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## COMMENTARY

# Evidence for Direct Perception From Cognition in the Wild

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This article describes a portion of a study of "cognition in the wild" that was conducted to investigate how human operators of nuclear power plants monitor the state of the plant to detect abnormalities. Although the study was originally motivated by applied concerns, it surprisingly led to evidence relevant to basic theories of perception. The findings reveal that the instruments in the control room that operators can use for monitoring are both fallible and limited in their informativeness, thereby occasionally providing an inaccurate indication of plant status. As a result, operators sometimes leave the control room to directly observe components in the plant using their unaided perceptual systems. Because such information is lawfully constrained and not mediated by instruments, it provides a rich, reliable, and therefore, unique and highly valued indication of the true status of the environment. These findings show that Gibson's (1979/1986) distinction between directed and mediated perception is both pragmatically and psychologically relevant. The results also have very important implications for experiments on direct perception based on computer-simulated, rather than lawfully constrained, experimental stimuli.

Konrad Lorenz, an ethologist and Nobel Laureate, pointed out that naturalistic observation is a legitimate scientific activity, which should precede more traditional practices of formalization, quantification, and controlled experimentation (Lorenz, 1973). In fact, he made a career out of such descriptive science, admitting to never having published a paper in his life with a graph in it! The noted cognitive scientist,

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Thomas Landauer, has claimed that applied problems of the type encountered by cognitive engineers (see Vicente & Rasmussen, 1990) can lead to relevant insights for basic psychological research (Landauer, 1987; see also Vicente, 1994). James Gibson (1967/1982) also seemed to be of this opinion when he observed that:

> Putting my education to a practical test was a new education. I discovered that what I had known before did not work. I learned that when a science does not usefully apply to practical problems there is something seriously wrong with the theory of the science. (p. 18)

Combining these thoughts leads to the inference that naturalistic observations motivated by applied problems can serve as a proving ground for basic psychological theories. This article describes research whose results support this claim. More specifically, we conducted a field study of "cognition in the wild" (Hutchins, 1995), investigating how human operators monitor a nuclear power plant to detect abnormalities (Vicente & Burns, 1995). Surprisingly, our descriptive evidence indicates that *direct perception* (Gibson, 1966, 1979/1986) has a unique epistemological status that is also of significant practical value. Our findings also have important implications for a seemingly unrelated topic, namely the adequacy of computer-simulated stimuli (e.g., optical flow generated on a computer display) for experimental research on direct perception (cf. Stoffregen, 1993).

## DIRECT PERCEPTION

Before we describe our study, it is important to discuss the concept of direct perception. Exactly what is direct perception, and what distinguishes it from *indirect perception* (cf. Stoffregen's, 1993, question about what distinguishes "real" from "artificial" stimuli in experiments)? Although the form of the two adjectives might suggest otherwise, Austin (1962) astutely observed that "the notion of perceiving *in*directly wears the trousers—'directly' takes whatever sense it has from the contrast with its opposite" (p. 15). What, then, do we mean by indirect perception? One of Gibson's (1979/1986) definitions is as follows:

> Direct perception is what one gets from seeing Niagara Falls, say, as distinguished from seeing a picture of it. The latter kind of perception is *mediated*. So when I assert that perception of the environment is direct, I mean that it is not mediated by *retinal* pictures, *neural* pictures, or *mental* pictures. *Direct perception* is the activity of getting information from the ambient array of light. (p. 147)

This quotation suggests that direct and indirect perception may differ along more than one dimension. This suggestion can be evaluated by examining the literature to identify some of the different ways in which indirect, and thus direct perception, have been defined by various authors.

