e-Journal
Philosophie der
Psychologie

PILATE'S ERROR: THE VARIETIES OF PERCEPTION-ACTION COUPLING

von Boris Kotchoubey (Tübingen)

Abstract

The prevailing cognitive approach to human mind and behavior, taking its name from "cognition" (knowledge), presumes that the function of the mind (or the brain) is obtaining the adequate knowledge (frequently called representation) of the world outside. However, no proof is possible within this approach that the content of perception can truly represent reality. To the contrary, the ultimate wisdom of this approach is that the brain-mind actively models and constructs the world rather than to perceive it as it really exists. On the other hand, the opposite biological approach starts with the notion that mind and brain do not worry about true knowledge but are busy with control of behavioral adjustment. From this point of view, perception is a function, not of the external stimulation but of the organism's controlling actions. But controlling actions can only be successful if they are able to compensate for environmental disturbances. To do this each action must produce a force which is exactly equal to the external (to-be-compensated) force but has the opposite sign. Therefore, if a percept emerges from a set of controlling actions, it necessarily reflects the effect of environmental disturbances affecting the organism. The percept, as defined within this approach, must contain the true knowledge about the world (in the extent of how the world has affected the organism) exactly because the organism does not purposely search for this knowledge!

Zusammenfassung

Das seit Mitte des 20.Jh. herrschende kognitive Paradigma in der Bewusstseinsforschung geht von der Annahme aus, der Geist (bzw. das Gehirn) habe vor allem die Erkenntnis (lat. cognitio) der Welt als seine wichtigste Aufgabe. Als Ergebnis dieser Erkenntnistätigkeit bilde der Geist (das Gehirn) Repräsentationen äußerer Objekte. Das Paradox ist, dass im Rahmen dieses Paradigmas nicht bewiesen werden kann, dass jene Repräsentationen tatsächlich die Wahrheit über die Außenwelt enthalten. Im Gegenteil besteht die "letzte Weisheit" des kognitiven Ansatzes darin, dass das Gehirn seine Welt modelliert und konstruiert. Das entgegengesetzte biologische Paradigma behauptet dagegen, das Gehirn kümmere sich gar nicht um die Erkenntnis sondern bloß um die Kontrolle des adaptiven Verhaltens. Die Wahrnehmung ist aus dieser Sicht nicht von Außenreizen abhängig sondern von den steuernden Handlungen des Organismus. Solche Handlungen führen jedoch nur dann zum Erfolg, wenn sie die externen Störungen kompensieren, indem sie eine Kraft entwickeln, die der Störkraft genau gleich ist aber das umgekehrte Vorzeichen hat. Deshalb, wenn ein Perzept als eine Spur einer Reihe steuernder Handlungen entsteht, bildet es notwendigerweise die kompensierten externen Störungen ab. D.h., das Perzept beinhaltet das wahre Wissen über die Außenwelt, wie diese auf den Organismus gewirkt hat. So gesehen ist Wahrnehmung gerade deshalb wirklich "wahr", weil der handelnde Organismus nach dieser Wahrheit nicht gesucht hat!

> Pilate saith unto him, What is truth? And when
> he had said this, he went out again.
>
> King James Bible, John 18, 38

During the whole 19th century, mainly heated by political competition, the English and the French vehemently discussed who of the two great physiologists, Sir Charles Bell or François Magendie, was the first to describe the famous anatomic-physiological law (Bickel, 1901). The discussion remains unsolved up to now. However, the significance of this apparently simple law – that the anterior spinal nerve roots contain only motor fibres and the posterior roots only sensory fibres – has far going consequences even for our present-day understanding of brain and behavior.

The point is that the fundamental discovery – whether of Sir Charles, or Magendie, or both – gave a new impetus for the old idea that how we perceive the world around us is a function of sensory organs and sensory nerves. On the contrary, our actions are a function of motor centers and motor nerves. As Jordan (1999, 2003) puts it, since then perception and action were mapped on sensory and motor functions, or on input and output, respectively. This mapping underlies the cognitive approach which prevails since several decades in the description of brain function and behavior.

The cognitive approach

This approach is frequently referred to as the representational, computational, or – perhaps less cogent – stimulus-response approach. We shall call it heretofore "the cognitive approach" because its main postulate is that the brain is primarily *the organ of information processing* aimed at getting *knowledge* (from lat. cognitio = knowledge) about our environment. Paradoxically, because the cognitive approach is based on the search for true knowledge, it cannot find it. Perhaps Pilate was aware of this, and having asked "What is truth?" he did not even wait for an answer.

The cognitive approach assumes that there exists a world of physical objects each of which possesses a number of physical features, like mass, hardness, brightness, color, etc. One of these objects occasionally affects a sensory organ (e.g., retina) by means of a physical process (e.g., emission or reflection of light), thereby beginning an act of perception. The affecting agent (light, in this example) is called *stimulus*. A stimulus can be described as a combination of physical features reflecting some features of the objects in the environment[1]. The sensory data about these features (of the stimulus, and, thereby, of the object) are the starting point of perception. Later on, these data pass through some processing operations leading to the experience of perception. After intensive processing in which memory, motivational and emotional systems participate, the data constitute a basis on which the organism can prepare its own actions toward the environment. These actions can be called "responses" to stimuli – not because they are completely determined by stimuli but because, according to this view, they must follow thorough analysis of stimuli.

From this point of view, the function of perception is providing the mind (neurocognitive version: the brain) with raw data for reasoning and thought. Thus,

> perception consists of a sequence, stretching from events in the physical world external to the perceiver, through the translation of these events into patterns of activity within the perceiver's nervous system, culminating in the perceiver's experiential and behavioral reactions (Sekuler & Blake, 1994, p.1).

The basic character of the sequentiality principle is stressed by both critics (e.g., van Gelder, 1998) and proponents (e.g., Cowan & Wood, 1997) of cognitive theories of perception. "A fundamental assumption of cognitive psychology is that information processing occurs in series of contingent mental processes, or stages." (Smid, Böcker, van Touw, Mulder, & Brunia, 1996, p. 3).

Very often, these processes or stages in perception are roughly subdivided into primary operations which deal with fragmented "raw data" and are assumed to be unconscious and automatic, and further stages whose content is conscious and controlled. One very influential theory of visual perception, for instance, suggests that analysis of single features of visual stimuli is largely

---

[1] For some never explained reasons, this is a world of classical (i.e., Newtonian) physics, not of Aristotelian or relativistic physics. It is taken for granted, for instance, that wavelength is perceived but that spin and charm are not (see Bickhard & Richie, 1983; Gibson, 1961).

automatic and pre-attentive, but that attention is required to integrate these features into a holistic percept (Treisman, 1999; Treisman & Gelade, 1980).

This sequentiality principle gives rise to two problems. First, further stimulus processing is supposed to interpret the raw data of sense organs in light of the subject's past experience, motivation, personality, attention, etc. These higher-order processes are assumed to select relevant information and to filter out irrelevant one. Several authors see a serious logical difficulty in how these "subject-driven" processes can intervene into the primary sensory data (e.g., Allport, 1980; Van der Heijden, 1996). Namely, in order to select a relevant element among a group of irrelevant ones, this element should in some way be "marked"; it should possess some feature(s) distinguishing it from irrelevant elements. But if it already differs from irrelevant elements before being selected, the selection as a special process becomes unnecessary. This is basically the old argument against selective attention, put forward by both behaviorists and gestalt psychologists about 80 years ago: in order to pay attention to something important, I have to know what is important; but if I already know this before paying attention, why should I postulate attention as a special mechanism?

