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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Amazeen & Van Orden, Pedersen & Sigmundsson, and **Warwick-Evans** do not clearly distinguish between the claims that specificity exists in the global array and only in the global array, on the one hand, and the hypothesis that structure in the global array is detected by perceivers, on the other. Falsification of specificity in ambient arrays (the global array or any other) is an analytical problem, not an empirical problem (thus, specification is a testable hypothesis, but it cannot be tested using empirical data). As we noted in the target article and our response to the original commentaries (sects. 1, 6, R2, R5), the debate about the existence of specification is not about psychology but about ecological physics (Runeson & Vedeler 1993). Figure R1 illustrates the differences between reality, ambient arrays, and sensory stimulation (cf. Figure 1 of the target article).

The hypothesis of specification concerns relations between reality and ambient arrays. Characteristics of actual sensory stimulation are secondary, both temporally and logically, to relations between ambient energy and reality. Accordingly, empirical data, such as subjective reports and perceptually guided action, can be used to evaluate the detection and use of information in ambient arrays, but it cannot be used to determine whether patterns in ambient arrays bear a specificational relation to physical reality. Therefore, we regard the empirical effects discussed by **Amazeen & Van Orden, Pedersen & Sigmundsson,** and **Warwick-Evans** as being irrelevant to the physical issue of specification in the global array, and having relevance only to the psychological issue of whether perceivers detect and use structure in the global array or in single-energy arrays. The best way to test our hypothesis about the pick-up of information from the global array is to develop methods that will permit it to be contrasted empirically with other, competing theories of perception (sects. 7, R12). An essential first step in such an evaluation is analytically to derive structures in the global array that specify some aspect of the animal-environment interaction and which, therefore, might be detected and used to perceive that aspect.

R2. Specificity cannot exist in single-energy arrays

Amazeen & Van Orden discuss perception in the moving room paradigm, and they consider three interpretations of how people may perceive motion relative to gravito-inertial referents and illuminated referents. One interpretation is ours: that perception and action are based on the pick-up of information from the global array. The two alternative interpretations they offer both assume that perception operates at the level of single-energy arrays. We regard it as unfortunate that they do not discuss how their interpretations relate to the concept of specification. One of our central arguments was that previous concepts of specification lead inexorably to discrepancies in the motions suggested by patterns in different forms of ambient energy, which entails a lack of specificity (sects. 3, 4, 5). In suggesting that perception may operate at the level of single-energy arrays, Amazeen & Van Orden, **Radeau & Colin, Sanders,** and **Warwick-Evans** do not address this problem (which was also not addressed by several of the original commentators; e.g., McMichael & Bingham 2001; Michaels & Oudejans 2001; Peper & Beek 2001; Rosenblum & Gordon 2001; Runeson et al. 2001; see sect. R8 of our earlier response). For example, Sanders claims that there is "no reason to argue that the world never presents itself to animals via singular sensory modalities." We argued at some length (sects. 3, 4, 5, R8) that unambiguous information about the animal-environment interaction (i.e., specification) cannot exist in the structure of any individual form of ambient energy. Based on this, our rejoinder to the suggestions of Sanders and others is that there is no basis in the physical world for an argument that reality can be specified in any single-energy array. As two examples, consider the following. The advance of visual technology (e.g., spatiotemporal resolution), of simulation software (e.g., computer models of optical dynamics), and of motion tracking systems (which make it possible to couple a perceiver's movements to a visual simulation in real time) suggest that in the near future we will have reached a point where any pattern that can arise in the optic array as a result of "real"

