

---

# Reference frames for orientation anisotropies in face recognition and biological-motion perception

---

Nikolaus F Troje

Department of Psychology, Ruhr-Universität, D 44780 Bochum, Germany;  
e-mail: [troje@uni-bochum.de](mailto:troje@uni-bochum.de)

Received 3 June 2002, in revised form 18 October 2002; published online 27 January 2003

---

**Abstract.** Both face recognition and biological-motion perception are strongly orientation-dependent. Recognition performance decreases if the stimuli are rotated with respect to their normal upright orientation. Here, the question whether this effect operates in egocentric coordinates or in environmental coordinates is examined. In addition to the use of rotated stimuli the observers were also rotated and tested both with a same–different face-recognition task and with a biological-motion detection task. A strong orientation effect was found that depended only on the stimulus orientation relative to the observer. This result clearly indicates that orientation effects in both stimulus domains operate in an egocentric frame of reference. This finding is discussed in terms of the particular requirement of extracting sophisticated information for social recognition and communication from faces and biological motion.

## 1 Introduction

Many visual phenomena show strong dependence on the orientation of the stimulus. When faces are presented upside down, the ability to detect distortions and abnormalities is strongly impaired as has been demonstrated by Thompson's (1980) Thatcher illusion. A similar effect is observed in other face-recognition tasks (for a review see Valentine 1988; Yin 1969).

Another visual phenomenon that is strongly orientation-dependent is the salient pop-out effect of biological-motion displays as introduced into experimental psychology by Johansson (1973, 1976). With nothing showing but a few small point-lights attached to the major joints of a moving human body, this stimulus has been widely used to separate motion information from other sources of information. A number of studies have shown that inversion of biological-motion point-light displays impairs both the detection of an actor as well as the recognition of actions, emotions, identity, and many other attributes (Bertenthal et al 1987; Dittrich 1993; Dittrich et al 1996; Mitkin and Pavlova 1990; Pavlova and Sokolov 2000; Sumi 1984).

In a standard experimental setting with the observer sitting upright in front of a vertical screen, turning a stimulus upside-down means rotating it simultaneously with respect to a whole number of possible reference frames. On the one hand, there are environmental (ie external) reference frames such as the ones defined by gravity or by oriented lines in the visual scenery. On the other hand, there are egocentric reference frames which can be bound to either the body, the head, the eyes, or the retina of the observer (Rock 1973). Orientation-specific effects could be due to a rotation in either of them. Using conditions in which the observer is rotated rather than the stimulus, I wanted to explore the most interesting part of this question—namely whether these effects operate in an egocentric or an environmental frame of reference.

Orientation effects are common not only in face-recognition and biological-motion perception but also in many other domains. They relate to the more general question of the degree of viewpoint invariance that can be achieved by the visual system. The ability of the human visual system to generalise to a novel viewpoint is certainly impressive (Biederman 1987; Biederman and Gerhardstein 1993; Marr 1982) but by no means perfect (Edelman and Bühlhoff 1992; Tarr and Pinker 1989). The degree of viewpoint

---

invariance depends strongly on the level of discrimination required in a particular task. Viewpoint-independent recognition can be observed at the basic level, whereas viewpoint dependence is more pronounced on a subordinate level. As discussed by Bühlhoff et al (1995), recognition processes based on localised features are rather viewpoint-dependent and allow only for limited generalisation. Other features, such as the colour and the texture of an object, are diffuse and can be recognised independently of a particular viewpoint. This latter argument is particularly valid for solid, opaque objects and viewpoint changes about an axis in the image plane. In those cases, novel viewpoints can result in occlusion of diagnostic features while revealing others that could not be seen before. However, even if an object is rotated in the image plane, orientation effects occur (eg Jolicoeur 1988; Tarr and Pinker 1989).

