of such behavioral phenomena are provided in the studies of infant imitation done by Meltzoff and Moore (1977; 1983a; 1983b) in which they found that infants can contort their faces in imitation of another person's facial expressions within minutes of birth. Since these children have no idea how their faces look, visual cues thus seem to be leading to direct and immediate matches with tactile/proprioceptive sensations, with no time and no mechanism available for learning about correlations among distinctly apprehended sensory modalities.

Second, consideration of experiments like these suggests, more generally, that the early lives of neonates of all species must be rich in similar cross-modal sensory integration, given the sophistication of what they are able to do almost immediately. Although there is certainly no reason to argue that the world *never* presents itself to animals via singular sensory modalities, such presentations must be rare. Yet animals need to work with information in their environments almost immediately, and it is often the nuanced information that crosses and combines modalities that is most crucially needed, whether for balance, for reaching, for flight, or whatever. Animals simply do not have time to learn about the world by triangulating among independent contributions of several different senses.

Third, the idea that sensation is primitively multimodular makes considerable evolutionary sense. It seems likely that the several sense organs of each species have evolved as specializations of earlier less-specialized organs, based on the proven value of each specialization in enabling species members to survive and propagate. More general sensation must arrive on the evolutionary scene earliest, and then becomes more specific as a result of the contingencies of the niche. This seems consistent with a treatment of sensation that understands it most primitively as a global sensitivity to the environment, focused by opportunities and dangers available there, organized and differentiated by natural selection over time in terms of various sensory surfaces.

Finally, students of perception have frequently disagreed about how to understand the role of the several sensory modalities. It has seemed plain to anyone who has ever thought about sensation that colors are remarkably different from sounds, and although this has seemed to require a sharp distinction among the contributions of the several senses, there have also been suggestions that this distinction must be moderated in any suitable analysis.

George Berkeley (1709; 1713; 1733; Jessop 1937), for example, tried to distinguish between "immediate and proper" seeing and a more liberal sense of "seeing." The first – the bare immediate and proper "seeing" – is to be understood as uninterpreted, stripped of all learned associations. But Berkeley's own texts show that he was himself very uncomfortable with the traditionally conceived implications of this distinction.

This discomfort emerges quite clearly in Berkeley's examination of whether distance can be seen. His view was that although it cannot be seen "of itself and immediately," it can nevertheless be seen in a less restrictive sense. Indeed, according to Berkeley, there are a great many factors involved in determining our visual perception of distance, one of which is plainly the apparent magnitude of the thing seen. But this did not lead him to conclude that distance is seen indirectly via such cues as size, since that latter perception is often based on how far away we think the object is. Neither cue is less "directly" perceived than the other. Each can help in discerning the other. Another factor involved in determining *both* perception of magnitude and perception of distance is the apparent faintness of what is seen. But that is simply another factor in a very complicated contextual situation.

Berkeley argued, finally, that what one sees with regard to distance and magnitude is determined in part also by the posture of the head and eyes, and perhaps with the help of contributions from other sensory modalities. What is important here, though, is his forceful argument that no "judgment" or inference is involved in such seeing – the distance is suggested immediately. In sum, Berkeley's claim is not really that we do not see depth, for he explicitly says that we do. But he insisted equally that it is *we* who see . . . not our retinae (see Sanders, forthcoming).

This line of thinking shows, in any case, that even Berkeley's thoughts on the subject examined by S&B were not as antithetical to their thesis as might be imagined. There is also support here for the idea that a theory of "direct" perception need not be as counterintuitive as has sometimes been maintained. The line of study urged by S&B would amount to a Gestalt switch of sorts, it is true. And it is important to acknowledge, even in their proposed research program, the importance of studying the separate sensory modalities in order to further understand their contribution to sensation. The upshot would be, though, that sensation would be understood not as taking place at sensory surfaces, in particular, but throughout a larger global sensory system which has those surfaces as parts.

Multi-sensory processing facilitates perception but direct perception of global invariants remains unproven

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Abstract: The existence of sensory convergence does not establish that the senses function as a single unified perceptual system. Reality is fully specified only by a one:many mapping onto the totality of energy arrays, and these provide alternative frames of reference for movement. It is therefore possible that higher order crossmodal relationships are detected by skilled perceivers, but this has not been confirmed empirically.

After the initial agenda setting in the target article (sect. 1), Stoffregen & Bardy (S&B) (2001) consider in section 2 the three arguments (anatomy, energy, and neurophysiology) that are used to support the idea of the separate existence and functioning of each sense. They correctly reject the anatomy argument by pointing out that inputs are required from the two (anatomically separate) ears in order to localise sound; this establishes the point that anatomically distinct origins are not sufficient to preclude later functional interdependence. But the energy argument is not, as they claim, circular: the electromagnetic and vibrational energies to which the eye and ear respond can be defined independently of the eye and ear. The neurophysiology argument is a variation of the anatomy argument and similarly establishes that initial separation of sensory inputs is not evidence against later convergence and unified perception. In short, the anatomy and neurophysiology arguments are correct but not new, whereas the energy argument is incorrect. The authors' arguments from example do entail the limited (weak) conclusion that sometimes two or more senses act as a single perceptual system, but do not justify the universal (strong) claim that the senses never function as separate systems and that they all and always function together in a unitary and irreducible manner.

