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PERCEPTION-ACTION RELATIONSHIPS RECONSIDERED IN LIGHT OF SPATIAL DISPLAY INSTRUMENTS

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SUMMARY

Spatial display instruments convey information about both the identity and the location of objects in order to assist surgeons, astronauts, pilots, blind individuals, and others in identification, remote manipulations, navigation, and obstacle avoidance. Scientists believe that these instruments have not reached their full potential and that progress toward new applications, including the possibility of restoring sight to the blind, will be accelerated by advancing our understanding of perceptual processes. This stimulating challenge to basic researchers was advanced by Paul Bach-Y-Rita (1972) and by the National Academy of Science (1986) report on Electronic Aids for the Blind. Although progress has been made, new applications of spatial display instruments in medicine, space, aviation, and rehabilitation await improved theoretical and empirical foundations.

GAPS IN OUR UNDERSTANDING OF PERCEPTION-ACTION RELATIONSHIPS

What is it that applied researchers want to know that basic researchers can't tell them?

Inadequacies of the present foundations are revealed by considering a discrepancy between issues that are addressed by basic researchers in the field of perception and questions that are asked by developers of spatial display instruments. These groups have different perspectives on two major functions of our sensory system, which are 1) to provide a conscious representation of spatial-temporal relationships, and 2) to guide our performance as we interact with our environment. Perception researchers concentrate on the first of these functions, providing perceptual impressions (subjective experiences) of objects or events such as apparent shape, size, orientation, and movement. They describe how the world does appear to us, and they analyze the determinants of our subjective experience of the world. In contrast, human factors engineers, clinicians, and specialists in artificial intelligence develop spatial display instruments to enhance performance that depends upon sensory information. Consequently, they ask questions about the second function of the sensory system, guiding performance. Thus, there is a gap between the main issues that are addressed by researchers in the field of perception and the information that is needed by developers of spatial display instruments.

Ironically, this gap has gone unattended because a corresponding gap has existed for a long time in researchers' understanding of the relationships between stimulus information, perceptual impressions, and performance. One major approach to research, the direct perception approach, bases its research on the untested assumption of a one-to-one correspondence between stimulus information and performance (e.g., Gibson, 1979; Turvey and Solomon, 1983). Other major approaches, mediated perception approaches, base their research on untested assumptions about the relationship between appearance and performance. Experimental tasks depend upon the availability of a representation of spatial-temporal relationships, and it is often assumed that the representation upon which performance is based corresponds to perceptual impressions of spatial-temporal relationships. Some paradigms carry this untested assumption to an extreme by inferring registered values of space in one task from perceptual impressions on a different task (e.g., Gogel, 1980). Accordingly, both direct perception researchers and mediated perception researchers have substituted untested assumptions for an empirically based theoretical foundation for understanding relationships between stimulus information, perceptual impressions, and performance.

Previous literature suggests that these relationships are complex and variable from situation to situation. During natural events in information-rich environments, there sometimes is a one-to-one correspondence between stimulus information and performance (e.g., Lee and Reddish, 1981; Turvey and Carello, 1986; Warren, 1984) and there sometimes is not (e.g., Shebilske, 1981, 1987a, 1987b; Shebilske, Karmiohl, and Proffitt, 1984). This variability is complicated by the fact that there is no general way to predict what the relationship will be in any given natural event.

Understanding the relationship between perceptual impressions and performance is similarly complicated not only by evidence that there are at least three modes of perceptual impressions (Rock, 1983) and that instructions can affect which one of these modes will correlate with performance (e.g., Carlson, 1977; Leibowitz and Harvey, 1969; Ebenholtz and Shebilske, 1973), but also by the finding of both tight and loose relationships. At one extreme, there is evidence for a very tight relationship (e.g., Coren, 1981). At the other extreme, there is evidence of very loose relationships. Examples include subliminal priming, which is an "unseen" word facilitating the recognition of another word (Marcel, 1983); blindsight, which is pointing at targets that cannot be "seen" (Bridgeman and Staggs, 1982); and paradoxical perceptions, such as apparent motion without apparent change in position (Shebilske and Proffitt, 1983).

Attempts to explain this variability include arguments for top-down influences. For example, Gogel (1977) stated that objects can be cognitively judged to be in a different location than they appear and that performance can reflect these cognitive judgments. Bottom-up influences have also been proposed. Shebilske and Proffitt (1981) suggested, for example, that apparent motions of a stimulus during head movements might be based "solely on motion information and principles of perceptual organization that make no use of distance information." Simultaneously, the same stimulus might elicit pointing responses that are based on distance information from one set of sources and size estimations that are based on distance information from another set of sources.

The problem is that our empirical and theoretical foundation is inadequate to predict when top-down and/or bottom-up influences will alter the relationships between stimulus information, perceptual impressions, and performance. The consequence of this inadequacy is, at the very least, a bottleneck in the transfer of information from basic research about perception to applications that depend upon sensory input, such as spatial display instrumentation. An even worse consequence is the danger of undermining parts of our basic research foundation that are based upon untested assumptions about these relationships.

ECOLOGICAL EFFERENCE MEDIATION THEORY

Operations for encoding sensory information should approach optimal efficiency in the environment in which a species evolved, according to an ecological point of view (Gibson, 1979; Shebilske and Fisher, 1984; Shebilske, Proffitt, and Fisher, 1984; Turvey, 1979; Turvey and Solomon, 1983). Based on this axiom and the observation that efference-based and higher order light-based information interact to determine performance during natural events, Shebilske (1984, 1987a, 1987b) proposed an Ecological Efference Mediation Theory of natural event perception. According to this theory, both the phylogeny and the ontogony of the visual system are shaped by internal state variables as well as by environmental variables. When the preceding discussion is recast in terms of this theory, the question becomes: How can fluctuations in relationships between stimulus information, perceptual impressions, and performance afford an adaptive advantage relative to all the conditions to which humans are exposed? Attempts to answer this question resulted in a hypothesis about Ecologically Insulated Event Input Operations (EIEIO). This EIEIO hypothesis will be explained in the remainder of this essay.

