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Ames's window in proprioception

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Abstract. When holding a small-scale model of Ames's trapezoidal window with the arms fully extended, several observers experience a striking proprioceptive distortion (eg one hand appears farther from the other, or one arm appears longer than the other). However, data from a matching experiment suggest that the proprioceptive misalignment of the hands is, in fact, rather less than the apparent slant of the window when this is not held. This finding argues against a 'visual-capture' account, supports an explanation in terms of bimodal integrative processes, and underscores the importance of supplementing phenomenological observations with objective measures.

1 Introduction

Do vision and touch interact when we perceive the position of our body parts in space? And if they do, what is the nature of such interaction? Since Berkeley (1709) and Piaget (1937), a number of investigators have suggested that proprioception and kinaesthesia (the muscular senses of body position and body movement) can instruct vision about the three-dimensional structure of objects within one's reach (for a recent version of the idea, see Atkins et al 2001). The 'touch-teaches-vision' view naturally leads to hypothesising the primacy of touch in providing information about posture and limb position.

Contrary to the traditional view, however, recent work on the so-called 'body schema' has emphasised a more complex view of multimodal interactions (Maravita et al 2003), allowing for visual predominance in many cases. For instance, visual localisation can influence tactual localisation when the apparent visual location is different from the veridical one (Pavani et al 2000). Visual information about the body may be used to rescale tactile impressions across different regions of the skin, for the purpose of achieving tactile size constancy (Taylor-Clarke et al 2004). Findings such as these echo earlier reports of visual dominance in bimodal judgments of the location of one's fingers (Hay et al 1965; Pick et al 1969).

Visual dominance in judgments of one's body position are consistent with classic reports of visual dominance in the perception of object size by eye and hand (Rock and Victor 1964). However, it is well established that tactual information can have a sizable influence on several multimodal judgments, including some that have sometimes been reported to yield visual dominance. For instance, when the visual size and the touched size conflict, many observers show tactual rather than visual dominance (McDonnell and Duffett 1972). Touch appears to dominate vision in the speeded discrimination of textures (Guest and Spence 2003).

2 Optimal integration

These seemingly contradictory findings have recently found an appropriate theoretical framework within the theory of optimal information integration. Within this framework, several recent studies of multimodal integration have shown that separate sensory channels are often combined in a fashion that approaches statistical optimality; that is, by a combination rule that weighs different sensory channels according to their reliability in a given situation (Ernst and Banks 2002; Ernst and Bülthoff 2004). Among factors that have been shown to affect the weights are intersensory consistency (Ernst et al 2000), viewing geometry (Gepshtein and Banks 2003), or the preferred mode of exploration associated with each perceptual modality (Newell et al 2001). The idea has been extended successfully even to the interaction of vision with audition (Alais and Burr 2004).

Optimal or quasi-optimal intermodal integration provides a plausible explanation for both visual dominance (under conditions which cause visual weights to predominate) and tactual dominance (under opposite conditions), as well as for intermodal 'compromise solutions' (when the relative sensory reliabilities are comparable) in visual and haptic judgments of three-dimensional form, position, or slant. Whether optimal integration theory can also predict multimodal judgments about one's position in space has been relatively less studied. However, some findings suggest that this may be the case (van Beers et al 1999, 2002; Rossetti et al 1995). Here we report a novel observation that may be of interest as a tool for further investigating the interaction of vision and proprioception when sensing one's body position in space.

3 An observation on Ames's window, vision, and proprioception

The trapezoidal window is a well-known demonstration devised by Adalbert Ames as a tool to investigate the interpretation of monocular information about surface slant and its effect on other visual processes, such as motion perception (Ames 1951). While performing informal observations of a hand-held reproduction of Ames's display, we were able to observe an intriguing effect of the visually induced slant on one's sense of position in space. The procedure that produces the effect most readily in our observers is as follows. We always started by applying a blindfold to one of the eyes of the observer and familiarising observers with the experience of monocular vision. Next, we asked them to temporarily close both eyes and to lower both hands in front of the hips while fully extending their arms. While the eyes were closed, we placed the trapezoidal surface in contact with the hands and helped them shape the thumb and index finger of each hand such that they could hold the surface with a two-finger grip, as illustrated in figure 1. Finally, we asked them to raise both hands while keeping the arms fully extended, until the surface was in front of their face. At this point, we instructed them to open the unoccluded eye.