Section 3 of the target article distinguishes four possible relationships (no specification, modal, multiple independent, and multiple amodal specification) between reality and the ambient array. The authors conclude that "each (relationship) . . . is confronted with problems" (sect. 3.4) and that "all theories of perception derived from existing views of specification are compromised by fundamental errors" (sect. 1). Their pivotal reason for rejecting all four views is that (1) each view involves the possibility of sensory conflict, and (2) since the senses act as a unified single perceptual system, there cannot be conflict between the separate senses. This argument would not be sufficient to reject the four views even if the strong version of sensory unity were correct, because there is no a priori reason why there cannot be conflict within a system. Additionally, there is a major inconsistency between rejecting the independent amodal view of specificity defined as "a one:many mapping, with properties of reality being

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specified by patterns existing in different ambient arrays"[1] (sect. 3.3.2) and later concluding that "specification exists . . . structure exists in the global array"(sect. 7). Furthermore, I would argue that there is no possible alternative to this view, not on any empirical grounds, but because it is a tautology: it is necessarily true since the reality of an object or event is *defined by* its effects on the ambient energy arrays. A more direct rebuttal of the argument that sensory conflict presents an insuperable problem for all four views can be derived from the fact that each sense uses a different form of energy for its frame of reference (see sect. 3.1.2, where this idea seems to be dismissed as the incorrect view of others, and sect. 5.1, where it is presented as their own correct analysis); consequently, there is no sensory conflict in the situation where one is stationary with respect to Newtonian three-dimensional coordinates but moving with respect to the illuminated or acoustic environment.

Section 4 reminds us that all movement is relative, that our senses provide movement information in relation to multiple, often independent, frames of reference, and that the relevant frame of reference for the control of behaviour is not always the surface of the earth. One might add that a much more widespread class of examples than diving for a fly ball is any action (e.g., pouring a drink) in a moving vehicle. It is, however, misleading to state without qualification that perception involves motions of receptor systems; for example, visual perception can be successful with the eye muscles anaesthetised and the head restrained by a dental bite, and one can correctly perceive speech via radio and telephone while motionless and therefore with no movement of receptors. In short, movement facilitates perception but is not essential.

Although the arguments in section 5 again show that reality cannot always be specified by one single energy array, they have two shortcomings. First, the examples here, as elsewhere in the target article, are limited to the McGurk effect and to movement. And what is unusually convenient about movement, but is not sufficient basis for the general conclusions that the authors wish to draw about all perception, is that, a fortiori, movement involves movement of perceptual systems. This is because almost every component of the organism is capable of responding to the energy fields associated with movement – for example, body surface, viscera, the flesh between skin and bone, free nerve endings, stretch-, pressure-, and angle-receptors, as well as otoliths, canals, auditory and visual systems.

Section 6 confuses physics with psychology. The *reality of the physics* is that the totality of energy arrays specify reality in two ways: first, by the state of each ambient array, and second, by the pattern of relationships across or between ambient arrays. It is not possible for one array to change without there being a change in at least some feature of the global pattern across the array, although a particular salient feature, such as the category of shapes conforming to triangularity, or the category of actions constituting destabilising movements, may remain an invariant. The claim that "the global array is influenced by events that do not structure single-energy arrays" is not supported by the subsequent examples of cars in motion or decelerating, static and dynamic ankle rotation, or Fouqué's pairwise comparisons; on the contrary these examples illustrate that changes in individual arrays entail a change in the global array. The *reality of the psychology* is uncertain: we *may* discern the separate activities of the different receptor types responding to different energy types, or the different activity in converging and diverging pathways and in the dedicated or shared projection areas; and by concurrently, or otherwise, processing this activity we may infer an appropriate percept. Alternatively, perception *may* be direct in the sense of being fully specified by the sensory input (including the perception of efference?) and requiring no memory, comparison, or inference, and what is directly perceived may be an intersensory superordinate relation. The heart of the authors' position is that there is direct perception of the left-hand side of the equation without the need for perception of the computational variables on the right-hand side. This latter view does not appear to be currently supported by any neurophysiological findings, nor could it ever be supported by a research agenda based on most of perceptual equations currently known, since these contain terms specific to only the same energy array (e.g., Equations 1 and 2 in the target article). Moreover, a study (Amazeen 1997) which yielded one of the few formulations relating perception to two types of energy array (perceived heaviness, dynamic touch$^{0.95}$, perceived volume $^{-0.18}$), also showed that each term from the right-hand side could be perceived separately.

To conclude, the article contains original analyses (types of specification, movement in relation to different frames of reference) and syntheses (the concept of sensitivity to the global array) and important practical recommendations (allowing participants to move during perception, assessing perception by action rather than by report); it demonstrates that in movement situations and sometimes in other situations veridical perception depends on more than one of the "separate senses"; it shows, perhaps unwittingly, that, within the limits of acuity and sensitivity, reality is fully specified both by the global array and by the total set of sensory inputs that constitute the global array; but it has not provided empirical evidence for direct perception of higher-order emergent properties in the global array.

NOTE

1. Although the word "redundant" appears in their first description of amodal specification, the authors later (sect. 3.3.3) ackowledged that this view includes both redundant and discrepant information.

Authors' Response

Theory testing and the global array

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Abstract: The new commentaries raise important issues about the target article (Stoffregen & Bardy 2001). The commentaries also highlight some assumptions, often implicit, that underlie traditional interpretations of perception. We argue that evaluation of the global array and its implications for perception requires both analytical research on specification in the global array and new empirical research on the use of information in the global array for the control of action.

R1. Physics versus psychology

Amazeen & Van Orden argue that the existence of specificity solely in the global array is a testable hypothesis, and they argue that other testable hypotheses also exist. We agree with both of these arguments (see sect. R12 in our response to the earlier commentaries).

In the target article, we made three claims. First, we claimed that specification cannot exist in single-energy arrays. Second, we claimed that specification exists in the global array. Third, we claimed that the information in the global array is necessary and sufficient for direct perception (i.e., perception that is accurate without inferential mental processing). This final claim led to the hypothesis that perceivers detect structure in the global array.

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