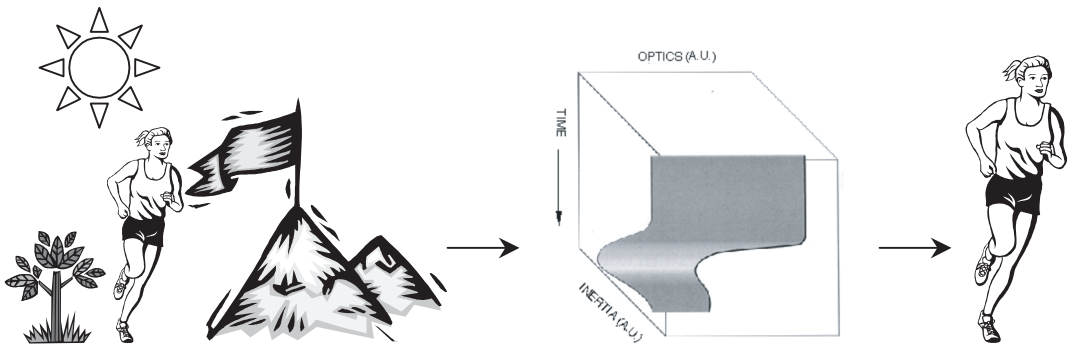


Figure R1. **A.** Animal-environment interaction (reality). **B.** Ambient energy fields (the global array). **C.** Sensory stimulation (activity at receptor surfaces). The animal-environment interaction structures ambient energy fields. Specification concerns only relations between reality and ambient energy fields. Perception depends upon sensitivity to properties of ambient energy fields (e.g., the nature of the energy, or the structure that it contains). The same person appears in A and C, indicating that actors are also perceivers, and that actions influence the information available to the actor's perceptual systems.

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movement can independently be created as a result of simulated movement. In other words, all possible patterns in the optic array will correspond to at least two states of the physical world: an object or event in the physical world, an object or event in a simulated world. Specificity requires that each pattern in an ambient array arise from and correspond to one and only one aspect of the animal-environment interaction. Visual technology will cause that requirement to be violated in the case of any and all patterns in the optic array and, accordingly, no pattern in the optic array can bear a unique or specificational relation to any object or event in the world (Stoffregen et al. 2003). The same is true of patterns in the acoustic array. Technology for acoustic simulation and reproduction is rapidly approaching the point at which any given pattern in the acoustic array can be created by at least two aspects of the animal-environment interaction: a "real" sound-producing event and a "simulated" sound-producing event. Thus, 1:1 correspondence between acoustic patterns and states of the world is violated and, accordingly, the acoustic array does not specify properties of the animal-environment interaction.

Another point concerns relations between different single-energy arrays. Like many of their predecessors (e.g., McMichael & Bingham 2001; Michaels & Oudejans 2001; Peper & Beek 2001; Rosenblum & Gordon 2001; Runeson et al. 2001; Thomas 2001), in arguing for the existence of specification within individual forms of ambient energy **Radeau & Colin, Sanders,** and **Warwick-Evans** do not address the fact of the constant, simultaneous stimulation of multiple perceptual systems (sects. 1, R8). Multimodal stimulation is ubiquitous and is known to be detected and used in the control of action, including movements of the body (e.g., Berthoz 1997), of the head and limbs (e.g., Peper et al. 1994), and so on. As a result, a pattern within a single type of ambient energy is never the sole stimulus, and is never the sole information that is picked up. If specification did exist in single energy arrays (a point that we continue to dispute), this would still leave open the issue of how the animal deals with the fact of constant, simultaneous stimulation of multiple perceptual systems. We argued that this could be accommodated in an ecological theory only within the concept of the global array (i.e., cooperative pickup of global structures). Warwick-Evans and other defenders of specification in single-energy arrays do not address this issue. Warwick-Evans notes that intersensory conflict is possible within individual perceptual systems. We accept this assertion, but it is beside the point. Intersensory conflict would exist only if animals attempted to perceive on the basis of patterns available in single-energy arrays. If specification exists in the global array, and if perceivers are sensitive to the global array, then conflict will not exist within or between perceptual systems.

R3. Selective pickup of information in the global array

The existence of information in higher-order patterns within the global array seems to have suggested to many readers that if perception is based on the global array, it must be omnivorous – that is, perceivers are obliged to pick up all available information. Such obligatory, omnivorous pickup would be a problem, and would fly in the face of the obvious facts that perceptual systems are not sensitive to all dimensions of the global array and that perception is selective. However, the existence of information in the global array does not imply any obligation for perceivers to pick up all available information. Perception is selective, regardless of the nature or locus of perceptual information (Gibson & Pick 2000).