Another well-known problem is the construction of the perceptual integrity (i.e., object perception) from the fragmentary sensory data. This is the so-called binding problem. At present, its solution is sought in close temporal correlation between features that compound an object: correlating features belong to the same object, not correlating, to different objects (Singer, 1999). The many difficulties of this explanation are also well known (e.g., Philips, 1998; Shadlen & Movshon, 1999). For example, the high flexibility of classification remains unexplained. If somebody is presented three stimuli (say, A, B, C) only one of which is important (e.g., A = alarm signal), he or she may disregard any difference between B and C. But as soon as the meaning of the stimuli changes (now B is alarm signal) the differentiation between B and C presents no problem. Moreover, the subject may now become completely ignorant about the differences between A and C that were clearly perceived a while ago. Further, abstract concepts are impossible. For instance, if all features of my cat are temporally related, I can recognize it as a distinct object ("my cat"), but since these features do not correlate with those of other cats, I cannot form the concept of "cat", let alone "animal" (if features of all cats are correlated, then I can recognize "the cat in general" but cannot distinguish between any two particular cats). Not surprisingly, the innateness of all basic representations ("primary concepts") remains as the last postulate for most thoroughgoing cognitive theorists (Fodor, 1998).

After stimulus information has been processed, the mind/brain develops a program to represent and to prepare the correspondent motor action (e.g., Kornblum, Hasbroucq, & Osman, 1990; Rosenbaum, 1980). The movement is organized as a hierarchy: higher (probably cortical) structures develop the motor program, which has to be realized by lower structures. The movement is deterministically governed by a set of commands sent from higher- to lower-order levels of control. Like perception, action is a chain of consecutive processing stages finishing in the motor command (Rosenbaum, 1980; Ulrich, Leuthold, & Sommer, 1998). Therefore the particular interest in the activation of the primary motor cortex: this activation is regarded as a key component that defines which movement is executed, the "point of no return". The question of Osman, Kornblum, & Meyer (1990) "Does motor programming necessitate response execution?" implies that the very ability of the system of subcortical motor centers to play an independent role is questioned.

The execution of an action brings the processing chain to a close. The organism has correctly analyzed the stimulation and found the appropriate response to it. The sequence of events from the point of view of an external observer is as follows: a stimulus is presented, and, after some hundred milliseconds, a response is recorded. Again, not only perception but also the whole act is regarded as consisting of a chain of sequential operations. Van Gelder (1997) indicates that this sequential nature is closely linked to the postulate of representations, i.e., internal constructs "standing for" things in the external world. Moreover, these representations are related to building homunculi, i.e., departments of the representational system:

> ...the whole device operates in a *cyclic* fashion; it first measures (or "perceives") its environment; it then internally computes an appropriate change...; it then effects this change ("acts" upon its environment)... These properties - representation, computation, sequential and cyclic operation, and homuncularity - form a mutually dependent cluster: a device with any one of them will standardly possess others (van Gelder, 1997; p.230-231, emphasis in original).

Characteristic of this approach is the principle PERCEPTION PRECEDES ACTION. In order to produce the response, the subject has to perceive the stimulus.

> The stimulus identification module... generates a stimulus vector that is passed on to the second module, the response production module. The stimulus vector consists of all the stimulus attributes or features encoded by the stimulus identification module. (Kornblum & Lee, 1995; p.856).

In classical cognitive models (Sternberg, 1969; Sternberg, 2001), this sequential character of operations was very strong. In contrast, later theories allowed stages of information processing to overlap in time (Eriksen & Schulz, 1979). For example, as soon as a sensory unit has specified one stimulus feature, it can already carry over this information to the next stage, while it continues to analyze further features. This assumption removes some constraints embedded in the strictly serial models. However, the direction of the main flow and the leading principle "perception precedes action" remain the same. Therefore, the principal characteristics of the cognitive approach are valid for its continuous flow version, too.

Being based on the linear chain of processes leading from stimulus to response, the cognitive approach is always in the danger of the regress to the old behaviorism which regards all the behavior as a function of stimuli (e.g., Hurley, 1998, 2001). But the cognitivism was introduced to overcome the problems related to the stimulus-response approach (Anderson, 1995). It admits, therefore, "the poverty of stimulus", the impossibility to explain mental states (e.g., percepts) from mere sensory signals. This is particularly evident in the case of visual perception. Evidence is abundant that signals on the retina have nothing in common with real objects in the real world (if they exist at all), nor are they similar to our percepts, that is, to how we see this world. We must, therefore, assume the existence of as many as three different entities: (a) objects as we see them, (b) objects as they exist in reality, and (c) objects' images on the retina which mediate between (a) and (b). But why (a) and (b) should be similar if (c), which mediates between them, is so different from both?

The usual (and, perhaps, the only possible) answer of cognitive science is that the brain (or mind) *constructs* visual reality again from the elements delivered by the visual system. But, as was already clear to Kant, no evidence is possible that our construction of reality is in any sense equivalent to the reality itself. At the psychological level, the ultimate explanation of Fodor (1998) and Chomsky (1981) was the inborn character of the basic units of cognition. At the epistemological level, the neuroconstructivism (Mareschal et al., 2007; see my commentary in Kotchoubey 2008) culminates in the ideas of Revonsuo (1995) and Metzinger (2003) that all the experience is just a model created, maybe, by a "brain in a vat". "The neural mechanisms bringing about any sort of sentience are buried inside our skulls and thus cannot reach out from there – the world outside the skull is … black and imperceptible" (Revonsuo, 1995; p. 13 of the electronic source). We can only construct a virtual world, but the real world is, for Revonsuo, "The Black Planet" in which we "cannot see anything, hear anything, feel anything", and which will forever remain "silent and dark". Metzinger puts it in more technical language:

> Neither the object component nor the physical body carrying the human brain has to exist … Any physical structure functionally isomorphic to the minimally sufficient neural correlate of the overall-reality model … will realize first-person phenomenology. A brain in a vat, of course, could – if approximately stimulated – activate the conscious experience of being a self in attending to the color of the book in its hands, in currently understanding the semantic contents of the sentences being read, or in selecting a particular, phenomenally simulated action … what the discovery of the correlates … could never help us decide is the question of how the brain in a vat could ever know that it is in this situation – or how you could know that you are now not this brain. (Metzinger, 2003, p. 415).

A biological approach

Like the cognitive approach, the alternative approach discussed in the present paper has many names. I prefer to call it "a biological approach", in the sense of Anokhin's (1974) "biological theory of conditional reflexes", to stress its main difference from the cognitive approach depicted above. Its main point is that behavior and related brain processes are part of the life, of the existence of a living being, which primarily must *survive* and *adjust* to its environment, rather than process information and obtain knowledge about this environment. In the same vein, Looren de Jong & Sanders (1990) also spoke about a "biological" (or, similarly, "naturalistic") way of thinking in psychology. I am really sorry for contrasting the Greek "life" (bios) to the Latin "knowledge" (cognitio), but the term "vitalism" is already busy.