Particularly interesting in the context of the current study are those orientation effects that are not simply caused by deviations between learned and tested views of an object, but that express an advantage of particular orientations independently of an explicit learning phase. Ernst Mach (1914) already observed that mirror symmetry about a vertical axis is much more salient than mirror symmetry about any other axis. This observation was confirmed by many recent studies (eg Onley and Volkman 1958; Wenderoth 1994). Salient meridional anisotropies are generally known in terms of the 'oblique effect' (Appelle 1972) and appear in the context of many different visual tasks, such as orientation discrimination (Buchanan-Smith and Heeley 1993), perception of right angles (Goldmeier 1937), vernier acuity measurements (Saarinin and Levi 1995), and motion detection (Coletta et al 1993; Gros et al 1998). Orientation anisotropies are also found for the tilt aftereffect (Coltheart and Cooper 1972; Day and Wade 1969).

Most of these anisotropies demonstrate a predominance of the vertical direction over other directions. This raises the question what verticality means, or, more specifically, within which reference system the reported phenomena operate. Ernst Mach (1914) thought that the predominance of mirror symmetry about a vertical axis is directly due to the bilateral symmetry of our visual system, including both the positions of the eyes in the head and the bilateral symmetry of the brain. This view implies dominance of egocentric reference frames. However, Rock and Leamann (1963) could show that environmental vertical mirror symmetry dominates even if the head is tilted.

The more recent literature yields an inhomogenous picture (Essock 1980). Many authors find that orientation effects operate in egocentric coordinates (Creem et al 2001; Day and Wade 1969; Gros et al 1998; Kanizsa and Tampiari 1968). On the other hand, there are many experiments demonstrating orientation effects which are bound to an environmental frame of reference (Attneave and Olson 1967; Buchanan-Smith and Heeley 1993; Ferrante et al 1995; Rock and Heimer 1957; Rock and Leamann 1963). Apparently, both environmental as well as egocentric reference systems can be used, depending on the particular task, on attentional effects, and sometimes simply on the availability of one or the other framework. In some cases, both kinds of reference frames can even be used at the same time (Friedman and Lawrence 1996).

The inversion effects observed in face recognition and in biological-motion perception are among the most prominent orientation effects. It is surprising that, although there exist many studies of other aspects of those phenomena, in none of them the question of the frame of reference within which the inversion effects occur has been examined. For face recognition, the only report is an informal observation by Köhler (1940) who was already interested in this question. Köhler bent down until his head was inverted and looked backwards between his legs at pictures of a face held by an assistant. When the picture remained upright, he had difficulty in making it out; when it was held upside down, he has no such difficulty. A similar informal observation was reported by Rock (1988).

Work on the reference frame for the inversion effect in biological-motion perception is similarly rare. The only investigation in which observers were rotated in addition to stimulus rotations is the one by Bingham et al (1995). However, rather than full-body biological-motion displays, a number of inanimate events were shown and observers had to recognise them. The displays were generated by thresholding grey-level images of simple events such as a free-falling object, a rolling ball, a pendulum, or stirred water. Observers were asked to describe what they perceived in the resulting two-tone images (“patch-light displays”). The authors included conditions with either the observer or the stimulus being rotated by  $180^\circ$ . Recognition was impaired in both conditions as compared to the normal upright condition, but the decrease in performance was stronger when the stimulus was inverted. This was particularly true for events that involved gravity (pendulum motion, falling ball). The authors suggested that event recognition depends on absolute display orientation in the gravitational field rather than on the relative orientation between display and observer.

I am not aware of any other study in which the question about the reference frames of both face recognition and biological-motion perception has been investigated. A retina-based frame of reference seems to be the simplest one the visual system could possibly use. Any other reference frame needs additional sensory information. In order to generate a head-based reference frame, oculomotor information is needed. A trunk-based reference frame requires additional information about head orientation relative to the body. Environmental reference frames rely on sophisticated image processing or the integration of non-visual modalities. A gravitational frame of reference could, for instance, be mediated by the vestibular system.