Ohlmann et al. argue that different animals should use the global array in different ways. We agree; we made just this point in responding to the original commentaries (sect. R11). In a given situation, different species or individuals will sample different portions of the global array, and a given species or individual will sample different portions of the global array in different situations, or when performing different tasks. However, the fact that perception is selective does not imply that perceivers will selectively sample structure in individual forms of ambient energy (in effect, Ohlmann et al. propose that people often ignore the global array). We agree that "subsets of reality" are sufficient for most behaviors and situations. Selective perception of situation-specific aspects of reality is commonplace. Selective perception implies that ambient information is sampled selectively and, therefore, in our account, the global array will be sampled selectively. But this does not imply that perceivers would choose to sample single forms of ambient energy. Sampling of structure in single forms of ambient energy would be useful only if a situation-specific subset of reality lawfully influenced the structure of only one form of ambient energy and did not influence the structure of the global array. Ohlmann et al. offer no argument as to how this could happen, or when it might. We have argued that anything that influences the structure of any single-energy array must also influence the structure of the global array (sect. 6). The heart of our critique of the concept of unimodal specification was our claim that, as a matter of physics, patterns in any single-energy array are intractably ambiguous with respect to physical motion (sects. 4 and 5). This leads to the conclusion that specification does not and cannot exist in single-energy arrays. Moreover, we noted that all objects and events that structure single-energy arrays also structure the global array. This leads us to argue that the information available in the global array is sufficient (in principal) for all perception.

Ohlmann et al. appear to assume that the fact of selective pickup implies selection on the basis of forms of ambient energy. This assumption suggests that they may have confused reality (what is perceived) with information (what enables perception). Reality is not categorized in terms of ambient energy. In daily life, people do not talk about "optical reality," "chemical reality," "gravito-inertial reality," and so forth. Rather, we classify reality into functional categories: food (eating), shelter (sleeping), friends (socializing), mates (reproducing), children (parenting), and so on. To assume that perception is categorized by forms of ambient energy appears to imply that we do not have direct sensitivity to the underlying reality; that is, it appears to imply that we have perceptual sensitivity only to ambient energy and not to the world that structures ambient energy. The ecological approach motivates the hypothesis that perceivers are directly sensitive to reality. If this is so, then there is little reason for perceivers to organize their perceptual-motor exploration in terms of individual forms of ambient energy. Indeed, perceivers should be strongly motivated to avoid limiting their pickup to single-energy arrays since (as we argued in sections 4 and 5) the patterns in single-energy arrays are fundamentally ambiguous with re-

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spect to physical motion, and therefore are very unlikely to prove useful for the perception or control of the animal-environment interaction.

Ohlmann et al. argue that, in well-practiced conditions, single-energy arrays may be sufficient for perception and control of action, and that in such situations animals are not "obliged" to "work at a higher level." For us, the logic of their argument is backwards. If specificity exists in the global array and does not exist in single-energy arrays, then animals would always be motivated to use the information in the global array because it is these patterns that provide reliable information about the animal-environment interaction. If, as we claim, single-energy arrays are not specific to reality, then why would perceivers ever be motivated to resort to them? Ohlmann et al. appear to assume that, given the choice, perceivers would prefer to use patterns in single-energy arrays, that single-energy patterns would be more familiar, or easier to use, and so on. We see these assumptions as being testable, and we have predicted that they will be disconfirmed (sect. 7). Testing of these assumptions will require new research that is designed to contrast patterns in single-energy arrays and in the global array.

Ohlmann et al. reiterate the argument of earlier commentators (Cabe 2001; Brenner & Smets 2001) that perception need not always be accurate. In response, we reiterate our argument that the accuracy of perception is independent of the issue of specification (sects. 7, R6). That is, specification makes it possible for perception to be accurate but does not mandate or guarantee accuracy. Perception may be inaccurate despite the existence of specification if, for example, the perceiver picks up the wrong information, as in the case of the train illusion, in which people perceive themselves to be in motion (relative to the earth) when in fact it is an adjacent vehicle that has moved relative to the earth. This is a clear case of perceptual error, but it does not imply that ambient arrays bear an ambiguous relation to reality.

Ohlmann et al. refer to redundancies in potential sensory stimulation, but make no response to our argument (sect. 3.1.3) that such redundancies are rare in ordinary life. Relative to one another, single-energy arrays are non-redundant far more often than they are redundant. Also, the argument from redundancy again assumes that the level of single-energy arrays is somehow the main or primary level of analysis for perception. Sometimes there are redundancies between single-energy arrays, but this does not imply that perception does or should operate at this level of analysis.