From this point of view, the starting point in a perceptual act is not a stimulus but a particular moment in the adaptation of the organism to its environment. This may be, for example, a motivational state ("need") which causes the organism to prepare for adequate stimuli in the environment. This preparation ("perceptual readiness") can be expressed in tuning of receptors or gating (pre-activation) of specific sensory paths. In addition, perceptual preparation is manifested in search movements of body parts which are related to sensory surfaces. These processes of *efferent perception* may be regarded as questions posed to the environment. How this latter answers is the perceived *event*, and in fact, many biologically oriented authors seriously insisted to replace the term *stimulus* with *event* (e.g., Reed, 1997). Whitehead (1925, 1930) introduced the term *event* in the philosophy in order to oppose it to the concept *fact*. First, an event is not an atomic entity, but always a component of a context of events (Whitehead, 1930) second, an event is not totally objective, but contains a reference to its importance for the subject (Whitehead, 1925).

Whereas some perceptual processes are related to the organism's current state, others are determined by the very construction of the organism (its functional anatomy). The corresponding aspects of perceived objects are, in the former case, referred to as "valence" (Lück, 2001), and in the latter case, as "affordance" (Gibson, 1966). So an object can be perceived as graspable and another as support independently of our actual need to grasp the former or to lie down on the latter. In any case, however, the perceiver lives in the ecological world, rather than a physical world (Kadar & Effken, 1994; Stoffregen, 2000) and perception orients itself to values (Hodges & Baron, 1992) rather than Newtonian features, with the term "values" being used in the existential, not in the moral sense. This approach to perception is hardly compatible with those neurophysiological theories which look for hard-wired detectors of Euclidian geometrical functions, like lines and angles (Hubel & Wiesel, 1968, 1977), although Grossberg (1982) has undertaken a far-reaching attempt to integrate these neurophysiological findings into a wider biological context. I do not regard this difficulty as very important, since the phenomenology of those classical studies can be clearly distinguished from the interpretative theory of neurons as feature detectors and since the same phenomenology can be reinterpreted in light of quite different theories (see Braitenberg & Schüz, 1991; Pribram, 1991). It should further be taken into account that the early data of readily depictable neuronal receptive fields were largely based on artifacts of animal immobility. On the other hand, the biological approach is in line with other neurophysiological theories that regard the activity of receptors as Fourier transformation of stimulus energy (Pribram, 1966), with different states of the organism being related to tuning of different frequencies of the spectrum of ambient energy (Pribram, 1991).

Here, the integrity of the perceived object is given from the very beginning of a perceptual act. There is *no binding problem at all* for the biological approach. The notorious "whole" of perception, which is construed with so much effort from fragmented sensory data by cognitive theories, is already specified by that adaptive behavior which the perception serves for. In the biological approach, not the whole but the details must be found out in the objects of the environment, they must be developed from the originally too general perceptual expectancies. The development of perception consists in differentiation rather than in the synthesis of raw data (Gibson, 1979).

Some biologically oriented authors (e.g., Latash & Latash, 1994; Reed, 1980; Reed, 1984) accuse the cognitive approach for "passivity". Cognitive theories would regard perception as largely determined by "bottom-up" processes, while the (active) biological approach considers it as associated with "top-down" processes. Latash & Latash (1994), for example, write that in theories here designated as biological "perception is the activity of the subject, and not a passive product of stimulation". From my point of view, this is a misleading oversimplification. All existing models of perception and action accept both "top-down" and "bottom-up" processes. The wrong dichotomy "active" versus "passive" misses the point. Not the balance between top-down and bottom-up processes matters, but the exact roles these processes play in different models. Not the "amount" of activity in perception is different between the cognitive and biological approaches, but what this activity does. Most, if not all, cognitive theories of perception assume that the information is actively *selected* and filtered by the brain. In biological theories, however, the information is actively *looked_for*. As Navon points out,

> ...sensory evidence for the presence of suggested stimuli is *actively sought*, in much the same way that a datum received from an information source which is diagnostic of a certain hypothesis will not only sensitize and bias an intelligence officer toward the incidental flow of other information which is indicative of the same hypothesis, but will presumably also lead the officer to *seek* such information. (Navon, 1977; p. 5, emphasis in original)

Contrary to the above opinion, "the subject" in the cognitive approach is, in a sense, even *more active* that in the biological approach, because, in order to construe the perceived world from raw sensory data, the brain has to dispose of numerous top-down operators on these data. This multiplicity of regulations characteristic of cognitive models is supposed to overcome the abundance of sensory data, which results from the fact that sensory systems can, in principle, record many more events each moment of time than it is necessary for the control of behavior.

> Even very simple visual objects... have elements of luminance, contrast, color, shape, orientation, depth, curvature, motion, and texture, and often show shading and spectral reflections... Hence, there is a vast number (greater than the factorial of the number of elementary features) of possible combinations of elementary features of any object, which together constitute a huge search space which cannot be searched comprehensively (Fotheringhame & Young, 1998; p. 55).

While the organism learns to recognize objects,

> when the inputs have as many dimensions as natural stimuli then it is impossible in any realistic time-scale to give examples that densely cover the whole input space, with the consequence that there will be large regions of input space in which the net has no experience to guide it (Philips, 1998; p.32).

The problem is, therefore, the practically unlimited number of "elementary stimulus features" and their combinations which could, potentially, be perceived by our sense organs, as well as the blatant contradiction between this huge number of variables and the unity and simplicity of the ordinary conscious perception. Remarkably, however, this contradiction in the domain of perception has its double in the domain of action. As first discovered by Bernstein (1967; first publication 1935), biomechanical systems like arms and legs have more degrees of freedom than the central executive is able to control. In the jargon of kinesiologists, "the inverse kinematic transformation cannot be uniquely solved", that is, any particular movement trajectory can be achieved by vary many (in principle, infinitely many) different patterns of muscle forces. As a result, the movement apparatus is organized into synergies or classes of functionally equivalent motor patterns. At about the same time as Bernstein, Lashley formulated a very close principle of "motor equivalence" (Beach, Hebb, Morgan, & Nissen, 1960). Lashley's student Hebb (1949) generalized this principle of equivalence to the entire cortical activity in his theory of cell assemblies. The further development of the same idea was the theory of neuronal group selection by Edelman (1987; Sporns & Edelman, 1993).

To mention only the most important features of biological models of action, this approach assumes: (1) distribution of functions between several regulative levels, with each subtask being solved at the lowest level which is able to solve it; thus higher levels do not have exact information about details of the action ("executive ignorance": Green, 1972; Turvey, 1977); (2) high degree of abstractness of the action plan which is probably represented in form of topological relations but not as a concrete sequence of muscle contractions or body movements (Georgopoulos, 1998; Georgopoulos, 1991); (3) strong separation between highly specific processes of tuning, gating, and preparation, on the one hand, and a nonspecific command, which is called "activation" or "Go-signal", on the other hand (Bernstein, 1967; Bullock & Grossberg, 1991; Green, 1972; Turvey, 1990). Thus the movement is organized as a heterarchy rather than a hierarchy of levels, as coordination rather than subordination; and its variability is not an error but its immanent feature (Sporns & Edelman, 1993).

Perception and action as forms of control

How can this self-organization of action be conceived of?