Traditionally, the debate over direct perception has focused on two different dimensions of indirectness: the necessity of *mental representations* and the need for *mental computations* (Fodor & Pylyshyn, 1981; Runeson, 1977; Turvey, Shaw, Reed, & Mace, 1981; Ullman, 1980). From these perspectives, direct perception is unique because it is not mediated by mental representations or because it does not require mental computations. There is a third notion of indirectness, which has not received as much attention in this debate, but that follows from the work of Gibson and Gibson (1955) on perceptual learning. From this third viewpoint, indirect perception is defined by the *addition of information* (e.g., via memories, associations, mental images, or inferences) beyond that obtained from the environment. Thus, perception would be direct if it relied solely on the information available from the environment.

Interestingly, Austin (1962) did not mention any of these notions of indirect perception. Instead, he considered three other dimensions to distinguish between these two forms of perception. The first is the direction in which the observer is looking. For example, seeing an object in the mirror would be a case of indirect perception because the perceiver's line of sight is not in the direction of the object being perceived. Austin criticized this notion of indirect perception because it cannot be meaningfully applied to other perceptual systems, most notably hearing. A second dimension that Austin considered is time. Under this interpretation, watching a movie or listening to an audio recording are both examples of indirect perception because the event being perceived occurred well beforehand. The limitation Austin alluded to in this case is that it is not clear how far back in time the event would have had to occur for perception to be indirect. For instance, is a delay caused by the speed of sound sufficient to cause the perception of a distant event to be labeled as indirect? A third dimension that Austin considered to distinguish between direct and indirect perception is the use of tools or instruments. In this case, viewing an event through a telescope or a pair of glasses would be examples of indirect perception, whereas viewing the same event with the naked eye would be an example of direct perception. As we see later, this definition of indirect perception is very similar to that discussed in Part 4 of Gibson (1979/1986; although it differs from that cited previously, from the beginning of Part 3 of Gibson, 1979/1986).

It is clear that these various definitions are far from independent, yet they have some differences as well, some obvious and others perhaps more subtle. To take but one example, is it not possible for perception to be direct, in the sense of not being mediated by tools or instruments, and yet still require either mental computations or mental representations (e.g., if the information available for perception is impoverished)? If so, then Austin (1962) was correct in claiming that there is no one consistent way in which direct and indirect perception can always be distinguished from each other. One thing seems certain—clearly identifying the differences and similarities between these various definitions is far from trivial and well beyond the scope of this article.

The purpose of discussing all of these definitions is instead to show that there may be various ways in which one can investigate Gibson's (1979/1986) theory of direct perception. Traditionally, experimental investigations of direct perception have focused primarily on the issue of what information people are picking up on, and by inference, whether there is any need to postulate mental representations or computations. In the field study presented here, we could not investigate direct perception in this way because we had no way of manipulating or measuring the information available for perception. Although we did not realize this initially, we were nevertheless fortunate because we were presented with a setting in which it is possible for people to perceive some objects and events, either through instruments or via their unaided perceptual systems. As a result, this provided a "naturalistic" environment for investigating the psychological implications of this particular definition of indirect perception. Before describing the study itself, we provide some background context.

## CONTEXT

Nuclear power plant operators are responsible for monitoring the plant to detect abnormalities, diagnosing problems when they do occur, and developing an appropriate compensation plan. Although the focus of our field study was on monitoring activities, to understand these it is important to know what action alternatives operators have available to them. In fault situations, operators may have to trade off two goals, namely maintaining safety and maximizing production. As a result, a choice may have to be made between shutting down the plant or developing a compensation plan that will keep the plant running. Compensation activities may consist of isolating a faulty component, bringing a backup system into operation, or using a redundant system to achieve production goals. Most of these compensatory activities (including shutting down the plant) can be implemented directly from the control room, via controls that affect the state of various components and subsystems out in the plant. Once a fault has been managed, operators may issue a work order to repair the faulty component(s). However, it is not their responsibility to carry out these repairs. This work is done by maintenance personnel.