With no other constraints existing, one would therefore assume that the ‘default’ reference frame is a retina-based system. Whereas there is no particular reason to assume that a different frame of reference is used in the context of face recognition, this is different for the perception of animate motion patterns. Like many dynamic physical systems, biological motion is strongly influenced by gravity (eg Alexander 1989), and at least some aspects of biological motion can be modelled in terms of an articulated set of pendulums (Barclay et al 1978; Cutting 1978; Kozlowski and Cutting 1977). It is still unclear what are the stimulus attributes that address the efficient sensory filter responding so reliably and efficiently to simple point-light patterns of biological motion. However, consistency with the laws of gravity might be an important aspect, and the existence of a prominent inversion effect for biological-motion perception would then be a direct consequence. It has been well documented that the visual system takes advantage of knowledge about gravity in many non-biological-motion tasks, such as estimating the length of a pendulum from the frequency with which it is swinging and similar tasks (Hecht et al 1996; Pittenger 1985, 1990; Saxberg 1987; Stappers and Waller 1993; Watson et al 1992). Assumptions about gravity also seem to play a role in judging the size of an animal shown as a biological-motion point-light display (Jokisch and Troje submitted). If knowledge about size and direction of gravity used for visual perception is directly mediated by the vestibular system, the inversion effect in biological-motion perception would be expected to be bound to a gravitational frame of reference.

In the present study, I tested observers both with a sequential same–different face-recognition task and with a biological-motion detection task. In each of the two experiments, observers were tested in four conditions: both the stimulus and the observer were oriented upright (0/0), either only the stimulus (90/0) or only the observer (0/90) was rotated by  $90^\circ$ , or both stimulus and observer were rotated (90/90). A rotation by  $90^\circ$  rather than a full  $180^\circ$  inversion was chosen to avoid the risk of physical problems. Pilot studies had shown that a  $90^\circ$  rotation produces a strong orientation effect with both tasks.

---

Compared to the 0/0 condition, we would expect reduced performance in the 0/90 and the 90/0 condition, but not in the 90/90 condition, if orientation effects would operate in an egocentric reference frame. In contrast, we would expect reduced performance in the 90/0 and in the 90/90 condition, but not in the 0/90 condition, if the orientation effects are due to rotation in environmental coordinates.

## 2 Experiment 1

The first experiment was a sequential same–different face-recognition task. Observers were presented with two images of faces and had to decide whether they were same or different.

### 2.1 Methods

2.1.1 *Participants.* Eight students from the psychology department participated in this experiment. They received credit for their participation. All participants had normal or corrected-to-normal vision. The same participants also took part in experiment 2.

2.1.2 *Stimuli.* I used a set of photorealistic images of human faces in frontal view originally derived from 3-D models of laser-scanned heads (Troje and Bühlhoff 1996). None of the persons depicted had a beard or wore any accessories such as glasses or earrings. The hair was removed digitally and only a small part of the neck was visible. Half of the images showed male faces and the other half showed female faces. Within each trial, the two faces were always of the same sex. In half of the trials male faces were shown, and in the other half female faces were shown. The images were presented on a computer screen. Faces subtended a visual angle of 10 deg at the viewing distance of 100 cm.

2.1.3 *Procedure and design.* Each trial began with the presentation of a fixation cross for 1000 ms followed by a 100 ms display of the first face. Then the fixation cross was shown again for 1200 ms, and finally the second face was shown for 100 ms. Now the observer was required to indicate whether the two faces were the same or different by using one of two keys on the computer keyboard. The next trial started automatically after an intertrial interval of 2000 ms.

The experiment was conducted with the use of a blocked  $2 \times 2$  factorial within-subject design. The first factor (OBS) encoded the orientation of the observer who was either sitting upright in front of the monitor or lying on his or her right side on a mattress such that the eyes were at the same height and had the same distance to the screen as during sitting. The second factor (STI) encoded the orientation of the stimulus. The stimulus was presented either upright or rotated  $90^\circ$  clockwise. A rotated display therefore matched the orientation of the observer when the latter was lying on the side. Each of the four blocks consisted of 80 trials. The order of the blocks was varied between observers, counterbalancing both the order of the observer orientation as well as the order of the stimulus orientation.