R4. Physical referents for perception and action

Relative motion in the physical world is at the center of our argument against the existence of specification in single-energy arrays (sects. 4, 5). For this reason, we were surprised that motion relative to different physical referents was not addressed by earlier commentators (e. g., Michaels & Oudejans 2001; Peper & Beek 2001; Rosenblum & Gordon 2001; Runeson et al. 2001) who argued that specification exists in single-energy arrays. Developing a response to our arguments about relative motion is a serious challenge for scientists who argue that specification exists in single-energy arrays (sect. R7 of earlier response).

Pedersen & Sigmundsson discuss subjective reports relating to self-motion. They appear to argue that in the moving room paradigm, imposed optic flow is ambiguous with respect to physical motion of the observer. We agree; we made exactly this point in sections 5.1 and 5.2 of the target article: The optic flow could be produced by motion of the room relative to an otherwise stationary observer, or by motion of the observer relative to an otherwise stationary room, or by different motions of the two. However, we did not claim that subjective reports of self-motion in moving rooms are fundamentally ambiguous. Rather, we pointed out the fact of relativistic physics that subjects in a moving room are actually in motion relative to the room, while simultaneously being actually in stasis relative to the earth.[1] There is no ambiguity in the physics; it is simply the case that subjects are in motion relative to some physical referents, while being in stasis relative to others. It is because of this that subjects can truthfully (accurately) report either that they are moving or that they are stationary, or both. The subjective reports are ambiguous only due to weakness in experimental design arising from the fact that experimenters, in requesting subjective reports, have neither (1) specified a physical referent for perception of motion or stasis, nor (2) asked subjects to indicate the referent that they are using.

We discussed perceptual reports in the moving room paradigm (sect. 5.2) as an example of the conceptual ambiguity that underlies many existing datasets. The main point of our example was that in most previous research there have been ambiguities (in design, in interpretation, or both) involving the physical referents for the perception of motion or the control of motion, or both. We agree with **Amazeen & Van Orden** that there may not be complete overlap between the information that influences consciousness and the information that is used to guide action, but this is tangential to the purpose of our example.

Warwick-Evans claims that we endorsed a position in one place and rejected the same position elsewhere. He notes, correctly, our rejection of sensory reference frames (sect. 3.1.2), but claims that in section 5.1 we endorse sensory reference frames. His latter characterization is incorrect. In section 5.1, we pointed out that individual forms of energy are structured by position and motion relative to limited classes of physical referents. Warwick-Evans appears to have confused sensory reference frames, in which the referent is the receptor, with reference frames in which the referent is something other than the receptor (e.g., rocks, moving rooms, planets, other people). In section 5.1 our discussion concerned referents that structure potential sensory stimulation, whereas in section 3.1.2 our discussion concerned referents (i.e., receptor surfaces) that structure actual sensory stimulation. There is, however, one point of similarity between our analyses of sensory reference frames (sect. 3.1.2) and of single-energy arrays (sect. 5.1). We argued that specification does not exist and cannot exist in sensory reference frames (i.e., patterns of actual sensory stimulation arising from a single form of ambient energy) or in single-energy ambient arrays.

Many of the commentaries, both previous and present, do not distinguish clearly between physical referents, ambient energy, and actual sensory stimulation (see Figure R1). Physical referents (e.g., rocks and trees) exist whether or not there are any ambient energy fields (e.g., they exist whether or not the environment is illuminated). Ambient energy fields (light, sound, and so on) exist whether or not there are perceiving animals or receptor systems, and whether or not animals search for, pick up, detect, or make

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use of the information that such fields may contain. Actual sensory stimulation depends upon the prior existence of physical referents and ambient energy fields. Physical referents, ambient energy fields, and actual sensory stimulation differ qualitatively. In principle, action might be perceived and controlled relative to any of these. Control of action relative to actual sensory stimulation (i.e., sensory reference frames) would be problematic because sensory reference frames bear an ambiguous relation to the animal's interaction with the physical environment. Control of action relative to referents in ambient energy fields (e.g., angular position in the optic array) would be problematic because in most cases the entities of interest are in the animal-environment interaction, not in energy fields. Control of action relative to physical referents, if possible, would be best because most of our behavioral goals are defined in terms of physical referents (e.g., we seek to eat food, rather than to eat patterns of light that reflect from food, or rather than to eat patterns of retinal activity that arise from light reflected from food). If specification exists, then perception and control action relative to physical referents is possible (sect. 6).

