We are better off without perfect perception

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Abstract: Stoffregen & Bardy's target article is based on the assumption that our senses' ultimate purpose is to provide us with perfect information about the outside world. We argue that it is often more important that information be available quickly than that it be perfect. Consequently our nervous system processes different aspects of information about our surrounding as separately as possible. The separation is not between the senses, but between separate aspects of our surrounding. This results in inconsistencies between judgments: sometimes because different frames of reference are used. Such inconsistencies are fundamental to the way the information is picked up, however, and hence cannot be avoided with clearer instructions to the subjects.

Since the Stoffregen & Bardy (S&B) target article deals with human interactions with the environment, it is impossible to ignore the physiology involved. Once one considers the physiology, it becomes evident that in practice there can be no "specification" of the kind described in the target article. For instance, in color vision it is well known that various combinations of wavelengths of light can stimulate the three kinds of cones in exactly the same manner, so that we are unable to distinguish between them. Similarly, various combinations of ego-motion and motion of the environment can give rise to the same global optical flow (sect. 5.1). These are examples of what S&B would call many-to-one mappings. Unless all information from all the senses is considered for every judgment, many-to-one mappings will give rise to conflicting judgments. S&B examine ways to avoid such conflicts. We question whether such conflicts have to be avoided.

Hidden behind worries about conflicting judgments is the assumption that our senses' ultimate purpose is to provide us with perfect information about the world "outside." To obtain such perfect information it makes sense to combine input from all the senses. However, attempting to gain access to perfect information has a price: time. For interacting with the environment, timing can be much more important than precision. There is no point knowing exactly when a ball will hit you if you only gain access to this information once it is too late to react to it.

We have shown that it takes 200 msec to react to a change in the speed of a target that one is trying to hit (Brenner et al. 1998), but only 110 msec to react to a change in its position (Brenner & Smeets 1997). Since these kinds of movements take only a few hundred milliseconds, this difference in timing is not negligible. When hitting moving targets the direction in which subjects move their hand does not appear to depend on the target's velocity (Brenner & Smeets 1996; Smeets & Brenner 1995), presumably because the disadvantages of waiting an additional 90 msec outweigh the advantages of having access to reliable velocity information.

In our opinion, the main task of our senses is to select the most suitable information for the task at hand, and to do so fast. From the moment the information reaches our senses separate aspects of the information are selected and analyzed for specific tasks, or parts of tasks. The selection starts even earlier if one considers the movements we make to obtain the information. Separate independent processing for different judgments can result in substantial conflicts between them (Abrams & Landgraf 1990; Brenner et al. 1996; Glennerster et al. 1996; Mack et al. 1985). Nevertheless, the separation seems be so complete that we even fail to notice conflicts between attributes when the conflicts themselves could give us valuable additional information (Brenner & Damme 1999; Brenner & Landy 1999). The main reason for our judgments normally being approximately consistent is presumably the consistency in the world "outside," in what S&B call the "global array."

Abandoning the need to avoid conflicts allows the nervous system to rely on different information for each judgment. We assume that each judgment is based on the most reliable information for that particular judgment. Thus, relative positions are judged from retinal information alone, but egocentric localization