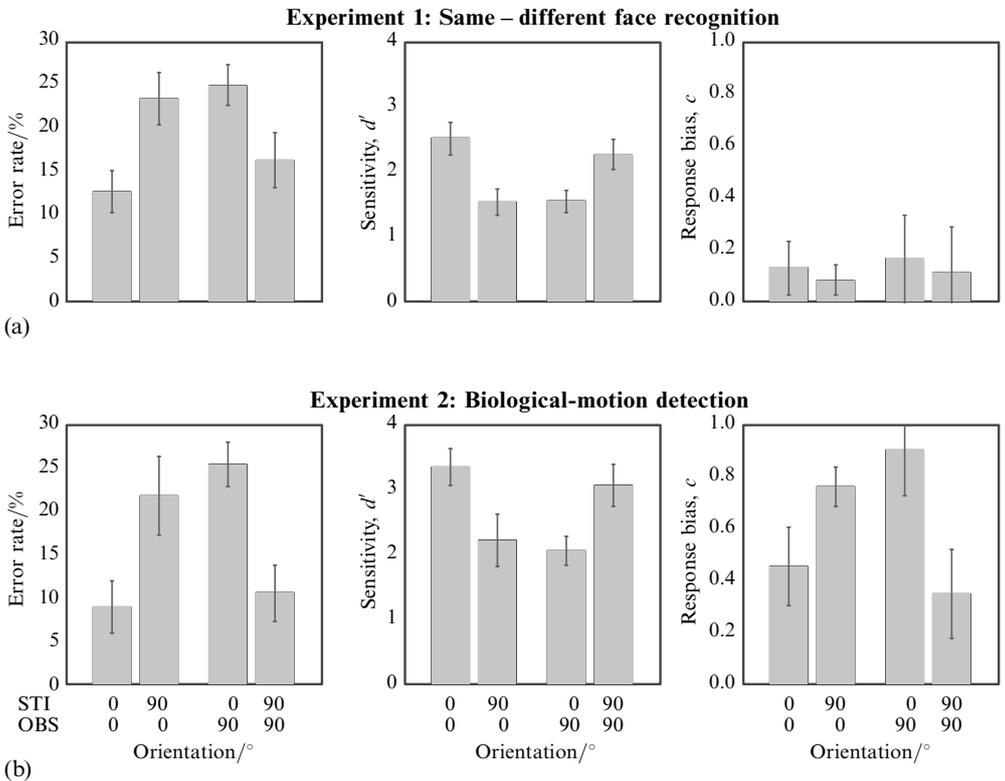
For technical reasons, the four blocks constituting experiment 1 and the four blocks constituting experiment 2 were interleaved in order to minimise disturbances due to the remounting of the bunk with the mattress and the chair. Half of the participants started running all the blocks in the upright (sitting) position followed by all the blocks in the lying position. The other half of the observers started with all the blocks in which they were lying followed by all the blocks in which they were sitting. All eight blocks (four face-recognition blocks and four biological-motion detection blocks) were run in succession, with 5 min breaks between blocks.

### 2.2 Results

I recorded error rates (false alarms and misses) and computed sensitivity  $d'$  and response bias  $c$  according to signal detection theory (Macmillan and Creelman 1991).

Error rates, sensitivities, and response biases were statistically analysed by means of a 2-factorial, repeated-measures ANOVA. Tukey's honestly significant difference (HSD) was used for a posteriori testing.

The results are depicted in figure 1a. Error rates are around 25% if either the stimulus or the observer was rotated. They decline to about 15% when the observer and the stimulus have the same orientation. There is neither a main effect of factor OBS nor of factor STI. The interaction, however, is highly significant ( $F_{1,7} = 23.7$ ,  $p < 0.005$ ). The error rates in the conditions in which stimulus and observer are aligned are statistically indistinguishable. The same is true for the two other conditions (Tukey HSD,  $p > 0.05$ , in both cases).



**Figure 1.** Mean error rates, sensitivities, and response biases of the eight observers participating in the two experiments. Error bars indicate the standard errors of the mean. Orientations of stimulus (STI) and observer (OBS) are given in degrees relative to gravitational upright.

Regarding sensitivity, the results are very similar to the ones obtained for the error rates. There is neither a main effect of factor OBS nor the factor STI, but the interaction is highly significant ( $F_{1,7} = 54.8$ ,  $p < 0.001$ ). Rotating the observer has the same effect as rotating the display (Tukey HSD,  $p > 0.05$ ). If both are rotated, performance is indistinguishable from the performance measured with both the observer and the display being upright (Tukey HSD,  $p > 0.05$ ).

Response bias was slightly positive in all conditions (mean, 0.12) with no effect of a single factor or their interaction. Clearly, face-recognition performance as measured in this task is only dependent on the orientation of the display within an egocentric frame of reference.