R5. Perceptual-motor development

Radeau & Colin and **Sanders** endorse the idea that in early life perception is "rich in cross-modal sensory integration." **Sanders** also observes that in evolutionary history the emergence of receptor systems that are keyed to individual forms of ambient energy is relatively recent. Empirical research has documented the multisensory sensitivity of even single-celled creatures (e.g., Berg 2000; Pittenger & Dent 1988; see also Stein & Meredith 1993).

Radeau & Colin suggest that early sensitivity to the global array is followed by development of sensitivity to structures in single-energy arrays. In making this suggestion they offer no reason why a perceiver who was sensitive to the global array would want to acquire sensitivity to anything else. As we noted in the target article (sect. 6) and in our response to the original commentaries (sect. R8), if specification exists only in the global array, and if perceivers are sensitive to information in the global array, then sensitivity to patterns in single-energy arrays would be of no benefit. Studies that purport to document a gradual emergence of sensitivity to structures in single-energy arrays can be reinterpreted. Rather than learning to differentiate among different types of ambient energy, it is possible that neonates learn to differentiate among different external referents for the control of action. If perception is direct, then we do not perceive sensory stimulation or forms of ambient energy; rather, we perceive the animal-environment interaction, as such. Thus, learning would be "learning about the animal-environment interaction" rather than "learning about visual stimulation, auditory stimulation, and so on" (Gibson & Pick 2000). This possibility can be evaluated only if researchers decline to *assume* that perception consists exclusively or primarily of sensitivity to sensory stimulation, as such.

R6. Visual capture and neurophysiology

Radeau & Colin discuss the ventriloquism effect, also known as *visual capture.* Many events that influence the structure of the acoustic array also influence the structure of the optic array. Examples are speech and dribbling a basketball. In experimental manipulations, it is possible to separate the acoustic and optical consequences of events, in both space and time. Visual capture refers to the fact that observers often experience audible events as originating from the spatial location of visible events, even when they do not. Radeau & Colin review some of the typical characteristics of visual capture, focusing on the fact that visual capture is associated with aftereffects on pointing. Exposure to spatially separate visible and audible events leads to systematic direction errors in subsequent attempts to point to an audible event (while blindfolded).

Two characteristics of the visual capture paradigm are of particular relevance in the present context. The first concerns the response measures that are used. There is a disjunction between the subjective experience of visual capture (i.e., the experience that visible and audible events have the same location), and aftereffects of the spatial disjunction on pointing. Radeau and Bertelson (1977) created experimental separation of visible and audible event location. In separate experiments, subjects were asked to point to the location of the audible event or to press a key to report the subjective experience that audible and visible events had the same location. The experimental manipulations had different effects on pointing and key pressing. The disjunction between subjective experience and perception-action has been found in a wide variety of situations (e.g., Bootsma 1989; Fouque et al. 1999). This disjunction does not, by itself, implicate any theory of perception.

The second relevant aspect of the visual capture paradigm relates to perceptual-motor exploration. In research on visual capture, subjects typically are seated with the head restrained by a bite bar (e.g., Radeau & Bertelson 1977), or by the requirement to keep the head in contact with a stationary device (e.g., Radeau & Bertelson 1974). These restrictions on head movement severely limit normal patterns of both visual and auditory exploration. Head movements are known to be essential for ordinary sound localization (e.g., Gibson 1966; Kellogg 1962; Rice 1967; Wallach 1940). The inability to localize audible events (as occurs with visual capture) may arise from artificial limitations on perceptual-motor exploration that characterize the experimental design, as appears to be true for a variety of laboratory illusions, such as the Ames room (Runeson 1988). Interestingly, in research on visual capture, head movements have been permitted only when the dependent variables are limited to reports of subjective experience, with no perception-action component (experiment 3, Radeau & Bertelson 1977).

Studies of nonhumans (e.g., Knudsen & Knudsen 1989) are of doubtful relevance to the ventriloquism effect. Such studies provide no data about the subjective localization of visible and audible events. For this reason, even though such studies can confirm that humans and nonhumans have similar perception-action adaptation to prisms, their relevance to the ventriloquism effect can be only conjectural.

