

cobs et al. 2000; Michaels & de Vries 1998; Runeson et al. 2000). Instead, they appear to rely on lower-order variables and to converge on the more informative variables only when given practice with feedback. That is, they educate their attention to optical variables that specify mass ratio or pulling force. Identifying a mass ratio of 2:1 or a pull of 250 N means that one has learned to pick up information that specifies mass ratio or pulling force. The education of attention is obviously learning, so it is only memory-as-stored-representation to which we object. We do not believe that one needs a qualitatively different theory to explain the education of attention to information that specifies that a bird is a chickadee or that a person is Fred. Identifying a chickadee or recognizing Fred is evidence that the education of attention has occurred; it is only spooky assumptions about time that entail the storage metaphor (cf. Michaels & Carello 1981).

We cited the above experiments in part because they involve making judgments, a putative ventral stream function in Norman's scheme. However, we differ from Norman by claiming that judgment is based on perception, not part of it. What is observable to the scientist is behavior – the participant can act on an environmental configuration or report what was perceived. Both types of observables are assumed to be a consequence of perception. In his section 5.2.2, Norman provides evidence of percept-percept coupling that favors the constructivist-ventral connection, but he and many of the authors he cites do not make a distinction between judging and perceiving. Equating reports of perception (i.e., judgments) with perception itself is an error that has led many investigators to conclude that percept-percept couplings occur. Traditionally, covariation, correlation and partial correlation have been used to investigate percept-percept coupling. These methods provide only a weak test of perceptual independence for two reasons: (1) they make no formal distinction between perceptual and judgmental process; and (2) while two independent variables are not correlated, uncorrelated variables need not be independent. Recent multivariate extensions of signal detection theory have addressed these limitations and established a method that makes a clear distinction between perception and judgment; and they provide a rigorous statistical definition of independence (Ashby & Townsend 1986).

The paradigmatic case of percept-percept coupling is the size-distance invariance hypothesis; it claims that a given visual angle determines a unique ratio of perceived size to perceived distance (Kilpatrick & Ittelson 1953). Cooper (1999) used the statistical advances of Ashby and Townsend (1986) to test the validity of the size-distance invariance hypothesis. In his experiment, observers viewed spheres (1.3, 1.5, and 1.7 cm diameter) placed at 3 viewing distances (780, 805, and 830 cm) under either monocular or binocular viewing conditions. Observers verbally reported both size and distance on each trial. While the analysis is too complex to describe here, the results clearly showed that size and distance are perceptually independent. This means that the perception of one dimension was in no way contingent upon or interacted with the perception of the other. These results suggest an alternative interpretation of the research Norman cites as evidence for the coupling of perceived size and distance in the ventral system. Namely, the apparent percept-percept coupling is due to post-perceptual decisional process, and not to an (unconscious) inferential process as Norman and the constructivists would argue.

We hope that, together, our comments suggest: (1) that perceptual learning, under the heading of the education of attention, is needed and expected in ecological psychology, and does not entail representations or comparisons; (2) that perception may or may not be faithfully preserved in the post-perceptual process of judgment, without impugning the perception on which judgment or inference is based; and (3) that the perceptual independence of size and distance refutes some of the evidence that Norman claims as support for a constructivist mode of perception in the ventral system.

Invariants and cues

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Abstract: The concepts of invariants and cues are useful, as are those of dorsal and ventral streams, but Norman overgeneralizes when interweaving them. Cues are not confined to identification tasks, invariants not to action, and both can be learned.

Norman has organized disparate metatheoretical views – one centrally represented by Gibson, the other by selected views of Helmholtz and of Rock – in terms of emergent binary schemes in neurophysiology over the last thirty years. From the latter, Norman has chosen the anatomical terms of dorsal and ventral, tried to make them functional, and provided an overview of several classes of data. The attempt at synthesis is laudable, but overgeneralization is its danger, and inconsistency a major cost. I note, in passing, that the perceptual evidence for a dorsal/ventral distinction is not always clear (Vishton et al. 1999), but I shall consider Norman's suggestion about dorsal invariants and ventral cues for the perception of space, or layout.

