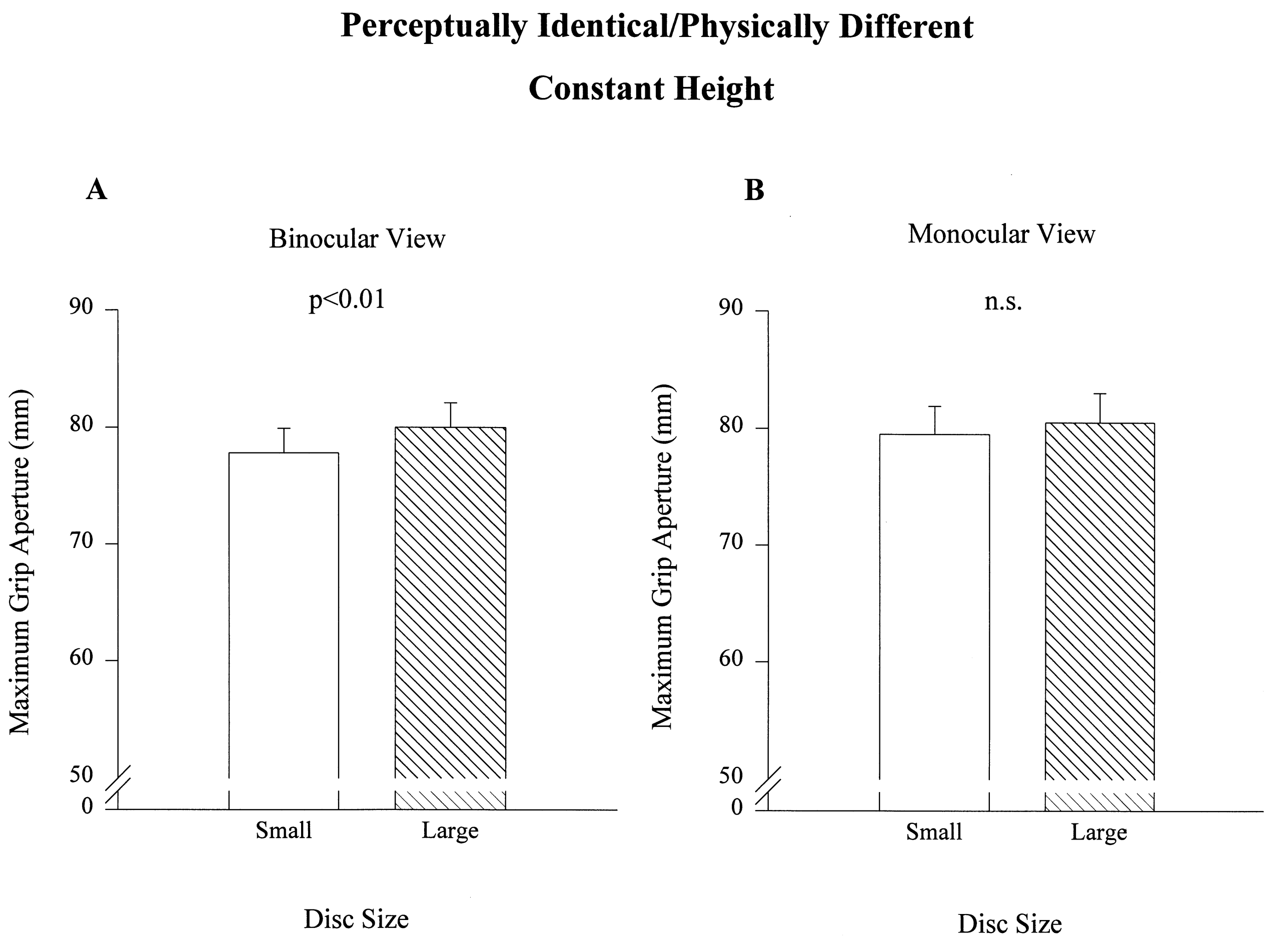

Fig. 3. Graphs illustrating maximum grip aperture on trials in which two physically different discs appeared identical in size under **A** Binocular and **B** Monocular Viewing Conditions at a constant presentation distance.

open their grip significantly wider for the larger disc ($t(14) = 2.60$, $P > 0.05$) when tested monocularly (Fig. 3B).