Radeau & Colin also review some of the research on multisensory neurophysiology. The existence of multisensory neurons is one of the most exciting discoveries in recent neurophysiological research. The foundational work of Stein and Meredith (1993) has given rise to a new field of research, and to the discovery that multisensory neurons can be found at several levels of the central nervous system (e.g. Wallace et al. 1992; 2004). We regard research on mul-

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tisensory neurophysiology as being of great potential relevance to our hypothesis that perceivers are sensitive to information in the global array. However, we note that the existence of multisensory neurons does not, by itself, implicate any theory of perception (cf. sect. R1 of the earlier response). Researchers often interpret such neurons as sites of multisensory "integration" or "processing." These interpretations typically reflect the assumption that the nervous system acts to alter or enrich incoming perceptual information. The hypothesis that multisensory information is integrated by the nervous system arises out of the traditional assumption that perception consists of a set of channels that have access to qualitatively different stimuli (i.e., different forms of ambient energy). By contrast, if information exists in higher-order patterns that extend across forms of ambient energy (i.e., if information exists in the global array), and if perceivers are sensitive to global array parameters, then there would no need for multisensory "integration"; the integration exists outside the head and does not need to be created inside the head. Rather than combining or integrating stimuli from different perceptual systems, multisensory neurons may act to detect higher-order properties of multisensory stimulation, as we argued in section 6.2.4 (see also Stoffregen & Bardy, in preparation). The ability of neurons to respond to higher-order properties of stimulation has been documented in the context of the optic array (Saito et al. 1986; Tanaka & Saito 1989). We predict that it will be possible to document neural sensitivity to higher-order patterns in the global array. To evaluate our prediction, it will be necessary, first, to identify parameters of the global array that can be manipulated experimentally and presented in the context of neural preparations. For two reasons, existing research on multisensory neurons does not meet this criterion. First, researchers have assumed that the only perceptual information present was in single-energy arrays; that is, they have not taken into account the fact that events that alter the structure of individual forms of ambient energy also (necessarily) alter the structure of superordinate, emergent patterns in the global array. Second, any attempt to identify or experimentally control patterns in the global array has been complicated by the creation of arbitrary pairings between events (e.g., a tone paired with a flash of light; Meredith & Stein 1986). Given the conceptual and methodological characteristics of these studies, the identification of neurons that may respond to patterns in the global array is all the more remarkable.

R7. Perception and action without deception

In interpreting perception in the moving room paradigm, **Amazeen & Van Orden** suggest that individual perceptual systems might yield independent percepts of motion relative to different physical referents, and that these percepts might interact only in the organization of responses. This could happen, they claim, "if the observer is misled to believe that the floor and walls must move together." Deception is not required for people to exhibit postural responses to a moving room (i.e., to stabilize the head and body relative to the room as the latter moves relative to the floor), or for the subjective experience of self-motion (Lishman & Lee 1973). In our research, we have never attempted to deceive subjects: On the contrary, we have explicitly informed subjects that the room moves relative to the floor (e.g., Oullier et al. 2002; 2004; Stoffregen 1985: 1986; Stoffregen & Smart 1998; Stoffregen et al. 2004). Other researchers also have not attempted to deceive subjects (e.g., Lee & Lishman 1975; Lishman & Lee 1973).

R8. Need for new research

Several of the commentators offer alternative interpretations of some of the studies that we discussed in the target article (e.g., **Amazeen & Van Orden, Pedersen & Sigmundsson,** and **Radeau & Colin**) or argue that perceptual sensitivity to the global array is not supported by existing research (e.g., **Warwick-Evans**). They point out (correctly) that our interpretation of existing data in terms of the global array is not the only possible interpretation, and they argue that the data also can be interpreted in other terms, such as percept-percept coupling or response bias. We agree that existing data are amenable to multiple interpretations. It is for this reason that we argued in the target article (sect. 7) and in our reply to the original commentaries (sect. R12) that only new research can be used to evaluate (i.e., falsify) the hypothesis that direct perception is based on specification in the global array. Empirical evaluation of the hypothesis that perceivers detect information in the global array will require tests in which patterns in single-energy arrays and in the global array are manipulated independently, under experimental control. Such manipulations are possible (we gave a detailed example in sect. R12). They can be done most rigorously and most easily if researchers begin by identifying analytically patterns in the global array that are influenced by particular aspects of the animal-environment interaction. This places a premium on formal, analytical modeling of patterns in the global array. That such analysis is possible is shown by parameters of the global array that have already been identified (e.g., Bingham & Stassen 1994; Peper et al. 1994; Stoffregen & Riccio 1988, Eqns. 4–6).