Several observers manifested surprise and reported at least one of the following impressions: (i) one of the hands appears smaller than the other; (ii) one of the hands appears farther away than the other; or (iii) one of the arms appears longer than the other. Most revealing of all, however, is that all observers report either a sense of tension in one of the shoulders or explicitly mention a muscular sensation of rotation

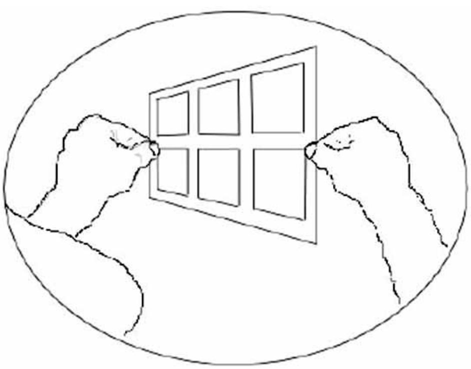

Figure 1. The monocular optic array when one opens the right eye while holding a small-scale model of Ames's trapezoidal window with both hands in front of one's face. The effect on proprioception is most obvious if previous binocular observation of the trapezoidal surface is prevented. A procedure for achieving this is described in the text.

of the shoulders, as if they were not exactly normal to the line of sight. In two cases, we have observed participants that were obviously compensating for this (illusory) distortion by actually rotating the shoulders in the opposite direction. In any case, the proprioceptive effect is robust: we have tried repeated presentations on ourselves and found essentially no reduction after several trials. In addition, it continues to affect one's appreciation of the position of the shoulders and of the hands even after the trapezoidal surface is gently removed while taking care not to move the observer's outstretched hands. One can, for instance, remove the surface and then ask the observer to bring the farther hand to the same distance from their body as the closer one. Observers have no problem understanding and executing this task—and, of course, end up with one of the hands now physically closer than the other.

Given that the novel information acquired when opening the eye has such an illusory effect both on the seen position of the hand and on the felt position of the shoulders, despite the abundance of veridical proprioceptive and kinaesthetic information, the phenomenon reported here may appear as an instance of visual dominance in the multimodal perception of one's position in space. However, our preliminary measures suggest that the proprioceptive misalignment of the hands may, in fact, be rather less than the apparent slant of the window when this is not held with the hands. To perform these measures, we used the two simple matching procedures described below.

3.1 *Visual estimate*

To estimate the visually specified slant (no tactual contribution) of the trapezoidal window, we mounted the surface on a stand and asked observers to open their unoccluded eye and adjust the position of two simple place holders (wooden sticks each mounted on a stand) until these appeared to be aligned in depth with the two sides of the surface. The adjustment was performed by providing verbal instructions to the experimenters, who moved the place holders back and forth as requested. The distance between the two place holders was measured, and the apparent slant angle was then derived by trigonometry. The observation distance was always equal to the observer's arm length and the surface was always physically frontoparallel.

3.2 *Visuo-proprioceptive estimate*

To estimate the apparent location of the hands and arms while holding the window (specified by visual and proprioceptive information), we adapted the procedure used for the visual estimate in the following way. After having placed the blindfold over one eye of the participant, and having asked him/her to keep both eyes closed, we asked him/her to hold the surface as described before, and to raise both hands until the hands were in front of the face. At this point, we asked the participant to open the unoccluded eye and report on the apparent misalignment of the hands by the same procedure that was used for the visual estimate. To this aim, we simply told the participants to align the place holders with the apparent position of their respective thumbnails.

In all measurements, the stimulus surface (either mounted on a stand, or handheld) was the same small-scale model of Ames's window. It consisted of a cardboard trapezoid with a coloured cardboard 'frame' attached to it. On this simulated frame there were six trapezoidal cut-outs simulating window panes. These were painted black. All trapezoids were designed to simulate the projection of a rectangular surface slanted towards the observer. The horizontal extent of the trapezoidal surface was 18 cm, whereas its longer and shorter vertical sides were 11 cm and 20 cm, respectively. The thickness of the surface was 3 mm and its weight was of the order of a few grammes.

We collected randomised judgments from thirteen participants (the authors and ten students who were unaware of the purpose of the measurements). To avoid stereotyped responses, each of the participants performed only one visual judgment and only one visuo-proprioceptive judgment. The distributions of the two groups of responses are presented in figure 2. They suggest that visuo-proprioceptive judgments (average ± 1 SEM $= 10.5° \pm 2.3°$) were in general more veridical than those based on vision alone ($28.8° \pm 2.6°$), but still substantially larger than the true slant (zero) for most observers. In support of this impression, a test of the paired differences between the visual and visuo-proprioceptive data demonstrated that the average difference between the two measures (18.2°) was statistically different from zero ($t_{12} = 6.8$, $p < 0.0001$). Additionally, a single-sample test on the visuo-proprioceptive judgments confirmed that their average was also different from zero ($t_{12} = 4.4$, $p < 0.0009$).

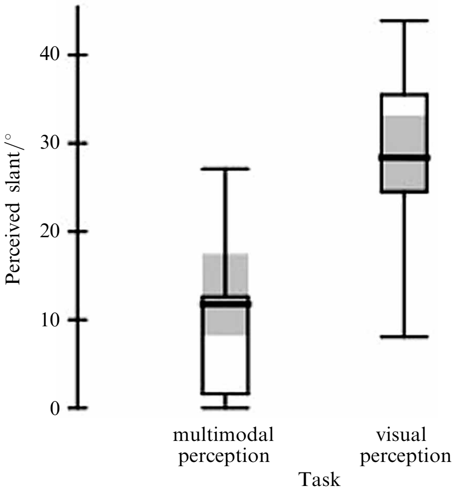

Figure 2. Perceive slant when seeing (visual perception, right) or seeing while holding in the hands (multimodal perception, left, see figure 1) a small-scale Ames's window. Whiskers show minimum and maximum values. Top and bottom of boxes indicate boundaries of first and third percentile. Grey areas show approximate confidence intervals around the group medians (thick lines).