Gibson's goal was to understand and explore the general trustworthiness of perception. Railing against the centuries of claims about perception's faultiness – often couched as the *argument from illusion* – Gibson suggested that organisms surviving in real environments – what can be called the *argument from evolution* (e.g., Cutting & Vishton 1995) – made it extremely unlikely that perception is systematically faulty. He embraced invariants as the reason for perception's trustworthiness, but without a lot of evidence.

Two of Gibson's invariants that Norman mentions are texture interception and the horizon ratio. Unfortunately, these are invariant only under very restricted circumstances. Gillam (1995) noted that the texture interception is not invariant for any vertical objects occluding texture lying on or near a ground plane. Consider an example. Any two identical objects that are one eye-height tall and at different distances will have tops that intercept the horizon and will cover different amounts of ground texture, in part because their bases occlude different amounts of texture nearest the observer. Gibson's rule is true only for flat-lying objects occluding flat-lying texture. The horizon ratio is similarly constrained. That is, given two identical objects at different depths intercepting a true horizon, the ratio of the proportion above to that below is the same (invariant) for both. But, as Sedgwick (1986) noted, this is true only for objects that are small relative to their distance, that are identical in height, and for object bases and an observer's feet that are coplanar. The stringency of these conditions suggests that neither invariant is likely to get one very far, dorsally speaking. Although a number of perceptual invariants have indeed been found – and some are about identifying objects (e.g., a rigid, toppling ladder; Cutting 1986), not about action – it seems unlikely that they govern all of perception coupled to action (Cutting 1993).

Norman suggests that invariants and cues engage different neural systems, invariants invoking hardwired, innate processes and cues demanding algorithmic, inferential processing. Perhaps. But consider research on the perception of one's heading (direction of locomotion), a domain where yet another Gibson invariant – the focus of expansion – has little currency, except at high speed (Cutting 1986; 2000). Consider further, an invariant and a cue (Best et al. 2002; Cutting et al. 2000; Cutting & Wang 2000; Wang & Cutting 1999). During locomotion, the convergence in the field of view of any two stationary objects at different distances specifies that one's heading is to the outside of the nearer object. The accelerating divergence of any two such objects, however, specifies nothing – 69% of the time heading is to the outside of the farther object, 22% of the time between them, and 9% to the outside of the nearer object. From computer simulations of travel through

modestly cluttered environments, it is clear that observers can use both of these sources of information for heading judgments, although they spend more time looking at members of an invariant pair, when available, than at those of a cue pair. Are completely different neural mechanisms used in the two cases? – innate for the convergence invariant and algorithmic for accelerating divergence cue? I think not. Following E. J. Gibson (1969), I suggest these information sources are experienced by the young traveler – one found very trustworthy (convergence), the other less so (accelerating divergence) – and differentiated through that experience. Why hardwire either from birth?

In summary, cues are not just “ventral,” and invariants not just “dorsal.” Moreover, invariants are probably too rare to govern all of action, and some are likely to be learned.

Ecological and constructivist approaches and the influence of illusions

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Abstract: Norman tries to link the ecological and constructivist approaches to the dorsal and ventral pathways of the visual system. Such a link implies that the distinction is not only one of approach, but that different issues are studied. Norman identifies these issues as perception and action. The influence of contextual illusions is critical for Norman’s arguments. We point out that fast (dorsal) actions can be fooled by contextual illusions while (ventral) perceptual judgements can be insensitive to them. We conclude that both approaches can, in principle, be used to study visual information processing in both pathways.

The visual system has two main pathways for processing visual information: the ventral and the dorsal. Color, texture, and shape are primarily analyzed in the ventral pathway, while motion and egocentric position are analyzed in the dorsal pathway (Mishkin et al.

1983). More important for Norman’s distinction, the ventral pathway is believed to consider contextual information, while the dorsal pathway is believed not to do so. This difference in processing contextual information is what distinguishes ecologists’ invariants from constructivists’ cues and constancies. Thus, the influence of illusions, which often arise from misinterpreting the context, can be considered critical for this debate. Many studies have compared information processing in the dorsal and ventral pathways by comparing the influence of illusions in perceptual and motor tasks. In perceptual tasks, assumed to be processed by the ventral system, illusions obviously show an influence on the measured variables (otherwise, they would not be illusions). In motor tasks, assumed to be processed by the dorsal system, often no influence is found.