Our analysis implies the detection of information in the global array. As suggested above, it has implications for how information is used in movement control – that is, for *control laws.* In the ecological approach to perception and action, control laws describe how animals can use some parameter of an ambient array to regulate a free parameter of the action system. Animals are assumed to select and exploit particular control laws to achieve particular behavioral goals. The concept was originally suggested by James Gibson (1958) and has recently undergone rapid development in the context of locomotion and navigation (Warren 1988; Fajen & Warren 2003) and manual interception (e.g., Montagne et al. 1999). For example, when lateral movements of the hand are used to intercept a ball in flight, Montagne et al. suggested that the lateral velocity of the hand is continuously coupled onto the optically specified velocity of the approaching ball. Control laws are important because they permit us to formalize the perceptual information that animals use to perceive and regulate behavior, on a task-specific basis. Ultimately, a successful theory of perception and action should be able to specify control laws for any given aspect of the animal-environment interaction. To date, however, efforts to formalize control laws have been conducted primarily in the context of single-energy arrays (e.g., Montagne et al. 1999; Warren 1988). We regard this effort as problematic because,

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as we have argued, parameters of single-energy arrays can never bear a specificational relation to the animal-environment interaction. If we are right, then laws of control cannot be formulated in terms of single-energy arrays.

There is no a priori reason why control laws should be limited to single-energy arrays. Regulation of action may be achieved by coupling parameters of the action system to patterns in the global array. Given that, by our analysis, specification exists solely in the global array, it follows that lawful relations between perception and action must refer solely to parameters in the global array. We argue that parameters of the action system can be appropriately tuned to properties of the global array, instead of properties of single dimensions of the global array (i.e., optics, acoustics). The existence of control laws that refer to the global array has been demonstrated in at least one instance. Equation 2 in the target article (sect. 5.3) constitutes a control law that is based on the global array. Peper et al. (1994) considered manual interception of moving objects. They developed a formal model in which the current velocity of the hand is continuously regulated based on a property of the global array. In section R12, we provided a detailed description of how perceptual reality of this control law might be tested. We suggested coordinated manipulation of optics (by deflating the ball during the approach) and haptics (by changing the eigenvectors of the hand's inertia tensor during the approach) that would be appropriate to contrast optical control laws and control laws based on the global array.

In the target article, we emphasized the need for analytical research that can formalize the existence of specification in the global array, and the need for new research that can test the hypothesis that perceivers are sensitive to information in the global array. We now note the need for two additional lines of effort: New analytical research is needed to derive control laws in which action can be regulated by parameters of the global array, and new empirical research is needed to determine whether action actually is regulated on the basis of these control laws.

R9. Concluding remarks

We are pleased that several of the new commentators (e.g., **Amazeen & Van Orden, Sanders**) appear to agree that our overall theoretical position has sufficient plausibility to merit further study. The utility of information in the global array arises out of relativistic physics, out of the facts that (1) perception and action must be controlled with respect to multiple, simultaneous physical referents, and (2) physical referents can move independent of one another, and animals can be in different types of motion relative to different referents. It is these relativistic physics that render single-energy arrays ambiguous with respect to reality (and, we argue, insufficient for perception and control of action). Yet these relativistic physics also give rise to specification in the global array. As we noted in section 6 of the target article, the global array is a fact, not a hypothesis. Higher-order relations between different forms of ambient energy exist. Research needs to be directed toward new questions that arise from the existence of the global array: Are patterns in the global array specific to reality, and, if so, do animals use information in the global array for the perception and control of action?

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NOTE

1. This description leaves out body sway; if we take sway into account, then the correct description would be that subjects were in different motions relative to the room and the earth. This is accurate but less helpful because subjects sometimes report stasis, which most likely means that they do not take into account their own body sway in formulating or expressing their subjective experience.

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[The letter "r" before author's initials stands for Authors' CC Response references]

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