Let us consider a system in whose activity we can record a variable V affected (for simplicity) by only two factors. One of these factors is external for the system (Fex), and the other is internal for the system (Fin). For example, V can be the force of a movement performed by an athlete, the internal factor Fin is the motor command sent by the brain to his muscles, and the external factor Fex is any external force which may disturb the movement (e.g., wind, or an action of the athlete's opponent). If the factors Fex and Fin are uncoordinated, then the variability of V is just the sum of the variances of Fex and Fin:

$$\mathrm{Var}\,(V) = \mathrm{Var}\,(Fex) + \mathrm{Var}\,(Fin) \qquad (1)$$

In vary many cases observed in living systems of different complexity, from microorganisms to humans, the situation is completely different. There are "essential variables" (Ashby, 1960) whose variability is much smaller than the sum of the variances of the factors affecting those variables. Thus the basic physiological constants of the organism, such as blood sugar or body temperature, vary only weakly despite huge variability of factors affecting them. For example, eating a big piece of cream cake, or being in Alaska in winter present serious external disturbances for blood sugar and body temperature, respectively; however, most of us can easily compensate them. This is also true for the above example. A skilled athlete can perform the necessary movement with the necessary force (not stronger, not weaker than necessary) in a broad range of different conditions. This means that

$$\mathrm{Var}\,(V) << \mathrm{Var}\,(Fex) + \mathrm{Var}\,(Fin) \qquad (2)$$

According to Marken (1988), the equation (2) is the *definition of control*. Whenever the variability of a parameter is kept within very narrow limits although the factors which can influence that parameter vary broadly, we can say that *the parameter is kept under control*. On the first glance the definition given by (2) may appear insufficient. In fact, we speak about control not only when we just keep something immobile but also when we can influence very complex processes in a very complex manner. But of course, all cases of as-complex-as-possible influences can be regarded as derivates of the equation (2). To exert a complex form of control means to keep constant, not the parameter V, but a very complex function *f*(V). From the qualitative point of view, this does not make a difference (Powers, 1992).

To keep its essential functions within narrow limits, an organism must perform actions which actively (in fact, in anticipatory manner) compensate for environmental disturbances. If a disturbing force is F, then, to keep our state constant (i.e., to keep our behavior under control) the organism should compensate for it by the force –F. In fact the inequation (2) is true if $Fin \sim -Fex$, and in the ideal case, if $Fin = -Fex$, $\mathrm{Var}\,(V) = 0$, i.e., $V = \mathrm{const}$. That is, control means that the organism develops exactly the same force that affects it, but with the opposite sign. For example, to drive straightforward despite a wind *from* the left side, we develop a force corresponding to the force of the wind, but directed *toward* the left side. Of course, disturbing forces can be produced by the organism itself. For example, if a complex movement is performed by a non-skilled individual, those "passive" parts of the body which do not participate in the movement produce forces disturbing the movement. A skilled individual has learnt to compensate for these disturbances producing opposing forces.

Like in the issue of perception, the wrong opposition between "active" and "passive" approaches in physiology and psychology of movements is an ideological obstacle for understanding these simple ideas. The concept of action as control presented here is very active and very passive at the same time. It is an active concept because it assumes that the organism continuously traces its essential variables trying to keep them constant (=under control). It is an active concept, furthermore, because it assumes that these controlling actions are largely anticipatory, i.e., the organism does not respond to environmental disturbances but prevents them before they occur. But it can also be regarded as a passive concept because it leads us to the conclusion that the pattern of the organism's anticipatory activity exactly corresponds to, or follow, the pattern of environmental disturbances. The better we adjust, the more freedom we have – an apparently paradoxical conclusion which was formulated, about one and half century ago, by the famous student of the above-mentioned Francois Magendie, the "immortal" Claude Bernard: "La fixité du milieu intérieur est la condition d'une vie libre et indépendante." ("The constancy of the internal environment is the condition for a free and independent life.")

What should be stressed in this account is the double meaning of the term "perception" within the above approach. On the one hand, we do, as usual, map perception onto input when we speak, e.g., about "perception of affordances". This meaning, let us call it *perception-1*, subsumes those sensory processes which guide controlling actions, those visual, tactile, proprio- and interoceptive cues which indicate environmental disturbances and signalize the success of control. These inputs are regarded as key phenomena by the control theory. Because only control (that is, elimination of disturbances) is important but not the motor activity which yields it, the control theory states that control systems control input but not output (Marken, 1988; Powers, 1992).

But does this perception-1 fully correspond to our intuitive notion of perception? Only exceptionally these cues can attain the level of reportability or approach object perception. The most striking of the "classical" properties of perception, namely the constancy, is lacking in those input signals. In fact, it is not simply lacking – it must be lacking. For input signals guiding our actions would be useless if we act toward an obstacle on a side of us in exactly the same way as toward one which is immediately in front of us.

This second notion of perception (call it *perception-2*) is not, like input signals, embedded into controlling action, but arises from it. It does not guide action but emerges as a result of the whole pattern of successful control.

I enjoy a cup of hot coffee. I clearly perceive the wonderful taste of coffee and the elegant shape and beautiful color of the cup. This is perception-2. If it were used as guidance for action I would not be able to take any slip! Both the weight of the cup and the temperature of the coffee change continuously during drinking. If my arm movement is based on the constant perception I would pour the coffee on my face rather than in my mouth, and in any case I would be unable to swallow. The ever-changing input would make any clear, reportable perception impossible. From this simple example we can see that perception-1 and perception-2 are as different as any two notions can be. Every science which uses the same word for two entities so different should not be surprised when its theories turn out to be confusing and self-contradictory.

Perception-1 as the component of action

The cognitive approach regards perception as a first stage of information processing, leading to formation of adequate representations of external objects. These adequate representations are necessary for organization of response.

Note that these ideas were based on the results of reaction time (RT) experiments in which the sensorimotor unit stimulated by the experimenter and the unit wherefrom the "response" is recorded differ. Most typically, manual responses (e.g., button press) to visual or auditory stimuli are recorded. This is different from typical everyday life sensorimotor coordinations such as reaching, grasping, or making a saccade, in which the sensory and the motor organ are the same.

The difference is important. If we use the eye for "perception" and the hand for "action", then, of course, we can separate the processes related to the former from those related to the latter. This is because different brain subsystems are related to eye and hand, respectively. But, obviously, visual perception is impossible without complex motor components (the eye is innervated by more motor nerves than any other organ), and the manual response such as button press necessarily includes aspects of somatosensory perception. In a typical visuomotor reaction time experiment, both visual perception and manual action include sensory as well as motor components.

This fact was emphasized as early as 1896 by Dewey in his analysis of the well known (already then!) child-candle case: a child sees a candle, is attracted by its light, grasps it, is burnt and withdraws his hand. The beginning of this process is not the light of the candle, but the child's act of looking at the candle. Looking and grasping are components of a primary sensorimotor coordination before it is enriched by the experience of burning:

> ... failing to see the unity of activity ... still leaves us with sensation, or peripheral stimulus; idea, or central process; and motor response, or act, as three disconnected existences, having to be somehow adjusted to each other, whether through the intervention of an extra-experimental soul, or by mechanical push and pull. (Dewey, 1896)

In an astute experiment Gottsdanker & Tietz (1992) demonstrated that in RT experiments with high stimulus-response compatibility, there can be no condition in which response selection would exist without stimulus discrimination or vice versa: stimulus- and response-related processes are "separate but inseparable" (p.154). In a similar vein, Frith & Done (1986) demonstrated the existence of a special "extra-fast" route to action in the RT task under naturalized conditions, and they interpreted this fact as action requiring *no representation of the stimulus*. Similar interpretation was also done by Bootsma & Wieringen (1990), who obtained extremely fast responses in tennis players. Movements in such naturalized conditions are characterized by the lack of the "psychological refractory period", as different movements can follow each other in a very fast sequence (Georgopoulos, 1998). Furthermore, "the RT under these conditions may increase only slightly, or not at all, with stimulus uncertainty [i.e., with the number of alternative stimuli]" (Georgopoulos, 1998; p.140). Thus in these highly compatible conditions, the famous Hick's law (Hick, 1952) is invalid.