However, although they have received less attention, many experiments show that motor tasks can be influenced by illusions. When hitting a moving target with one’s hand, a moving background can lead to changes in the hand’s speed (Smeets & Brenner 1995a) and in the hand’s direction (Smeets & Brenner 1995b). Bridgeman et al. (1997) studied pointing movements towards a target within a frame. For half their subjects, an offset of the frame from the subject’s objective median plane caused a bias in the pointing movements in the opposite direction. Brenner and Smeets (1996) demonstrated that the force exerted to lift an object is influenced by the Ponzo illusion. Jackson and Shaw (2000) found the same for grip force. Yamagishi et al. (2001) showed that pointing movements towards a small window with a moving grating displayed behind it were biased in the direction of the grating’s motion. These experiments show that when performing motor tasks, as used by the ecologists to study invariants, subjects can be fooled by illusions.

Individual illusions also do not influence performance in all perceptual tasks. Smeets and Brenner (1995a) showed that background motion influences the perceived motion of a target, but not the perceived position. Similarly, the Müller-Lyer illusion influences perceived size but not the perceived positions of the endpoints (Gillam & Chambers 1985). Vishton et al. (1999) showed that the horizontal-vertical illusion is reduced considerably if the perceptual judgement is an absolute judgement of a single element of the display instead of a relative judgement of two elements. Similar results were obtained for the Ebbinghaus illusion

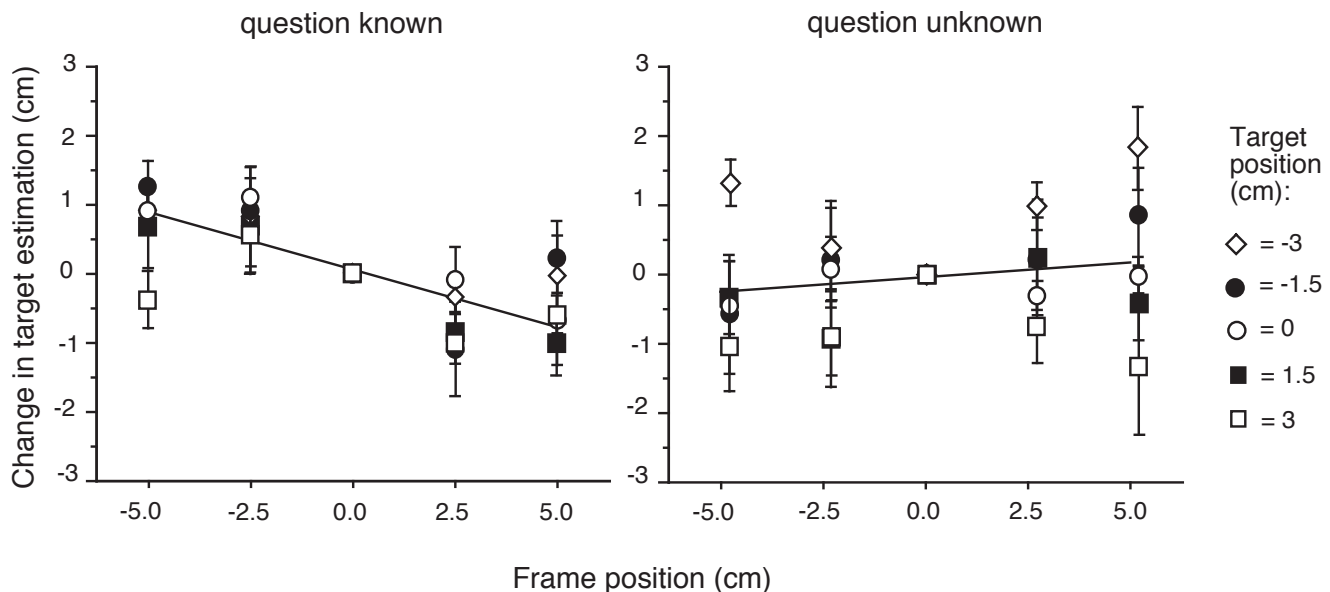


Figure 1 (de Grave et al.). Target estimation when the question was or was not known in advance. The values show the difference between the estimated position with the frame straight ahead and the estimated target position when the frame was shifted 2.5 or 5 cm to the left (negative) or right (positive). Error bars represent standard errors between subjects.