The EIEIO Hypothesis

Humans are able to perform in a wide range of transient internal and external states. The EIEIO hypothesis accounts for this flexibility by postulating separate input modules that are molded by interactions of an organism with its environment in an attempt to achieve maximally efficient performance of sensory guided skills within the prevailing internal and external states in which the skill is performed. Schmidt (1987) reviewed the history of thought on the theme that practice can change the way sensory information about the world is used to guide performance. He started with William James' observation (1890) that practice of skills seems to lead to more automatic, less mentally taxing behavior. This observation spawned considerable research leading to evidence for three separate process level changes that seem to contribute to this practice effect as follows: 1) tasks that are slow and guided shift from dependence on exproprioceptive information to dependence on proprioceptive information (e.g., Adams and Goetz, 1973); 2) tasks that have predictable parameters, such as predictable target locations in pointing tasks, shift to open-loop control (e.g., Schmidt and McCabe, 1976); and 3) tasks that have unpredictable parameters shift to fast, automatic, and parallel processing of the information needed to make decisions (e.g., Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977). The EIEIO hypothesis is a proposal of a fourth manner in which practice can change the way sensory information is used to guide performance. The proposal is that the bases for sensory guided performance can shift from conscious representations of spatial-temporal relationships to EIEIO representations that do not correspond to conscious perceptual impressions. In contrast to the other three mechanisms, which were identified through studies contrasting variables that are an integral part of the task, the EIEIO hypothesis emerged from considerations of the various internal and external contexts in which skills are performed. The EIEIO hypothesis encompasses five testable premises.

Premise 1. In addition to performance being guided by representations that correspond to conscious perceptual impressions of spatial-temporal relationships, performance can also be guided by one or more abstract, symbolic EIEIO representations of the same spatial-temporal relationships.

Premise 2. These EIEIO representations are insulated from each other and from the conscious one in the sense that they can be altered independently.

Premise 3. Differences between the accuracy, speed, and attention demands of EIEIO representations result from: 1) separate selective attention mechanisms that result in the picking up and processing of different potential sources of information, 2) different parsing routines that result in sampling units of different spatial sizes and/or different temporal durations, 3) different weightings that are used for various sources of information, and 4) different rules (e.g., rigidity assumption) and/or different principles of processing (e.g., minimum principle) that are used.

Premise 4. Conditions leading to the development and use of EIEIO representations during phylogeny or ontogeny depend upon interactions between an organism and its environment. Modules for forming EIEIO representations will result when an organism has the opportunity to perform the same skill repeatedly in an environment that 1) has contextual variability over a range that is narrower than the entire range in which the more general system must operate and 2) provides an opportunity to learn that the conscious representation is less efficient than an alternative one. The EIEIO representations that develop are utilized only when a skill is performed in the environment in which it was learned.

Premise 5. Whereas input operations corresponding to conscious representations are designed to be maximally efficient over the entire range of contextual variability to which an organism is exposed in its environmental niche, EIEIOs are designed to be maximally efficient within a narrower range of contextual variability within which a particular skill is performed. This premise is related to a familiar design for adaptability in biological systems. It is common to have a relatively narrow range of sensitivity available at any one moment, but to have this narrow range move over a much broader range in order to adapt to prevailing conditions. An example is light and dark adaptation in which a relatively narrow range of sensitivity to light exists at any given moment. But the absolute level of this momentary range can be adjusted up (light adaptation) or down (dark adaptation). The proposed design of EIEIOs, however, has an important unique feature. Specifically, a conscious representation that is based on very generalizable input operations is always available during normal waking consciousness as long as the stimulus information is above the momentary sensory threshold (or signal-detection criterion). However, after an extended opportunity to perform a skill under conditions that consistently have a relatively narrow range of contextual variability of internal and external states, the function of the conscious representation in guiding performance on that specific skill can be momentarily replaced by EIEIO representations that are more efficient within the prevailing narrow range of contextual variability. For example, gymnasts might be able to form more efficient EIEIO representations to guide their skilled performance by having their input operations take advantage of the fact that their skill is always performed in a well-lighted, highly structured environment. At the same time, the gymnasts would retain the more generalizable input operations that would result in continual access to a conscious representation at all times during normal waking consciousness, including whenever the gymnasts darted in and out of all the environmental conditions with which humans can be confronted.

CONCLUSIONS

Progress toward realizing the full potential of spatial display instruments is limited less by technology than by an inadequate understanding of perceptual processes. A bottleneck is encountered in understanding the relationships between stimulus information, experiential responses, and performance. In previous articles, I have taken stands against the postulation of a one-to-one correspondence in these relationships, and I have argued against development of theories, research methodologies, and applications based on this postulation. Here, I argued for steps aimed at developing a theoretical and empirical foundation for understanding, predicting, and controlling the perception-action link.

I reviewed three ways that have been proposed for how perception-action relationships can change. I then proffer a fourth way, the EIEIO hypothesis, which included five testable premises about the impact of contextual variability on perception and performance. Testing these premises in contexts that are relevant to spatial display instruments will advance spatial instrument technology by enhancing our ability to understand, predict, and control the many-to-one correspondence that often exists between stimulus information, perceptual impressions, and performance.

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