The fact that different components of the sensorimotor coordination in most experimental conditions interact with different aspects of the environment (e.g., the eye and the oculomotor system interact with stimuli, whereas the finger and the related system of tactile perception interact with the responding tool, i.e. key) leads to the possibility to selectively burden these components in different tasks. The simplest example is the presentation of noisy ("degraded") stimuli, which strongly reduces the precision of visual hypotheses on which the perception is based. These hypotheses must be additionally tested and rechecked, perhaps several times. At the same time, the difficulty imposed on the recorded response (e.g., key press) does not have to be enhanced, especially if this response is simple. However, the distinction between the oculomotor system and the manual control system should not be confused with the distinction between perception and action. Thus presentation of noisy stimuli results in sensory responses being changed, which could be measured by recording efferent impulsation to sensory organs (Alexandrov & Jarvilehto, 1993).

The building of such sensorimotor coordination involves parallel gating of sensory and motor subsystems (Brunia, 1993; Brunia, 2001), with preparation of particular perceptions being coupled with tuning of adequate motor structures. Thus perception does not, in general, precede action. At the level of neuroanatomy, Braitenberg & Schüz found no evidence for any clear distinction between perception and action as two consecutive stages of processing:

> ... the input areas (if we want to use this term for the so-called primary sensory areas) are arranged *in parallel* (emphasis in original) with the output areas, ... and the flow of information from the sensory to the motor areas*, if there is such a thing* (my emphasis – B.K.),... is not at all distinguished by any special wiring. (Braitenberg & Schüz, 1991, p.188)

These authors go on to suggest that networks connected with spinal motor units represent both motor *and* sensory aspects of the upcoming sensorimotor act. They wrote:

> A cell assembly may include cortical neurons which have axons connected with the motor output organs. The "event" represented by the cell assembly would then include motor response as well as the perception which leads to it. We may also think of such a combined motor and sensory cell assembly as representing a perception for which a motor act is essential... This double aspect, sensory and motor, of cell assemblies throws a new light on the strange geometry of the cortex, where... the motor and sensory areas are arranged in parallel rather than in series. We notice how misleading the scheme input-elaboration-output may be, implicit in the old tripartition of psychology into perception-cognition-action, and how even more restrictive is our thinking in terms of stimulus-response. (Braitenberg & Schüz, 1991, p. 203).

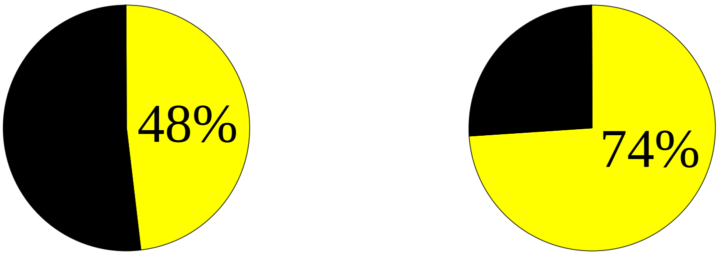
Two physiological phenomena have been used since the 80ies as reliable indicators of difficulties at the level of stimulus-related and movement-related processes, respectively. Specifically, any difficulty at the perceptual level (e.g., stimulus degradation) leads to a delay in the latency of the parietal P3 wave (Magliero, Bashore, Coles, & Donchin, 1984; McCarthy & Donchin, 1981). In bimanual response tasks, a difficulty at the level of response selection (right versus left hand) results in a typical asymmetry in electrical responses from the hand projection areas, known as the so called positive lateralized readiness potential (pLRP) (De Jong, Wierda, Mulder, & Mulder, 1988; Gehring, Gratton, Coles, & Donchin, 1992; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988).

If the cognitive approach is correct, and stimulus analysis and response selection are two consecutive stages of processing, then the P3 latency effect and the pLRP effect must be in a reciprocal relationship. The more of the task difficulty is explained by stimulus-related processes, the less remains to be explained by response selection, and vice versa. Particularly, if all the task difficulty is explained by the difficulty of stimulus evaluation, there must be no difficulty in response selection; otherwise, we would have a logical paradox of over-explanation (Kotchoubey, 2001).

This means that no pLRP can be observed when the P3 latency delay is equal to, or larger than, the RT delay.

My repeated meta-analyses of the published data (Kotchoubey, 1998, 2001; and the unpublished habilitation thesis at the University of Tübingen) demonstrated that this "impossible" option is, actually, the case (Fig. 1). Whenever a pLRP is observed, the P3 delay explains not a smaller (as predicted by the cognitive approach) but a larger portion of the response time, as compared with similar conditions without a pLRP. Moreover, pLRP is frequently recorded in the conditions in which all the RT delay is already explained by the P3 delay. This is the expected over-explanation. From the alternative viewpoint (as formulated, e.g., by Dewey more than 100 years ago), the paradox is easy to solve: stimulus evaluation and response selection are not two consecutive stages, but run in parallel within the sensorimotor coordination constituting a given RT task.

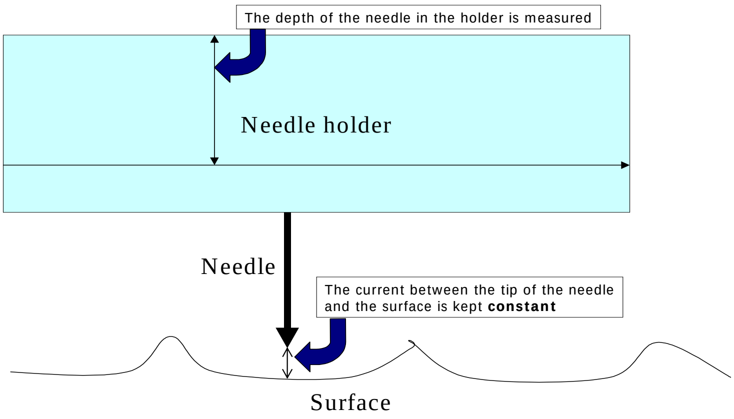
Figure 1. Percentage of RT delay explained by P3 delay. Left: No problem with response selection, P3 explains about one-half of the task difficulty. Right: There are additional problems with response selection. Nevertheless, P3 explains about three-fourth of the task difficulty.



Perception-2 as a function of control actions

In his seminal 1988 article, Hershberger (1998) discusses the principle of the scanning tunneling microscope (Eigler & Schweizer, 1990) which is able to "perceive" a three-dimensional grid of atoms (Fig. 2). An electrified needle runs across the grid being examined. The depth of the needle continuously varies in such a way that the current "tunneling" across the gap between the surface and the tip of the needle is kept constant. Because the current is "actively" controlled, i.e., set a priori and kept at a constant value, the depth of the needle "passively" reflects the depth of the surface, and the record of all needle's positions is a picture of the scanned grid.

Figure 2. A simplified scheme of scanning tunneling microscope mode of operation.