---

### 3 Experiment 2

The second experiment was a biological-motion detection task (Cutting et al 1988). By pressing one of two keys on the computer keyboard, observers had to indicate whether a display of 50 moving dots contained a point-light walker or not.

#### 3.1 Methods

3.1.1 *Participants.* The same eight students that took part in experiment 1 also participated in experiment 2.

3.1.2 *Stimuli.* The walker consisted of 10 points positioned at the major joints of the human body. The walker was shown in sagittal view facing to the right side and walking in one place, as if on a treadmill. The walker was generated according to an algorithm provided by Cutting (1978). The position of the walker within the display varied randomly from trial to trial according to a uniform distribution subtending 2.5 deg vertically and 4 deg horizontally.

The target walker was masked by four scrambled walkers. This number was chosen because pilot studies have shown that a detection task with upright presentation resulted in error rates between 10% and 15%. This rate should ensure that we would get neither ceiling effects in the upright condition nor floor effects in the conditions with reduced performance. A scrambled walker was derived from the normal walker by adding constant random positional offsets to the trajectories of the individual dots of the walker. The masking scrambled walkers moved in phase with the target walker. The trials with no target walker contained an additional scrambled walker such that the overall number of dots remained constant throughout the experiment. The displays subtended a visual angle of 10 deg. The height of the walker was 7 deg. The display was shown until the observer responded. If no response was given within 5 s, the trial was stopped and recorded as a false response.

3.1.3 *Procedure and design.* Most of the experimental details were similar to the ones in the previous experiment. A blocked  $2 \times 2$  factorial within-subject design with factors observer orientation (OBS) and stimulus orientation (STI) was used. Observers were either sitting upright or lying on their right side. The stimulus was presented either upright or rotated 90° clockwise. A rotated display therefore matched the orientation of the observer when the latter was lying on the side. Each of the four blocks consisted of 80 trials. Half of the trials contained a walker, and half of the trials contained only masking dots. Each trial had to be started by pressing the 'space' key. The order of the blocks was varied between observers, counterbalancing both the order of the observer orientation as well as the order of the stimulus orientation. Prior to each experimental block, observers were informed about the respective orientation of the target walker. Before the experiment started, observers were familiarised with the stimulus by showing them eight trials with and without the target walker. The first and second demonstration trials presented target walkers with only one and two masking walkers, respectively.

#### 3.2 Results

As in the previous experiment, records were made of error rates (false alarms and misses) and sensitivity  $d'$  and response bias  $c$  were computed according to signal detection theory (Macmillan and Creelman 1991). Error rates, sensitivities, and response biases were analysed by means of a 2-factorial, repeated-measures ANOVA and Tukey's honestly significant difference (HSD) was used for a posteriori testing.

The results are in many respects similar to the ones obtained in experiment 1 (figure 1b). Error rates are relatively high (mean, 24%) if either the stimulus or the observer was rotated, and they decline (mean, 9%) if the orientations of stimulus and

observer match. The ANOVA yields no main effects, but a significant interaction ( $F_{1,7} = 22.6, p < 0.005$ ). Error rates in the two conditions with identical orientations of stimulus and observer are statistically indistinguishable as are the error rates in the other two conditions (Tukey HSD,  $p > 0.05$ , in both cases).

The sensitivities match this result. The ANOVA yields no main effects but a significant interaction ( $F_{1,7} = 18.08, p < 0.005$ ). A posteriori tests reveal no difference in performance between the conditions in which either only the stimulus or only the observer was rotated (Tukey HSD,  $p > 0.05$ ). There is also no difference in performance for the two conditions in which stimulus and observer orientation were aligned (Tukey HSD,  $p > 0.05$ ).

In contrast to the previous experiment, the response biases are much larger (mean, 0.61). This result reflects the different nature of this detection task. The false-alarm rate is relatively low (mean, 5%) and the misses rate is much higher (mean, 29%). Furthermore, the response bias depends on the condition. The ANOVA does not yield any main effect, but a significant interaction ( $F_{1,7} = 18.6, p < 0.005$ ). Response bias is lower in the conditions in which the stimulus and the observer are aligned. This result shows that the false-alarm rate is rather independent of stimulus and observer orientation. Most of the differences in sensitivity across conditions are reflected in the hit rates. With the observer lying and the stimulus upright, hit rates approach chance level (55%). If the observer is sitting upright and the stimulus is rotated, the average hit rate is 60%. In both conditions with the stimulus and the observer aligned the hit rate reaches 84%.