In the perceptually different/physically identical conditions, two large discs or two small discs were presented together on the illusory background. Although there was a suggestion that the grasps directed at the target located in the annulus of small surrounding circles was larger than the grasp directed at the target located in the annulus of large surrounding circles, none of these differences was significant in either the binocular or the monocular viewing conditions for the pair of large or for the pair of small discs ($P > 0.05$).

Experiment 2

For this experiment the difference in size between the two target discs that produced judgements of perceptual equivalence for each subject was 2.6 mm, averaged across the 12 subjects we tested.

There was an overall significant within subjects effect ($F(11) = 4.20$, $P < 0.001$). As in Experiment 1, under binocular viewing conditions, although subjects saw the illusion it did not influence their grip aperture, which was scaled to the true size of the target disc under both the perceptually different/physically identical ($t(11) = 4.13$, $P < 0.0\ 1$) and perceptually identical/physically different ($t(11) = 3.25$, $P < 0.05$) conditions (Figs 4A and 5A, respectively).

Under the monocular viewing condition, subjects did not open their grip wider for the larger disc in either the perceptually different/physically identical ($t(11) = 0.34$, $P > 0.05$) or the perceptually identical/physically different ($t(11) = 2.49$, $P > 0.05$) conditions (Figs 4B and 5B, respectively).

Again comparisons made between grasps directed at equivalent-sized discs in the two different annuli of the perceptual different/physically identical trials did not yield any significant differences for either the binocular or the monocular viewing conditions ($P > 0.05$).

Discussion

The fact that subjects were always able to scale their grip accurately to the true size of the target disc in both the constant and varied height presentations when using