Likewise, when the eye follows the flight of a plane in the sky, the spatial position of the plane's retinal image is kept constant (in this sense, the retinal position is controlled). It is easy to show that when we fix our eyes, thereby maximizing the extent of the retinal movement, the quality of the percept is very poor. To the contrary, if our gaze follows the plane's movement, thus minimizing the retinal image, this quality is optimal. Everybody who believes in the sensory theory of perception must be very puzzled. Obviously, the perception of the flight originates not from efferent processes related to the movement of the image through the retina but from the afferent processes necessary to control the retinal position (Hershberger, 1998).

A prediction which may be deduced from the notion of perception as control is as follows: *any physiological function that can be controlled can also be perceived*. The dependence of the subjective sensory discrimination on the behavioral task, described for gut perception (Hölzl, Erasmus, & Möltner, 1996), is in line with such a notion. However, such findings do not contradict the notion of perception as processing sensory information sent by receptors, because inner organs contain specialized sensors (e.g., mechano-, thermo- and chemoreceptors) which inform the brain about the actual state of affairs (Hollerbach et al., 1997; Schandry, Sparrer, & Weitkunat, 1986; Weitkunat & Schandry, 1990). A case which would have much more weight in this discussion on perception is the acquired ability to control the EEG because no specialized receptive structures in the brain tissue are known for the central brain functions expressed in the EEG. Accordingly, there are no data suggesting that changes in brain potentials can ever be perceived. In fact, the impossibility of such "self-perception" of the brain is even taken for granted (Prinz, 1992).

For practical reasons, most experiments on self-regulation of the EEG in humans used only one or a few learning sessions. The impossibility to detect a new kind of perception in these experiments may have resulted from this limited practice (Roberts, Birbaumer, Rockstroh, Lutzenberger, & Elbert, 1989). Another possible cause is the straightforward interviewing technique, which could reveal this perception only if it attained the level of lucid awareness and could be expressed as a verbal report. In our study, reported in details elsewhere (Kotchoubey, Kübler, Strehl, Flor, & Birbaumer, 2002), we employed a course of biofeedback treatment of patients with intractable epilepsy who participated in 35 training sessions, and the results of a severely paralyzed patient who was trained for hundreds of sessions. The method used for the estimation of perception did not address reflexive awareness.

Patients had to produce a slow EEG shift in either positive or negative direction (slow cortical potentials, SCP; see Birbaumer, Elbert, Canavan, & Rockstroh, 1990) while continuous feedback on the SCP amplitude was provided (feedback trials). In other trials, they had to produce SCP shifts without feedback (transfer trials). A self-perception procedure was introduced in the transfer condition three times during the course of treatment: in the 2nd, 15th, and 30th session. After each transfer trial patients had to estimate how large they believed was the SCP shift they had produced in the just preceding trial. They were asked, immediately after the end of a trial, to spell a number between 1 and 7, with 7 corresponding to the maximal success (i.e., very large SCP shift in the required direction) and 1 to a failure (i.e., producing an SCP shift in the opposite direction). Patients were explicitly required to respond as fast as possible according to their immediate impression after the end of the trial, and not to think in an attempt to give an accurate estimation.

Three findings of that study (Kotchoubey et al., 2002) are of importance in the present context. First, like subjects of Roberts et al. (1989), our epilepsy patients could not give consistent explicit verbal descriptions of their cognitive strategies while they controlled the SCPs. Nevertheless, when asked to estimate their SCP using a simple number from 1 to 7 immediately after each trial, they attained a high degree of accord with their real SCP amplitude measures, which increased from the 2^{nd} to the 30th session. Additional analyses (see Kotchoubey et al., 2002) allowed us to rule out several alternative explanations and to come to the conclusion that patients learned to adequately perceive their produced EEG function (i.e., SCP). Second, the ability to estimate one's SCPs was related to the ability to control them, with better perception of the SCP being found in those patients who also were more successful in producing the required SCP. Third, Brener (1974, 1982) suggested that in biofeedback experiments subjects learn to control a physiological function on the basis of successful perceptual discrimination. If this theory is correct, in the course of long training perception would precede successful control. Exactly the opposite temporal order was found: patients first learned to control their SCP shifts, and only after this, they acquired the ability to correctly estimate them.

In other words, a brain function can be perceived when it becomes the target function in operant learning. What is perceived from that point of view are strategies used for control. Just as the flying airplane in the Hershberger's (1998) example is clearly perceived due to the efferent (motor) activity required to keep the afferentation (i.e., the image of the plane on the retina) controlled, the SCPs are perceived due to the efferent activity (supposedly imagination) necessary to keep the feedback signal under control. Importantly, this new perceptive ability was acquired without any receptive information, thus radically undermining the notion of perception as a processing of "raw sensory data" – indeed, no sensory data about brain activity exist. This finding may be regarded as a strong argument for the notion of perception as a function of behavioral control.

Conclusion: Back to Pilate

To summarize, the following points distinguish between the two approaches:

In the cognitive approach, behavior is stimulus-driven ("at the beginning was the stimulus") and internally structured. This means that in order to understand behavioral patterns we must understand inner (mental or neurophysiological) processing mechanisms. In the biological approach, behavior is organism-driven ("at the beginning is the organism with its needs") and externally patterned. This means that in order to understand behavior we must know interactions between the organism and its environment.

In the cognitive approach, the processing of stimulus information and the organization of motor response are two different entities. The former is perception (mapped onto sensory functions) and precedes action planning, which is mapped onto motor functions. We must first perceive, than act. The biological approach, to the contrary, does not regard perception as a self-sufficient process outside the control of behavior. Stimulus- and response-related processes are but different sites of sensorimotor coordination. Perception and action do not map onto input and output, respectively. Instead, both perception and action include both sensory and motor components.

In the cognitive approach, perception is necessary to prepare action. Actions (which are assumed to be outputs) are controlled by the organism (or its brain). In the biological approach, perception and action are forms of behavioral control. What is controlled is not output but input. This means that movement patterns produced to obtain the necessary result are variable and not essential. Essential is only the result but not the means of its achievement.

Some examples can illustrate the different stories the cognitive and the biological approach tell us:

I draw my hand away from a hot iron. The first story is: I perceive the iron's heat, make a decision (unconscious, of course) to draw my hand, and therefore, I draw it. The alternative story is: I pursue the intactness of my body as an essential variable which I must control. Therefore, I draw my hand to avoid damage facing the temperature disturbance (e.g., hot iron). Because I do it, I perceive that the iron was hot.

I am driving my car, and the road goes uphill, thus I give more gas. The first story is: I perceive that the road goes uphill, therefore I give more gas. The alternative story is: To keep the velocity constant facing a disturbance, I have to give more gas. Because I do it, I know that the road goes uphill.

If we accept the alternative stories, this implies that what we perceive is largely a trace of our adaptive activity aimed at controlling our external or internal environment. Therefore, a percept is like a mirror reflection of the environmental forces the organism is compensating for. Any product of our perception is thus equal to an element, or aspect, of the real world *as it affects us*.

This may appear paradoxical. Philosophers, psychologists, and brain scientists ever asked for a proof that our perception is true. As said above, cognitive science (which holds the prevailing view on the nature of human mind for the last 50 years) even takes its name from the basic assumption that the main function of brain and mind is to get knowledge about the external world. But as long as we map perception and action onto input and output, respectively (and cognitive psychology does exactly this), we can never know what we can know. As long as we pursue knowledge we cannot obtain it. It always remains elusive, and the gap between things as such and things as they appear to us cannot be overbridged.

