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Perceived size and perceived distance of targets viewed from between the legs: Evidence for proprioceptive theory

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Abstract

We investigated, using three comparisons, perceived size and perceived distance of targets seen from between the legs. Five targets, varying from 32 to 163 cm in height, were presented at viewing distances of 2.5–45 m, and a total of 90 observers verbally judged the perceived size and perceived distance of each target. In comparison 1, 15 observers inverted their heads upside down and saw the targets between their own legs; another 15 observers viewed them while being erect on the ground. The results showed that inverting the head lowered the degree of size constancy and compressed the scale for distance. To examine whether these results were due to an inversion of retinal-image or body orientation, comparisons 2 and 3 were performed. In comparison 2, 15 observers stood upright and saw the targets with prism goggles that rotated the visual field 180°, while other 15 observers stood upright, but viewed the targets with a hollow frame lacking the prisms. The results showed that, in both goggle conditions, size constancy prevailed and perceived distance was a linear function of physical distance. In comparison 3, 15 observers wore the 180° rotation goggles and viewed the targets by bending their heads forwardly, and the other 15 observers viewed them while wearing hollow goggles and lying on the belly. The results showed a low degree of size constancy and compressed the scale for distance. Therefore, it is suggested that perceived size and perceived distance are affected by an inversion of body orientation, not of retinal image orientation. When path analysis and partial correlation analysis were applied to the whole data, perceived size was found to be independent of perceived distance. These results supported the direct perception model, rather than the apparent distance model.

Keywords: Space; Perception; Size; Distance; Between-leg viewing; Head; Retinal image; Visual cues; Proprioceptive cues; Apparent distance model; Direct perception model

1. Introduction

Proprioceptive information, which is produced by bending the body, tilting the neck, or raising or lowering the eyes, greatly influences visual space perception (Howard, 1986; Lackner & DiZio, 2005). This paper focuses on the perceived size and perceived distance of targets observed from between the legs when bending the upper part of the body forward. One of the earliest careful observations on this subject comes from Helmholtz, 1866/1911, who put it thus:

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"But the instant we take an unusual position, and look at the landscape with the head under one arm, let us say, or between the legs, it all appears like a flat picture; partly on account of the strange position of the image in the eye, and partly because,... the binocular judgment of distance becomes less accurate (pp. 8–9)."

He continued,

"It may even happen that with the head upside down the clouds have the correct perspective, whereas the objects on the earth appear like a painting on a vertical surface, as the clouds in the sky usually do."

These statements suggest that, in observations with the head upside down, perceived depth betweens objects is reduced, although it is not clear whether the absolute perceived distance from the observer to the object is also shortened. One may also infer that, since binocular (stereoscopic) cues are present equally in both parts of the field, the restriction of the perceived distance variation to the lower visual field implies that the perceived size of an object is likely to be based on visual angle.

If a landscape is viewed from between the legs, two orientations change compared to normal upright posture. One is the orientation of the upper body, including the head and chest. The upper body is so inverted that the low back muscles are stretched and the belly muscles are contracted, otolithic stimulation in the inner ears is disturbed and the head is congested with blood. The other is the orientation of the retinal image. By inverting the head upside down, the retinal image is reversed from left to right and is inverted from up to down. Note that when we attempt to see a landscape between our own legs, we have to direct our back to it and bend the body forward. This transformation of the retinal image is equivalent to a 180° rotation of the visual field.

The problem to be addressed in this study is how the visual and proprioceptive sources of information affect perceived size and perceived distance of objects seen between the legs. As has already been cited, Helmholtz accounted for the changes to the perceived size and perceived distance in terms of the information on the retinal image. He assumed that, in the inverted posture, the retinal image is formed on a site that differs from the usual site of stimulation (i.e., the sky, for example, is projected on the upper portion of the retina and the ground is projected on its lower portion), and binocular stereoscopic distance judgment becomes less accurate. As a consequence, perceived depth between objects is compressed, and perceived size of objects is reduced according to size–distance invariance. Meili (1960) similarly interpreted changes of the perceived size of objects when viewed from between the legs. We call this interpretation the "apparent distance theory."

Some may wonder why inversion of the retinal image reduces perceived depth? We think that Helmholtz's account is based on perceptual learning during space perception: we see objects as near unless we learn to see them as far (see Ross & Plug, 2002; pp. 121–122 for review). This idea is restated: (1) most of our experience is of terrestrial scene, viewed from the upright posture, (2) we learn to perceive terrestrial distance accurately in this circumstance, but it is difficult for this learning to transfer to unfamiliar scene (e.g., viewing of the inverted retinal image). As a result, perceived depth between objects is foreshortened when viewing the scene between the legs.

By accurate perceived distance, we mean that perceived distance is proportional to objective distance. In other words, the exponent of the power function, which has been used to construct the scale for distance (Wiest & Bell, 1985), approximates unity. If the exponent is smaller than unity, it means that perceived distance is compressed, whereas an exponent that is larger than unity means that perceived distance is expanded. The apparent distance theory assumes that the exponent of the power function would be smaller than unity only when the retinal images are inverted.

Another theory of 'between legs' perception is based on the changes of proprioceptive information coming from the orientation of the eye, neck, or body (see Ross & Plug, 2002, pp. 153–186; for review). The crucial assumption of the proprioceptive theory is that size constancy is dominant in usual normal posture, but is more reduced the more unusual the posture (Ching, Peng, & Fang, 1963; Hermans, 1954; Holway & Boring, 1940a, 1940b; Suzuki, 1991, 1998; Van der Geer & Zwaan, 1964; Wood, Zinkus, & Mountjoy, 1968). Although no one has ever specified a physiological process underlying this assumption, it seems to us that those authors who emphasize the role of proprioceptive information on perceived size have assumed that perceptual learning regarding size constancy develops under normal posture, and it is deteriorated when this normal posture is changed (Higashiyama, 1996), because the neural context of the judgment circuits is changed.

By usual normal posture, we mean that the eyes are at the primary position, and the head and trunk are kept upright with respect to the direction of the gravity. According to this definition, raising or lowering the eyes produces unusual proprioceptive information of the eye. Also, tilting the head laterally or backward while keeping the trunk erect produces unusual proprioceptive information of the neck. Similarly, bending the trunk forward or lying in a supine position on a bench produces unusual proprioceptive information of the trunk. However, standing on one leg and raising both hands, for example, is not unusual in the light of our definition, because, in this case, observer's head and trunk agree with the direction of the gravity. Orientation of the limbs including the arms and feet is presumably not so crucial in judging size and distance as orientation of the eyes, head, and trunk.

How does the proprioceptive theory explain the high degree of size constancy that is achieved in normal posture? To achieve a high degree of size constancy, we need a visual skill that has been learned from birth onward (Brislin & Leibowitz, 1970), and this skill—a habit that works automatically for objects that we see—has been polished up under normal posture. It is thus possible to say that size constancy is conditioned to normal proprioceptive information (Van der Geer & Zwaan, 1964). This visual skill is assumed to work best under the normal proprioceptive condition in which it has been formed. If an observer receives unusual proprioceptive information by bending the body, tilting the neck, or raising or lowering the eyes, this is degraded, so that perceived size of an object is likely to be based on the visual angle (i.e., a low degree of size constancy). For example, as the viewing distance to an object increases, the size of the object appears constant under normal upright posture; but it appears smaller with the trunk bent forward, because the object at a farther