Now that the structure of operators' action alternatives has been briefly described, we can turn to the issue of monitoring itself. Operators have several sources of information available to them that they can use to monitor the plant. The most obvious sources are the instruments in the control room that serve as a mediating interface between the operators and the plant itself (cf. Vicente & Rasmussen, 1990). There, one can find literally hundreds of analog meters showing the status of individual plant variables. In addition, there is an alarm system that provides an auditory and visual alert each time one or more parameters go outside of their predefined operating range.

Operators also could potentially get information about the state of the plant through less obvious means. Although some parts of the plant cannot be accessed safely by people because of dangerous exposure to radiation, there are other parts that can be. Operators can travel to these parts of the plant to directly observe the state of particular components or subsystems. Alternatively, they can send field personnel to "take a look," while they themselves remain in the control room.

Given the background provided previously, one might think that going out into the plant would be completely unnecessary. First, the control room contains hundreds of displays and alarms that can be used for monitoring, so why would operators not just rely on those to do their job? Second, the control room also contains hundreds of controls that operators can use to manipulate the status of components out in the plant. As a result, operators do not have to go out into the plant to perform the actions required to implement a compensation plan. Third, operators are not responsible for performing maintenance work, so they do not have to go out into the plant to repair components either. Fourth, by going out into the plant, operators would no longer be able to observe all of the information in the control room displays and alarms. Consequently, they would become out of touch with the status of the rest of the plant. (It is possible to compensate for this particular problem by phoning other personnel who remain in the control room or to avoid the problem entirely by sending someone else to go look).

There are two other more pragmatic reasons for not going into the field. First, going out to make observations in the plant requires a fair amount of time, because the distance between the control room and the components of interest out in the plant can be quite large. Second, the control room is an isolated, controlled environment that is maintained at a comfortable temperature. In contrast, some areas of the plant are uncomfortable places to be because they can be very noisy (requiring hearing protection), cold in the winter, and hot in the summer. Given all of these factors, the choice between monitoring from the control room and monitoring by going out into the plant seems to be a straightforward one. To use a colloquial expression, it should be a "no-brainer" to figure out that the control room has many advantages as a source of information for monitoring the plant.

## METHOD

We conducted a field study to understand how operators monitor the status of the plant under normal operating conditions (Vicente & Burns, 1995). As far as we know, no study of this type had ever been conducted in the nuclear industry, because the focus has justifiably been on investigating operator performance under (simulated) emergency situations, rather than under normal operations. Two observers conducted independent observations in the control room. A total of six different operators were observed over 10 different shifts for a total of approximately 77 hr.

The operators were extremely cooperative, allowing us to watch closely all of their work activities. In addition, when time permitted, we also were allowed to ask questions, either to understand the actions operators had taken or to develop further our general understanding of their jobs. In many cases, the operators actively volunteered information that they thought was germane to our study. Both observers took notes in the control room, but did not communicate with each other during the period of observation. Afterwards, the observers wrote independent summaries of their findings. At that point, the summaries were compared, and differences were resolved. A detailed account of all of our findings can be found in Vicente and Burns (1995). The small subset of findings pertinent to the focus of this article is presented next.

## FINDINGS

The findings described in this section were based on interviews with the operators, rather than on direct observations. There are several reasons for this. First, our study was exploratory and descriptive in nature, so it would be premature to test hypotheses by observing operators' behaviors. Second, no attempt was made to quantify the frequency of certain behaviors because we did not have, a priori, a deep enough understanding to categorize meaningful behaviors. Third, events that are problematic or challenging, and which would therefore be particularly revealing and pertinent to our goals, occur (thankfully) very infrequently in nuclear power plants. As a result, the insights we gathered were derived from operators' explanations of how they do their job, as well as their accounts of specific incidents which had occurred in the past.

### Operators Go to the Field to Take a Look

Despite these methodological limitations, our field study led to a meaningful and surprising set of findings. The first result of interest is that, although operators rely mainly on the control room interface, they frequently send maintenance personnel out into the field to monitor the status of the plant (essentially on a daily basis), and they also go out into the field themselves to monitor specific components, albeit much less frequently. By going out in the plant, one can see that a component (e.g., a pump) may be making a great deal of noise, vibrating intensely, or leaking. Although not designed as part of the human–machine interface, this information is complementary to that available in the control room.