#### 4 Discussion

The results presented here suggest that orientation effects in face recognition as well as in biological-motion perception are both operating in egocentric coordinates. In both cases, aligning the stimulus with the environmental upright does not result in any performance improvement compared to the condition in which the stimulus was aligned neither with the retinal upright nor with the environmental upright.

If it is assumed that a retinal coordinate system is the default and that any deviation from it requires additional computational expenses, this result is not surprising with respect to face recognition, as already discussed in section 1. The only particular reason to assume that face recognition might be linked to a gravitational reference frame is the fact that faces usually are oriented vertically. If the face-recognition system would be operating in an environmental, gravitational coordinate system, it would be most robust to changes of the observer's head orientation. However, since observers are generally able to alter and freely choose their head orientation, this may not be a large disadvantage. The expenses for transforming retinal coordinates into gravitational coordinates may not account for the small gain of having a visual recognition system that would be independent of observer's head orientation.

Whereas there seems to exist no particular reason for assuming that faces are processed in environmental coordinates, this is different for biological motion. Bio-mechanics of animate motion is strongly influenced by gravity (eg Alexander 1989). Understanding and interpreting the movements of another person requires assumptions about the forces associated with gravity. If this information is provided directly by the observer's vestibular system, biological-motion perception should operate in an environmental, gravitational frame of reference. The finding that biological-motion perception does also work within an egocentric reference frame probably reflects the fact that gravity on the Earth is generally constant. The visual system is apparently not using updated, new measurements from the vestibular system but relies on implicit knowledge about the magnitude and orientation of gravity.

Face recognition and biological-motion perception share a level of sophistication that allows not only simple detection of a face or a moving body, but enables us to retrieve detailed information about the identity, intentions, emotion, and other attributes of a particular person. Very small changes in configural or dynamic parameters can communicate important, socially significant information. Faces and moving bodies also share the fact that we encounter them in most cases in an environmental upright position. Therefore, the probability that a face (as well as a moving body) is aligned with the retina of an upright observer is quite high. On assuming a computational trade-off between the level of sophistication achieved with respect to the processing of detailed, socially relevant information and the ability to make the system invariant to rotations in the image plane, a strategy that focuses on this most probable case might be optimal.

Whereas verticality per se may not be of primary importance for face recognition and in biological-motion perception, this is different in the context of many other tasks. Many manual skills require knowledge about absolute vertical or horizontal orientations in a gravitational reference system. If we put an orange on a surface, we need to know the orientation of the surface to make sure that the orange does not roll away. Water surfaces can be recognised by their horizontal orientation. Predicting where a falling object will hit the ground requires knowledge about verticality. There are many more examples that demonstrate that a notion of gravitational upright is a necessity and a prerequisite for many ecologically relevant tasks. The versions of the oblique effect that do show a predominance of environmental reference frames usually comprise tasks that do not require sophisticated form discrimination but rather the detection of line orientations. The Goldmeier effect (Ferrante et al 1995; Goldmeier 1937), for instance, which demonstrates that the detection of a right angle is facilitated if one of the lines forming the angle is aligned with environmental upright, is an example for the processing of a relatively simple shape. The mechanisms used to identify a right angle might directly employ visual modules used to detect vertical and horizontal lines in a gravitational reference frame.

To summarise, using a retinal reference frame for face recognition and for biological-motion perception is assumed to be the basis and a prerequisite for the fascinating level of sophistication reached by those visual modes. A system that is able to detect and process the minute subtleties encoding emotion, personality, and other socially relevant and communicatively important attributes cannot afford any loss in the quality of image processing which may go along with a coordinate transformation with only little benefit.