But when, instead, we begin with behavioural control, then, together with successful control, we also obtain knowledge! Namely,

(1) the content of our (conscious) percepts results not from a processing of sensory stimuli randomly striking receptors, but from the controlling activity directed to keeping some sensory variables constant;

(2) this controlling activity consists of developing compensatory forces –F which must be equal to the external forces F imposed upon us but having the opposite sign (otherwise we fail to control);

(3) hence, the content of percepts must reflect some components of the real world as it encountered us in our experience. The German word for perception ("Wahrnehmung") contains the root "wahr", meaning "true". In fact, perception (Wahrnehmung) is always true.

Perhaps, Pilate was overhasted to go away. Of course, we cannot know exactly what Jesus would have answered if Pilate stayed there. In the novel of Bulgakov "The Master and Margarita", Pilate interrogates Jesus during a severe migraine attack, which makes him particularly hate the prisoner. When asking his famous question, he wants to go out, but Bulgakov, using his priviledge as a fiction author, lets Jesus time to answer:

> The truth is, first of all, that your head aches, and aches so badly that you're having faint-hearted thoughts of death. You're not only unable to speak to me, but it is even hard for you to look at me. And I am now your unwilling torturer, which upsets me. You can't even think about anything and only dream that your dog should come, apparently the one being you are attached to. But your suffering will soon be over, your headache will go away. (Bulgakov, 1997, Ch.2, transl. by R. Pevear and L. Volokhonsky)

If I correctly grasp at least one of the many ideas contained in the Bulgakov's passage, the truth is, primarily and largely, in the immediate experience. Like many important truths in the life, the truth of the true knowledge about the world can be found only if we do *not* look for it. We need no specific "cognitive activity" aiming to obtain knowledge. We get knowledge about the objective reality gratis, for nothing, when we execute effective control.

But there are two issues to stop at. First, everybody who likes shopping would immediately object that there must be cheating here. Nothing in the world can really be gratis, free of charge. If a seller offers you the second item free whenever you buy one item, this does not mean that he is concerned with your profit instead of his own. Rather, this means that the costs of the second item are already included in the price of the first one.

And the Mother Nature does exactly the same! Exerting successful control has already required a lot of resources to withstand disturbances of the hard world outside. Adjustment to this world is very expensive. Thus "for free" is, of course, an elliptical expression; the costs have already been calculated. You need not pay *extra* for true knowledge, because *you have already paid* it.

Second, we have said that our perception truly reflects aspects of objective reality *as it affects us*. This is because perception is related to compensatory activity to overcome external disturbances. We know truth about the world, but only in the extent of how this world disturbs our homeostasis, in the broadest sense of the word. Therefore, although our knowledge is true, it is only true within the limits of our experience. In a court trial, witnesses swear to tell truth, only truth, and the whole truth; our perceptual systems in contrast, tell truth and only truth – but not the whole truth. For this reason, although your percepts and my percepts, and my cat's percepts are all true, they can radically differ from each other. This is, however, because of the difference in experience between different beings (e.g., you and me and my cat), but not because each being (or its mind, or its brain) "constructs" its own reality. *The multiplicity of truth does not mean its relativity* (e.g., Dreyfus, 1991).

This fact raises the question, whether our perception must always be limited by the borders of our experience, or there is some way to transcend these borders. However, answering this question can only be done in another article, at least as large as the present one.

REFERENCES

Alexandrov, Y., & Jarvilehto, T. (1993). Activity versus reactivity in psychology and neurophysiology. *Ecological Psychology, 5*(1), 85-103.

Allport, D. A. (1980). Attention and performance. In G. Claxton (Ed.), *Cognitive Psychology - New Directions*. London: Routledge & Kegan Paul.

Anderson, J. R. (1995). *Cognitive Psychology and Its Implications.* New York: W. H. Freeman & Co.

Anokhin, P. K. (1974). *Biology and neurophysiology of the conditioned reflex and its role in adaptive behavior* (R. Dartau, J. Epp & V. Kirilcuk, Trans.). Oxford: Pergamon Press.

Beach, F. A., Hebb, D. O., Morgan, C. T., & Nissen, H. W. (1960). *The Neuropsychology of Lashley*. New York: McGraw-Hill.

Bernstein, N. A. (1967). *The Coordination and Regulation of Movements*. Oxford: Pergamon.

Bickel, A. (1901). Eine historische Studie über die Entdeckung des Magendie-Bell'schen Lehrsatzes. *Pflugers Archiv für die gesamte Physiologie - European Journal of Physiology, 84*, 276-303.

Bickhard, M. H., & Richie, D. M. (1983). *On the Nature of Representation: A Case Study of James J. Gibson's Theory of Perception*. New York: Praeger.

Birbaumer, N., Elbert, T., Canavan, A. G. M., & Rockstroh, B. (1990). Slow potentials of the cerebral cortex and behavior. *Physioloogical Reviews, 70*(1), 1-41.

Bootsma, R. J., & Wieringen, P. C. von (1990). Timing an attacking forehand drive in table tennis. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 21-29.

Braitenberg, V., & Schüz, A. (1991). *Anatomy of the Cortex: Statistics and Geometry*. Berlin: Springer.

Brener, J. M. (1974). A general model of voluntary control applied to the phenomena of learned cardiovascular change. In P. A. Obrist, A. H. Black, J. Brener & L. V. DiCara (Eds.), *Cardiovascular Psychophysiology* (pp. 365-391). Chicago: Aldine.

Brener, J. M. (1982). Psychobiological mechanisms in biofeedback. In L. White & B. Tursky (Eds.), *Clinical Biofeedback* (pp. 24-47). New York: Guilford.

Brunia, C. H. M. (1993). Waiting in readiness: Gating in attention and motor preparation. *Psychophysiology, 30*, 327-339.

Brunia, C. H. M. (2001). Thalamo-cortical relations in attention and consciousness. *International Journal of Psychophysiology, 43*, 1-4.

Bulgakov, M. (1997). http://lib.ru/BULGAKOW/master97_engl.txt

Bullock, D., & Grossberg, S. (1991). Adaptive neural networks for control of movement trajectories invariant under speed and force rescaling. *Human Movement Science, 10*, 3-53.

Chomsky, N. (1981). Knowledge of language: Its elements and origins. *Philosophical Transactions of the Royal Society of London, 295*(1077), 223-234.

Cowan, N., & Wood, N. L. (1997). Constraints on awareness, attention, processing, and memory: Some recent investigations with ignored speech. *Consciousness and Cognition, 6*, 182-203.

De Jong, R., Wierda, M., Mulder, G., & Mulder, L. J. M. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance, 14*(4), 682-692.

Dewey, J. (1896). The reflex arc concept in psychology. *Psychological Review, 3*, 357-370.

Dreyfus, H. (1991). *Being-in-the-World: A Commentary on Heidegger's Being and Time, Division I*. Cambridge, MA: MIT Press.

Edelman, G. (1987). *Neural Darwinism*. New York: Basic Books, Inc.

Eigler, D. M., & Schweizer, E. K. (1990). Positionining single atoms with a scanning tunneling microscope. *Nature, 344*, 524-526.

Eriksen, C. W., & Schulz, D. W. (1979). Information processing in visual search: Some theoretical considerations and experimental results. *Perception and Psychophysics, 25*, 249-263.