### Why Do They Bother?

The second result, which is more important for the purpose of this article, is the set of justifications that operators provided for going out, or sending someone, to observe components in the field. The most important justification is that instruments can lie (i.e., fail), whereas information obtained by observation of components out in the plant cannot. To take a simple example, sometimes the light bulbs that serve as indicators on the control room panels burn out, and as a result, can provide a misleading indication of what is really going on in the plant. This occurs relatively regularly because of the hundreds of light bulb indicators on the control room panels. Although burnt-out light bulbs may seem like a trivial problem, they are a source of extreme frustration because of the ambiguity they cause. Operators do not always know if the symptoms they are observing from the control room panels are a true indication of plant state, or whether they are due to instrument failures, or a combination of both. In contrast, if operators observe a pump with their unaided perceptual systems and hear the shriek of metal grinding (this does sometimes happen!), then there is no doubt that there is a problem. Consequently, rather than relying on the fallible instruments in the control room alone, operators also rely on perception of components out in the field to discover the true state of the plant.

Operators also gave two other reasons for taking the time and trouble to go out, or send someone, to look at components in the field. First, they told us that an event may be perceivable both in the field and in the control room, but that the field situation provides "better" information than the control room. For example, one operator told us: "Numbers and instruments are great but if you really want to understand what's going on, you have to go out there and see it and feel it." Another operator told us: "Most of the time, your instruments give you a very good idea of what state the plant is in. But numbers by themselves don't mean anything. If I tell you that turbine vibration is 200 mm, you know that's not good [i.e., beyond the normal limit], but it's not the same as taking you out there and showing you the [metal] turbine rails moving violently back and forth." Thus, even in cases in which the same event can be perceived from the control room or the field, operators claim that the latter is richer than the former, providing a better basis for understanding.

Second, there are some situations in which the information to specify the event of interest is only available in the field. An example of this category is provided by the following incident. One day, operators knew that there was a leak of radioactive heavy water inside the containment building and had to determine if the leak was greater than 50 kg/hr. According to the rules that are set up for safe operation of the plant, if a leak greater than this amount occurs, then the operators are supposed to shut down the plant. Before the operators went out in the field, they collected a cup of known volume and a watch with a seconds hand, went to a nearby sink, and adjusted the tap until they generated a flowrate of 50 kg/hr. As the operator who participated in this experiment told us: "You might think that 50 kg/hr sounds big, that it might be a gusher, but it's not. It was just a trickle."

This episode has two morals. First, perception of components in the field can provide information that cannot be obtained in the control room. Second, there is a difference between knowing that the shutdown limit is 50 kg/hr and seeing water flow from a tap at that rate, a difference significant enough to cause operators to take the time and effort to conduct an informal experiment to create the latter.

## DISCUSSION

The findings just presented remind us of a story we were told once about the renowned artist, Pablo Picasso. We do not know if the story is true, but it is worth recounting here because of its relevance to this discussion.

Picasso struck up a conversation with a fellow passenger on a train. After settling into the conversation, the passenger asked Picasso: "I have always wondered, why don't you paint people the way they really look?" Picasso replied: "I don't understand." The passenger reemphasized his question: "You know, why don't you paint people so that they look like real people?" "I'm not sure what you mean," Picasso replied, confused. Finally, the frustrated passenger pulled a photograph of his wife out of his wallet, and said: "For instance, here is a picture of my wife. This is what she *really* looks like!" Picasso replied: "She looks very flat and small to me."