4 Discussion

The effect of Ames's window on the perception of one's body position in space confirms that such perception generally depends on a compromise between visual and proprioceptive information. When first noticing the proprioceptive illusion induced by the monocular window, most observers manifest considerable surprise. The surprise provoked by the apparent misalignment of the hands and shoulders, despite abundant proprioceptive information, initially suggests a classification of the effect as one of visual dominance. A simple measurement, however, suggests that such apparent misalignment corresponds to only about one third of the apparent rotation induced by the monocular gradient on the trapezoidal surface. These results therefore suggest that the multimodal perception of the position of one's hands and shoulders in the present conditions is for a large part determined by the proprioceptive, not the visual signal.

An analysis of the relevant visual and proprioceptive information demonstrates that this outcome is, in fact, rather consistent with the relative reliability of the two sources in the present conditions. Note, first of all, that the monocular trapezoidal surface is perceived as a rectangular window that has been rotated around the y-axis by about 35° from the frontoparallel plane. In these conditions, therefore, there is misperception of the actual slant of the surface, which is in fact frontoparallel to the observer. This misperception is usually explained by noting that the monocular optic array containing the solid angles projected by the trapezoidal window is locally ambiguous (owing to the trade-off between surface form and surface slant), and by invoking a priori assumptions within the visual system (see Kilpatrick 1961) that favour the interpretation of a rectangle slanted towards to the observer. In addition, there are excellent reasons to predict that the perceptual system should be 'aware' of the relative lack of reliability of a monocular view under the present conditions. For instance, several lines of reasoning converge in suggesting that binocular information plays a crucial role in spatial tasks within peripersonal space, for reasons connected with the nature of spatial information (Bruno and Cutting 1988; Cutting and Vishton 1995) and with the control of precision movements by the hand (Mon-Williams et al 2001). Given the role of binocular information in peripersonal space, one would expect precisely that monocular viewing conditions are automatically classified as less reliable under these conditions.

Consider, instead, the nature of proprioceptive and kinaesthetic information in our conditions. In our situation, the surface is first held by both hands, with the arms fully extended, and while keeping the eyes closed. As long as the eyes are closed, one clearly feels that the hands are symmetrically placed in front of the body, at the same distance from the corresponding shoulders, and, of course, there is no proprioceptive experience of the shoulders being rotated. In addition, recall that before they are allowed to open the eye, observers raise their hands symmetrically to bring the surface in front of the head. This action provides unambiguous, time-varying kinaesthetic information about the relative positions of the arms, hands, and shoulders. Thus, proprioceptive information veridically informs one's perceptual system about the position of the hands and of the shoulders when the surface is held at arm's length.

Given this a priori asymmetry between the reliability of the visual and proprioceptive information in our demonstration, it is not surprising that the multimodally perceived position of the hands is in fact much closer to its proprioceptive than to its visual specification. It remains to be explained why the unambiguous proprioceptive and kinaesthetic information remains insufficient to overcome vision completely, such that a misalignment of the shoulders is nonetheless experienced. We speculate that the residual weight associated with the visual information may result from the temporal misalignment of the proprioceptive and visual inputs. The rich, time-varying proprioceptive signal occurs before one opens the eyes, whereas the visual signal becomes available when one is in fact already with the arms in a stationary position. Although the sequence of events is very fast, it may well be that the proprioceptive stationary signal has already started to become weaker as soon as the movement ends. However, a more certain answer to these questions will require explicit manipulations of the reliability associated with each sensory modality. Given that our purpose here was simply to report a novel effect in multimodal perception, we will make such manipulations the object of a second paper which is currently in preparation.

5 Conclusions

The proprioceptive Ames's window provides a simple, well-defined domain for further investigations of the integration of vision, proprioception, and kinaesthesia. Given the simplicity and portability of the employed apparatus, it also provides a useful tool for in-class demonstrations or science exhibits pertaining to the interaction between sensory modalities. Most interesting, however, it provides a clear methodological lesson about the importance of supplementing phenomenal descriptions with quantitative measurements. In the case of the present demonstration, the initial phenomenology is so striking, because the perceived position of one's hands and shoulders so clearly violates the previous knowledge of how one has moved and positioned the limbs, as well as one's knowledge of the relative length of the arms. The associated surprise tends to emphasise these violations and, therefore, the effect of vision on proprioception. Quantitative measurements, even in a minimal form as reported here, instead provide a different picture which may well be fully consistent with current models of the integration of vision and touch.

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