Perceptually Different/Physically Identical

Varied Height

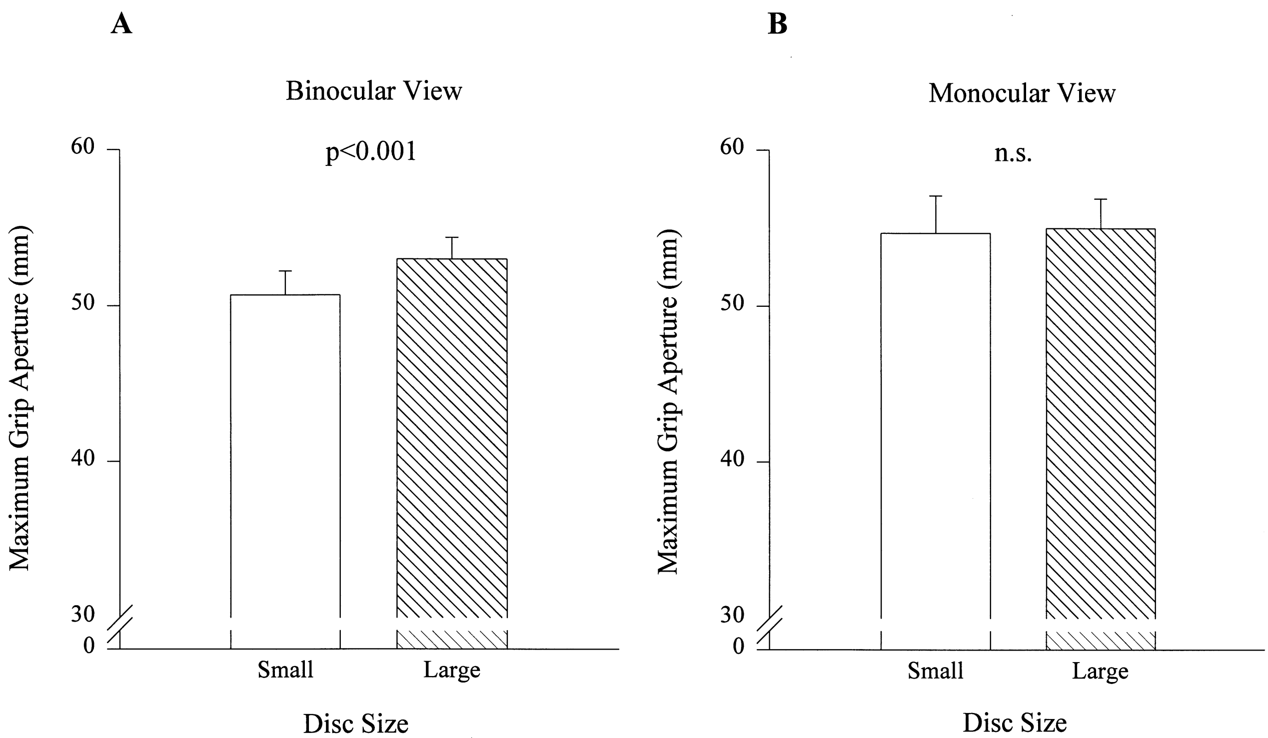

Fig. 4. Graphs illustrating maximum grip aperture on trials in which two physically identical discs appeared different in size under **A** Binocular and **B** Monocular Viewing Conditions at varied presentation distances.