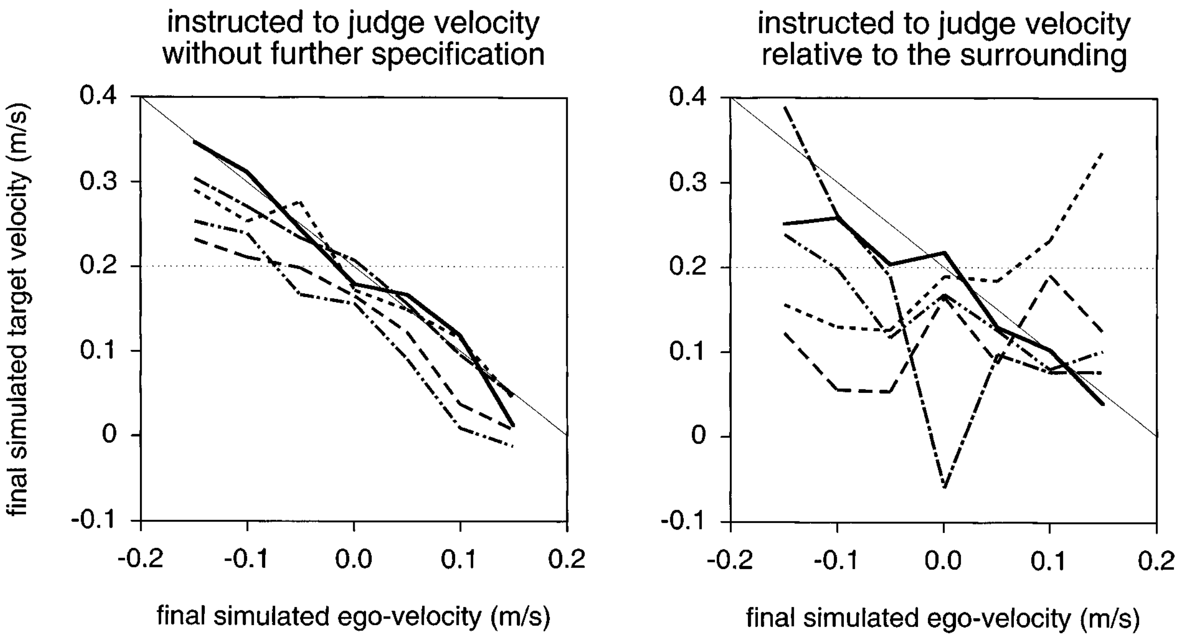

Figure 1 (Brenner & Smeets). Target velocity during simulated ego-motion that matched the simulated velocity in a preceding interval without simulated ego-motion. All velocities are relative to the visual surrounding. Each thick line connects the centres of the ranges of acceptable target velocities for the seven simulated ego-velocities for one of the five subjects. The thin diagonal line represents a constant velocity of 0.2 m/sec of the target relative to the observer, ignoring the visually simulated ego-motion. The thin dashed line represents a constant velocity of 0.2 m/sec of the target relative to the visual surrounding. The two panels show the same subjects' performance with two different instructions.

needs extra-retinal information about the orientation of our eyes as well (Brenner & Cornelissen 2000) In this example the difference in information is associated with a difference in the referent that is involved (see sect. 4.5). Our view implies that the referent is fixed for any given judgment, rather than being something subjects can choose as S&B suggest in section 5.

We examined subjects' freedom in choosing a referent by asking them to compare the initial and final velocities of an approaching target (simulated with both monocular and binocular cues on a large screen). The methods were very similar to those used in a similar study on lateral motion (Brenner 1991) The target initially approached at 0.2 m/sec while the background was static. During the presentation the visual background started moving in depth so that the optic flow was consistent with forward or backward ego-motion of the subject. At the same time the target could change its velocity. We determined how fast the target had to move during the simulated ego-motion for it to appear to continue to move at the same speed.

The subjects were initially instructed to judge whether the targets' velocity changed, without explaining what we meant by "the velocity." Subjects had no difficulty with this task, and all five subjects spontaneously judged the target's velocity relative to themselves, ignoring the visually simulated ego-motion (left panel in Fig. 1). These results are consistent with previous work on lateral motion, in which velocity judgments also appeared to be related to oneself (Brenner 1991; Brenner & van den Berg 1996).

We then showed the subjects their data and explained to them that we were simulating ego-motion and that we wanted them to judge the target's velocity relative to the surrounding. Subjects found this much more difficult. The results are shown in the right panel of Figure 1. It is clear from the variability that none of the subjects was really able to do this task. Perhaps they would have been able to do so if they had actually experienced vection, or if the simulation was not only visual, but apparently they were not able to select the visual surrounding as a referent.

How many systems make a global array?

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Abstract: Stoffregen & Bardy suggest that the global array provides the specification that is lacking when senses are considered in isolation. This seems to beg the question of the minimum number of senses in a global array. Individuals with sensory loss manage with fewer senses, and humans manage with fewer than electric fish; so specification, if it exists, cannot require all possible senses.