## References

- Alexander R M, 1989 "Optimization and gaits in the locomotion of vertebrates" *Physiological Reviews* **69** 1199–1227
- Appelle S, 1972 "Perception and discrimination as a function of stimulus orientation: The oblique effect in man and animals" *Psychological Bulletin* **78** 266–278
- Attneave F, Olson R K, 1967 "Discriminability of stimuli varying in physical and retinal orientation" *Journal of Experimental Psychology* **47** 323–328
- Barclay C D, Cutting J E, Kozlowski L T, 1978 "Temporal and spatial factors in gait perception that influence gender recognition" *Perception & Psychophysics* **23** 145–152
- Bertenthal B, Proffitt D R, Kramer S J, 1987 "Perception of biological motion by infants: implementation of various processing constraints" *Journal of Experimental Psychology: Human Perception and Performance* **13** 577–585
- Biederman I, 1987 "Recognition-by-components: a theory of human image understanding" *Psychological Review* **94** 115–147
- Biederman I, Gerhardstein P C, 1993 "Recognizing depth-rotated objects: evidence and conditions for three-dimensional viewpoint invariance" *Journal of Experimental Psychology: Human Perception and Performance* **19** 1162–1182; erratum 1994 **20** 80

- Bingham G P, Schmidt R C, Rosenblum L D, 1995 "Dynamics and the orientation of kinematic forms in visual event recognition" *Journal of Experimental Psychology: Human Perception and Performance* **21** 1473–1493
- Buchanan-Smith H M, Heeley D W, 1993 "Anisotropic axes in orientation perception are not retinotopically mapped" *Perception* **22** 1389–1402
- Bülthoff H H, Edelman S, Tarr M J, 1995 "How are three-dimensional objects represented in the brain?" *Cerebral Cortex* **5** 247–260
- Coletta N J, Segu P, Tiana C L, 1993 "An oblique effect in parafoveal motion perception" *Vision Research* **33** 2747–2756
- Coltheart M, Cooper C M, 1972 "The retinal reference of the tilt aftereffect" *Perception & Psychophysics* **11** 321–324
- Creem S H, Wraga M, Proffitt D R, 2001 "Imagining physically impossible self-rotations: geometry is more important than gravity" *Cognition* **81** 41–64
- Cutting J E, 1978 "A program to generate synthetic walkers as dynamic point-light displays" *Behavior Research Methods & Instrumentation* **10** 91–94
- Cutting J E, Moore C, Morrison R, 1988 "Masking the motions of human gait" *Perception & Psychophysics* **44** 339–347
- Day R H, Wade N J, 1969 "The reference for visual normalization" *American Journal of Psychology* **82** 191–197
- Dittrich W H, 1993 "Action categories and the perception of biological motion" *Perception* **22** 15–22
- Dittrich W H, Troscianko T, Lea S, Morgan D, 1996 "Perception of emotion from dynamic point-light displays represented in dance" *Perception* **25** 727–738
- Edelman S, Bülthoff H H, 1992 "Orientation dependence in the recognition of familiar and novel views of three-dimensional objects" *Vision Research* **32** 2385–2400
- Essock E A, 1980 "The oblique effect of stimulus identification considered with respect to two classes of oblique effects" *Perception* **9** 37–46
- Ferrante D, Gerbino W, Rock I, 1995 "Retinal vs environmental orientation" *Acta Psychologica* **88** 25–32
- Friedman A, Lawrence H D, 1996 "The importance of being upright: use of environmental and viewer-centered reference frames in shape discriminations of novel three-dimensional objects" *Memory & Cognition* **24** 285–295
- Goldmeier E, 1937 "Über Ähnlichkeit bei gesehene[n] Figure[n]" *Psychologische Forschung* **21** 146–208
- Gros B L, Blake R, Hiris E, 1998 "Anisotropies in visual motion perception: A fresh look" *Journal of the Optical Society of America A* **15** 2003–2011
- Hecht H, Kaiser M K, Banks M S, 1996 "Gravitational acceleration as a cue for absolute size and distance?" *Perception & Psychophysics* **58** 1066–1075
- Johansson G, 1973 "Visual perception of biological motion and a model for its analysis" *Perception & Psychophysics* **14** 201–211
- Johansson G, 1976 "Spatio-temporal differentiation and integration in visual motion perception" *Psychological Research* **38** 379–393
- Jokisch D, Troje N F, submitted "Biological motion as a cue for the perception of size" *Journal of Vision*
- Jolicoeur P, 1988 "Mental rotation and the identification of disoriented objects" *Canadian Journal of Psychology* **42** 461–478
- Kanizsa G, Tampiari G, 1968 "Nuove osservazioni sull' orientamento retinico ed ambientale", in *Ricerche Sperimentali sulla Percezione* Eds G Kanizsa, G Vicario (Trieste: Università degli Studi di Trieste)
- Köhler W, 1940 *Dynamics in Psychology* (New York: Liveright)
- Kozlowski L T, Cutting J E, 1977 "Recognizing the sex of a walker from a dynamic point-light display" *Perception & Psychophysics* **21** 575–580
- Mach E, 1914 *The Analysis of Sensations* (Chicago and London: Open Court)
- Macmillan N A, Creelman C D, 1991 *Detection Theory: A User's Guide* (Cambridge: Cambridge University Press)
- Marr D, 1982 *Vision* (New York: W H Freeman)
- Mitkin A A, Pavlova M A, 1990 "Changing a natural orientation: Recognition of biological motion pattern by children and adults" *Psychologische Beiträge* **32** 28–35
- Onley J W, Volkman J, 1958 "The visual perception of perpendicularity" *American Journal of Psychology* **71** 504–516
- Pavlova M, Sokolov A, 2000 "Orientation specificity in biological motion perception" *Perception & Psychophysics* **62** 889–899