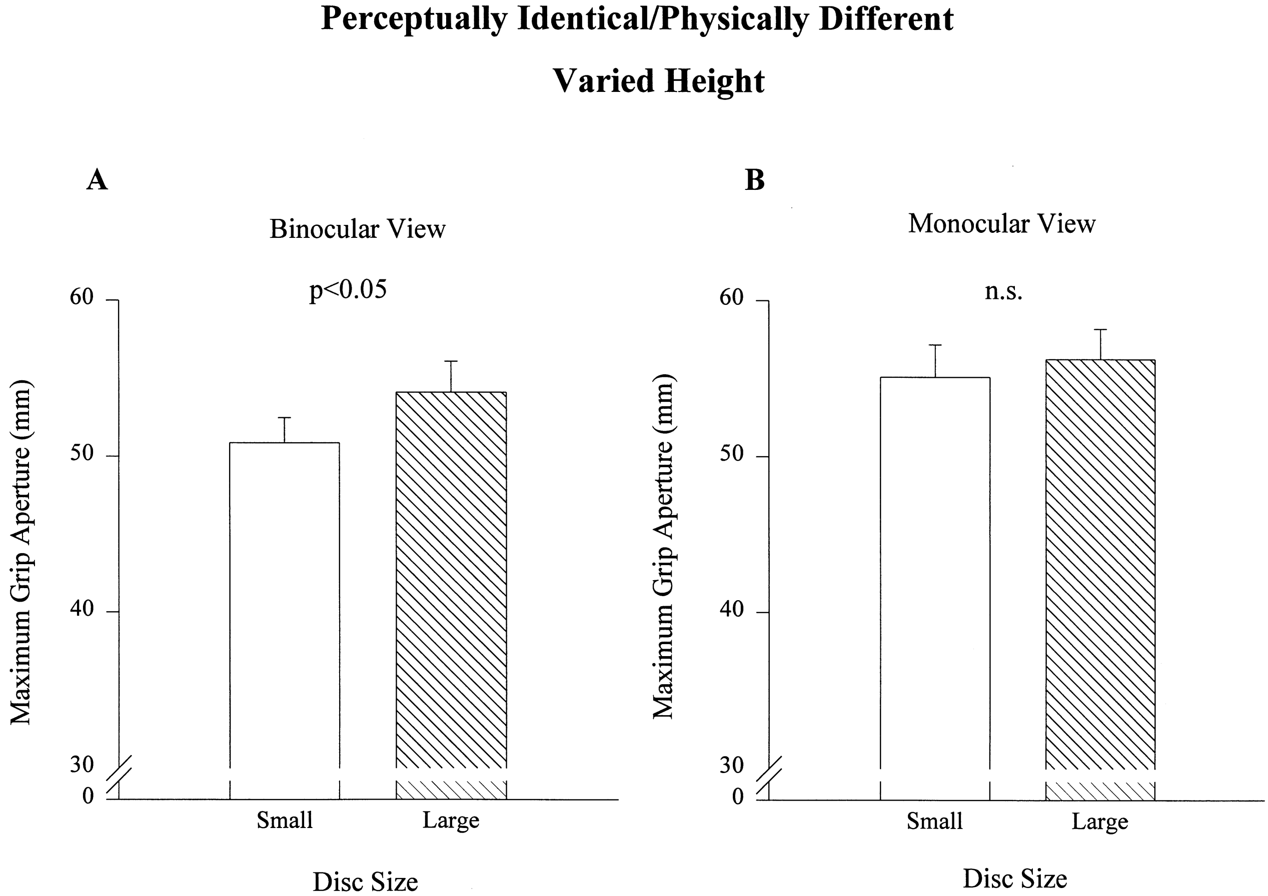

Fig. 5. Graphs illustrating maximum grip aperture on trials in which two physically different discs appeared identical in size under **A** Binocular and **B** Monocular Viewing Conditions at varied presentation distances.

binocular vision—but not monocular vision—suggests that binocular vision is of primary importance in calibrating grip aperture to the true size of the goal object. Perhaps the most telling comparison can be seen in the different grasps made in the perceptually identical/physically different condition. In this case, despite the fact that subjects had earlier claimed that the two discs appeared to be the same size, they continued to scale their grasp to the true size of the discs under binocular viewing conditions—even when the height of the platform was varied from trial to trial.

Under monocular viewing, however, subjects appeared to be influenced by the illusion even when the display was presented at a constant viewing distance from trial to trial. Thus, when confronted with physically different target discs displayed on backgrounds that made them appear equivalent in size, subjects treated the two discs as equivalent—even when picking them up. When the height of the display was varied from trial to trial, their monocular grip scaling was never correlated with the true size of the disc in any condition. Indeed, when subjects could not count on the distance remaining the same from trial to trial, monocular cues appeared insufficient for calibrating the grasp in this situation. Of course, as soon as they could use binocular cues, the varying height was no longer a problem. The only scaling that was evident under monocular viewing occurred with perceptually different/physically identical displays presented at a constant height: here grasps to the two large discs were reliably larger than grasps directed at the two small discs, a difference that could not have been influenced by the size-contrast illusion, since the large and small discs were always presented on different trials and an explicit comparison was never demanded. One might have expected to see an effect of the illusion on these monocular trials with perceptually different/physically identical arrays when one compared responses to the same-sized discs. Unfortunately, the data were not reliable enough to yield this result. Nevertheless, the behaviour on the other trials indicates that the effect of the illusion on grasp is only seen under monocular viewing conditions.

Sakata [10] has argued that areas in the posterior parietal cortex are more important than inferotemporal cortex for the computation of 3D structure and orientation of objects and that this computation is dependent on stereopsis. He suggests that the major purpose of the 3D representation of objects in the parietal cortex is the visual guidance of hand action, following the proposal of Milner and Goodale [8]. This may explain why manual prehension is not influenced by the Ebbinghaus (Titchener) Circles illusion when binocular information is available to guide manual prehension. Previous research from our laboratory [5, 6], has provided evidence that when binocular vision is not available, subjects rely more on monocular pictorial cues to program and control their reaching and grasping movements. When the Ebbinghaus (Titchener) Circles illusion is presented under monocular viewing conditions, the visuomotor system is forced to rely on the pictorial information that drives the illusion—information which is presumably mediated by the circuitry in the occipitotemporal pathway that has been implicated in the visual perception of objects [8]. This reliance on pictorial information appears to make people more likely to calibrate their grasp on the basis of the false information about size provided by the illusion. When binocular information is available of course, the control of the reaching movement can utilize the ancient dorsal pathway through the posterior parietal lobe—a pathway which appears to depend more on reliable cues to distance and size such as those provided by binocular vision.

In summary, these results, combined with earlier work from our laboratory [6, 7, 11], suggests that binocular information plays a critical role in normal human prehension but when this information is not available the visuomotor system is able to ''fall back'' on the remaining monocular cues, which can cause the visuomotor system to be susceptible to pictorial illusions.

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