Stoffregen & Bardy's (S&B's) major theme is well worth endorsing, in principle. Nonetheless, I remain unconvinced that evidence against the assumption of separate senses is strong enough to demand changes in traditional perceptual experiments, or that the utility of their global array construct can survive the problematic question of the minimum number of "separate" senses that make a global array.

Here are three interesting contentions of S&B's. First, there is no airtight way to logically distinguish any two classic senses more definitively than any other two pieces of sensory equipment (like the two ears). Second, the "separate senses" construct is illogical, as is the prototypical experiment focusing on single senses, because distinct senses never work in isolation. Third, the concept of perceptual specification can only be saved by adherence to the global array construct.

S&B state the arbitrary-distinction argument most forcefully in section 2, analyzing whether the classic senses can be distinguished reliably by one of several means. I am afraid that I was unpersuaded by the repeated claim that a particular distinction is invalid because it presupposes the distinction it is supposed to demonstrate. One could use this strategy to disqualify any distinction whatsoever. Stronger arguments: anatomical distinctions will not work because there are other anatomical distinctions that definitely do not indicate a functional difference. Physical media and most brain centers are not generally dedicated to only one of the classic senses. Though these arguments seem solid, section 2 neglects some stronger justifications, like qualia-based distinctions (audition and vision are experienced differently), deficit based distinctions (people can be blind but not deaf), and evolutionary distinctions (electric fish have electric sense but humans do not). Two of these last are treated in other sections but their implications are more serious than S&B realize, as I will discuss later.

To support the second point of the analysis, that senses rarely work in isolation, S&B give examples of cooperation of the classic senses and present an important argument in section 6.2.5 about implicit cooperation when senses seem to work in isolation. However, evidence that sensory cooperation exists does not prove that the senses "operate as a unit" (sect. 7), nor does this cooperation necessarily follow from the arbitrary distinction argument. Furthermore, perceptual researchers are justified in believing that they have learned much from studies in which a particular sense or subsense is isolated; research that discovered pheremones useful in pest control might serve as one particularly practical example.

The third part of S&B's argument, that the global array concept is the only way to save perceptual specification, seems more like a wish. Their implication is that a qualitative difference exists between perception through a single sensory channel (if that is even possible) and by means of the global array. For S&B, perception through multiple integrated sensory channels provides a tighter and more trustworthy contact with the world than perception through a single channel.

With such implications, one cannot help but wonder how many systems are necessary to have a global array; one hopes the answer is not "all of them." Clearly, it is more than just two. The authors use the example of airplane simulators that include visual and inertial information. This environment that looks and feels like an airplane is not one, so optic and inertial information in isolation or even working as a set do not specify aircraft flight. Since S&B think the global array provides specificity in the simulator, some other system (which they do not name) must disambiguate the simulator from the real thing. So in this example at least three systems are necessary. Do all perceivables require three systems or more? Consider perception of cold. If I need to put on a coat, I do not think that haptic, olfactory or visual information should change my intention. If some perceivables require multiple systems but others can "get by" on one or two, will an animal or person actually know in any given situation whether a particular thing was perceived or whether they were "forced to obtain this information through inferential processing" (sect. 6.1)? If I perceive something critical but cannot distinguish whether it was specified or inferred, does the specification notion have any meaning at all?

Perhaps S&B would contend that specification always requires all systems, the whole global array, even in cases that superficially seem to require just one. A person under great stress may ignore the cold, so perhaps my perception of cold necessarily implies that I do not, through manifold other channels, perceive some more urgent source of stress. Aside from leaning toward tautology, this strategy seems contradicted by the authors' discussion of other distinctions in sensory resources, sensory deficits, and cross-species differences.

In section 6.2.3, it is suggested that blind people enjoy a global array that still includes numerous sources of information, even if one has been lost. Furthermore, the success of eyeless creatures is a demonstration (not to mention, I would add, poor electric-sense deprived humanity), that the global array of any particular individual of a particular species does not have to include any particular sense. If humans can enjoy specification without electric sense, then logically some perceivables in the Umwelt of the elec-