- 
- Pittenger J B, 1985 "Estimation of pendulum length from information in motion" *Perception* **14** 247–256
- Pittenger J B, 1990 "Detection of violations of the law of pendulum motion: Observers' sensitivity to the relation between period and length" *Ecological Psychology* **2** 55–81
- Rock I, 1973 *Orientation and Form* (New York: Academic Press)
- Rock I, 1988 "On Thompson's inverted-face phenomenon" *Perception* **17** 815–817
- Rock I, Heimer W, 1957 "The effect of retinal and phenomenal orientation on the perception of form" *American Journal of Psychology* **70** 493–511
- Rock I, Leamann R, 1963 "An experimental analysis of visual symmetry" *Acta Psychologica* **21** 171–183
- Saarinin J, Levi D M, 1995 "Orientation anisotropy in vernier acuity" *Vision Research* **35** 1449–1461
- Saxberg B V, 1987 "Projected free fall trajectories. II. Human experiments" *Biological Cybernetics* **56** 177–184
- Stappers P J, Waller P E, 1993 "Using the free fall of objects under gravity for visual depth estimation" *Bulletin of the Psychonomic Society* **31** 125–127
- Sumi S, 1984 "Upside-down presentation of the Johansson moving light-spot pattern" *Perception* **13** 283–286
- Tarr M J, Pinker S, 1989 "Mental rotation and orientation-dependence in shape recognition" *Cognitive Psychology* **21** 233–282
- Thompson P, 1980 "Margaret Thatcher—A new illusion" *Perception* **9** 483–484
- Troje N F, Bühlhoff H H, 1996 "Face recognition under varying poses: the role of texture and shape" *Vision Research* **36** 1761–1771
- Valentine T, 1988 "Upside-down faces: a review of the effect of inversion upon face recognition" *British Journal of Psychology* **79** 471–491
- Watson J S, Banks M S, Hofsten C von, Royden C S, 1992 "Gravity as a monocular cue for perception of absolute distance and/or absolute size" *Perception* **21** 69–76
- Wenderoth P, 1994 "The salience of vertical symmetry" *Perception* **23** 221–236
- Yin R K, 1969 "Looking at upside-down faces" *Journal of Experimental Psychology* **81** 141–145

ISSN 0301-0066 (print)

ISSN 1468-4233 (electronic)

# PERCEPTION

VOLUME 32 2003

[www.perceptionweb.com](http://www.perceptionweb.com)

**Conditions of use.** This article may be downloaded from the Perception website for personal research by members of subscribing organisations. Authors are entitled to distribute their own article (in printed form or by e-mail) to up to 50 people. This PDF may not be placed on any website (or other online distribution system) without permission of the publisher.