Although this was not the original intention of our field study, the findings we obtained (and the story about Picasso) have implications for basic theories of perception. What is the difference between reading a dial and actually going out to take a look? Some accounts of perception based on information processing theories would have us believe that there is no substantial difference. For example, some theories make no distinction between perception of the environment, perception of pictures, or perception of illusions (e.g., Gregory, 1966). Other theories fail to make any distinction between perception mediated by external representations on the one hand and perception of objects unmediated by external or internal representation on the other, by denying that the latter is even possible (e.g., Vera & Simon, 1993). Any of these theories would have a difficult time explaining the findings uncovered by our field study. And as the opening quote from Gibson (1967/1982) points out, if such theories do not apply to practical problems, then there is something seriously wrong with those theories.

In contrast, the findings from our field study are perfectly consistent with the theoretical distinctions made in Gibson's (1966, 1979/1986) theory of direct perception, despite the extreme dissimilarity in motivations and contexts behind the two lines of research. Gibson (1979/1986) pointed out that perception can be more or less direct, and that the direct–indirect distinction lies on a continuum:

> All sorts of instruments have been devised for mediating apprehension. Some optical instruments merely enhance the information that vision is ready to pick up; others … require some inference; still others … demand a complex chain of inferences. Some measuring instruments are closer to perception than others. (p. 260)

The analog meters and alarm indicators that control room operators have available to them seem to be good examples of what Gibson had in mind when he referred to perception mediated by instruments.

Perhaps more importantly, our results also are consistent with Gibson's claim that there are crucial differences between direct perception and indirect perception mediated by instruments. These differences arise from the fact that direct perception is based on *information*, whereas indirect perception via instruments is based on external *symbolic* representations (cf. Turvey & Kugler, 1984). The former always has a lawful basis, whereas the latter do not. Our findings indicate that this distinction leads to four important implications.

Pragmatically, the most important implication is that direct perception is more reliable than indirect perception. Again, Gibson (1979/1986) anticipated this in the following description of perception mediated by instruments: "The reality testing that accompanies the pickup of natural information is missing. ... The invariants have already been extracted. You have to trust the original perceiver" (p. 261). In our case, we could say that the operators would have to trust the control room designers and the technology on which the control room is based —but in practice, they do not. Because both the designers and the technology are fallible, the information provided by the control room is not lawfully determined, unlike the information obtained by direct perception of components. Smoke, vibrations, and noise do not lie in this environment. And because operators are ultimately held responsible for plant safety, they do not put complete faith in the control room instruments, and instead, occasionally go out in the field and more frequently send maintenance personnel to the field, to directly perceive the components of interest.

A second implication of the distinction between information and symbols is that, compared to mediated perception, direct perception can lead to a better understanding of the events of interest. For example, directly perceiving a rail moving violently back and forth provides a richer understanding of the situation than reading the value 200 mm on an analog meter, because the former has a meaningful physical context, whereas the latter is a sterile representation extracted from the natural context defining the event of interest. As Austin (1962) observed, there are many different ways of classifying a perceived object or event, but any of these classifications is, by definition, an abstraction. Thus, perception provides a richer basis for knowing than description. In our study, direct perception provides operators with a much better understanding of why an instrument reading of 200 mm is bad to begin with. It does not take a great deal of training, nor many inferences, to determine that it is not good for metal rails to shake violently back and forth because it is obvious that they may eventually break. This is an unavoidable consequence of physical laws and seems to be directly perceived as such by operators in the field.

A third implication of the information–symbol distinction is that direct perception is also richer in the sense that it can provide information that will not be available from instruments. The leak example presented earlier shows that perception mediated by representations (i.e., instruments) is constrained by the low-dimensional nature of those representations. Operators had to search for information that the instrumentation was not designed to provide. In principle, this can always occur because the events in the plant are homomorphic with the data on the instruments in the control room (i.e., the mapping is many-to-one). Note that the same is true if one follows the advice of Vicente and Rasmussen (1990) and tries to design human–computer interfaces so that they "make visible the invisible" by creating a one-to-one mapping between the perceptual features of the interface and the otherwise unobservable goal-relevant properties in the plant (e.g., energy). Therefore, no matter how clever the designer or how advanced the technology, the natural setting will always provide information to specify events that cannot be observed from the control room because the instruments are presenting, by definition, an abstracted description of the state of the physical system. Many of these events are not relevant to controlling the plant, but some of them may be.[1]

The leak example also can be used to make a final point about the education of attention (Gibson, 1966). In performing their creative experiment, operators essentially were generating an approximation of the information in the optic array that would specify the critical leak size. Note, however, that this referent was perceptual, rather than symbolic. In essence, operators were educating their attention to the information that would allow them to discriminate between the action alternatives available to them at the time. This indicates that there is an important psychological distinction between a symbolic description of a goal-relevant state of the environment (i.e., 50 kg/hr) and the optical information specifying that same state (i.e., seeing water flow from the tap at that rate). Why would operators take the time to generate the latter?

The reason seems to be that this strategy avoids the effortful and unreliable process of having to compare a symbolic mental representation (i.e., the symbol string, 50 kg/hr) with the perceptually available information in the optic array. By creating a referent that is in the "same currency" as the information available in the environment, monitoring is facilitated.

## CONCLUSIONS

Much of the research on direct perception has taken the form of controlled experiments conducted in the laboratory. That body of research has generated important empirical insights and significant theoretical advances. However, as Stoffregen (1993) has pointed out, the relation between some of these experiments and perception outside of the laboratory is, at best, complex, and, at worst,

[1]It is precisely for this reason that Rasmussen's (1985) abstraction hierarchy contains the bottom level known as Physical Form, which describes the plant in terms of the spatial location and appearance of its components. With multimedia computer technology, it is now possible to try to bring some of this level of description into the control room (e.g., via live video images of remote plant components as in Zinser & Frischenschlager, 1994). However, even these sophisticated displays will never be as informative as direct perception of components out in the field, because they only provide a description (albeit of high bandwidth) of the components. As a result, the opportunities for active exploration on the part of the control room operator are limited (e.g., by the viewing angle of the video camera), and certain properties will not be captured by the video image (e.g., the heat given off by the component that could otherwise be perceived by directly touching the actual object).

equivocal. Thus, it is significant to find that evidence of direct perception, supporting the theoretical distinctions made by Gibson (1966, 1979/1986), can be observed in the wild, where people are engaged in complex and meaningful work that has an important impact on public safety. Moreover, it also may be of interest to learn that, even in an ecology that represents the height of technological achievement, direct perception provides a rich, reliable, and therefore, unique and highly valued means of knowing the true state of the environment.

The findings and arguments presented here also have important implications for laboratory experiments on direct perception that use nonphysical stimuli (e.g., optical flow simulated on a computer screen) rather than stimuli that are physical (in the sense of being directly constrained by physical laws). Stoffregen (1993) has initiated a discussion along these lines, so we quote from him directly: "It could be argued that all research relying on nonphysical displays is fundamentally research on the perception of depictions rather than the perception of physical objects and events." What makes this observation so crucial to the interpretation of experimental results is the possibility (highly likely) that observers' responses to nonphysical depictions may differ in significant ways from the responses they would otherwise exhibit to analogous physical events. Stoffregen cited the example of an animated gun on a computer screen being fired at an observer, compared with a real gun being fired. Although (as he admitted) the example is an extreme one, Stoffregen's (1993) point is well taken: "We should not assume that presentation of the 'same event' in nonphysical displays is, in general, meaningfully equivalent to the corresponding physical event. Typically, participants are well aware that they are being presented with nonphysical displays." This caution has very important methodological implications for the conduct of experimental research on direct perception. Moreover, it suggests that some research findings using nonphysical depictions may not generalize to lawfully constrained physical events, which after all, are the intended domain of investigation. Clearly, these issues are of foundational importance to research in ecological psychology and therefore deserve to be confronted and resolved.

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