Fodor, J. A. (1998). *Concepts: Where Cognitive Science Went Wrong?* Oxford: Clarendon Press.

Fotheringhame, D. K., & Young, M. P. (1998). Neural coding schemes for sensory representation: Theoretical proposals and empirical evidence. In M. D. Rugg (Ed.), *Cognitive Neuroscience* (pp. 47-76). Hove, UK: Psychology Press.

Frith, C. D., & Done, D. J. (1986). Routes to action in reaction time task. *Psychological Research, 48*, 169-177.

Gehring, W. J., Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Probability effects on stimulus evaluation and response processes. *Journal of Experimental Psychology: Human Perception and Performance, 18*(1), 192-216.

Georgopoulos, A. (1998). Voluntary movement: Computational principles and neural mechanisms. In M. D. Rugg (Ed.), *Cognitive Neuroscience* (pp. 131-168). Hove, UK: Psychology Press.

Georgopoulos, A. P. (1991). Higher order motor control. *Annual Review of Neuroscience, 14*, 361-377.

Gibson, J. J. (1961). Ecological optics. *Vision Research, 1*, 253-262.

Gibson, J. J. (1966). *The Senses Considered as Perceptual Systems*. Boston: Houghton Mifflin Co.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Co.

Gottsdanker, R., & Tietz, J. D. (1992). An "exhaustive" search for tasks that fall between the choice and simple reactions. *Journal of Motor Behavior, 24*(2), 147-156.

Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and poststimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 331-344.

Green, P. H. (1972). Problems of organization of motor systems. In R. Rosen & F. Snell (Eds.), *Progress in Theoretical Biology* (pp. 303-338). New York: Academic Press.

Grossberg, S. (1982). *Studies in Mind and Brain* (Vol. 70). Dordrecht: Reidel Publishing Company.

Hebb, D. O. (1949). *The Organization of Behavior*. New York: Wiley.

Hershberger, W. A. (1998). Control systems with a priori intentions register environmental disturbances a posteriori. In J. S. Jordan (Ed.), *Systems Theories and A Priori Aspects of Perception* (Vol. 126, pp. 3-24). Amsterdam: Elsevier.

Hick, W. E. (1952). On the rate of gain of information. *Quarterly Journal of Experimental Psychology, 4*, 11-26.

Hodges, B. H., & Baron, R. M. (1992). Values as constraints on affordances: Perceiving and acting properly. *Journal of the Theory of Social Behavior, 22*(3), 263-294.

Hollerbach, S., Kullmann, F., Frund, R., Lock, G., Geissler, A., Scholmerich, J., et al. (1997). Auditory event-related cerebral potentials (P300) in hepatic encephalopathy - topographic distribution and correlation with clinical and psychometric assessment. *Hepatogastroenterology, 44*(16), 1002-1012.

Hölzl, R., Erasmus, L. P., & Möltner, A. (1996). Detection, discrimination and sensation of visceral stimuli. *Biological Psychology, 42*, 199-214.

Hubel, D. N., & Wiesel, T. N. (1968). Receptive fields and functional architecture of monkey striate cortex. *Journal of Physiology, 195*, 215-243.

Hubel, D. N., & Wiesel, T. N. (1977). Functional architecture of Macaque monkey visual cortex. *Proceeding of the Royal Academy of London, 198*, 1-59.

Hurley, S. (1998). *Consciousness in Action*. Cambridge, MA: Harward University Press.

Hurley, S. (2001). Perception and action: Alternative views. *Synthese, 129*, 3-40.

Jordan, J. S. (1999). Cognition and spatial perception: Production of output or control of input? In G. Ascherleben, T. Bachmann & J. Müsseler (Eds.), *Cognitive Contributions to the Perception of Spatial and Temporal Events* (pp. 69-90). Amsterdam: Elsevier.

Jordan, J. S. (2003). Emergence of self and other in perception and action: An event-control approach. *Consciousness and Cognition, 12*, 633-646.

Kadar, E. E., & Effken, J. (1994). Heideggerian meditations on an alternative ontology for ecological psychology: A response to Turvey's proposal. *Ecological Psychology, 6*(4), 297-341.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility - a model and taxonomy. *Psychological Review, 97*, 253-270.

Kornblum, S., & Lee, J. W. (1995). Stimulus-response compatibility with relevant and irrelevant stimulus dimensions that do and do not overlap with the response. *Journal of Experimental Psychology: Human Perception and Performance, 21*(4), 855-875.

Kotchoubey, B. (1998). What do event-related brain potentials tell us about perception and action. In J. S. Jordan (Ed.), *Systems Theories and A Priori Aspects of Perception* (Vol. 126, pp. 209-257). Amsterdam: Elsevier.

Kotchoubey, B. (2001). About hens and eggs: Perception and action, psychology and neuroscience. A reply to Michaels (2000). *Ecological Psychology, 13*(2), 123-133.

Kotchoubey, B. (2008). Beyond mechanism and constructivism. *Behavioral and Brain Sciences, 31*(3), 341-342.

Kotchoubey, B., Kübler, A., Strehl, U., Flor, H., & Birbaumer, N. (2002). Can humans perceive their brain states? *Consciousness and Cognition, 11*, 98-113.

Latash, L. P., & Latash, M. L. (1994). A new book of N.A.Bernstein "On Dexterity and Its Development". *Journal of Motor Behavior, 26*(1), 56-62.

Looren de Jong, H., & Sanders, A. F. (1990). Stratification in perception and action. *Psychological Research, 52*, 216-228.

Magliero, A., Bashore, T. R., Coles, M. G. H., & Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology, 21*, 171-186.

Mareshal, D., Johnson, M. J., Sirois, S., Spratling, M. W., Thomas, M. C. S., & Westermann, G. (2007). *Neuroconstructivism: How the Brain Constructs Cognition* (Vol. 1). New York: Oxford University Press.

Marken, R. S. (1988). The nature of behavior: Control as fact and theory. *Behavioral Science, 33*, 197-205.

McCarthy, G., & Donchin, E. (1981). A metric for thought: A comparison of P300 latency and reaction time. *Science, 211*, 77-80.

Metzinger, T. (2003). *Being No One. The Self-Model Theory of Subjectivity*. Cambridge MA: MIT Press.

Navon, D. (1977). The forest revised: More on global precedence. *Psychological Bulletin, 43*, 1-32.

Osman, A., Kornblum, S., & Meyer, D. E. (1990). Does motor programming necessitate response execution? *Journal of Experimental Psychology: Human Perception and Performance, 16*(1), 183-198.

Philips, W. A. (1998). Theories of cortical computation. In M. D. Rugg (Ed.), *Cognitive Neuroscience* (pp. 11-46). Hove, UK: Psychology Press.

Powers, W. T. (1992). *Living Control Systems* (Vol. 2). Gravel Switch, Kentucky: The Control System Group.

Pribram, K. H. (1966). *Languages of the Brain: Experimental Paradoxes and Principles in Neuropsychology*. Englewood Cliffs, NJ: Prentice-Hall.

Pribram, K. H. (1991). *Brain and Perception*. Hillsdail, NJ: Lawrence Erlbaum Associates, Inc.

Prinz, W. (1992). Why don't we perceive our brain states? *European Journal of Cognitive Psychology, 4*(1), 1-20.

Reed, E. S. (1980). Information pickup is the activity of perception. *Behavioral and Brain Sciences, 3*, 397-398.

Reed, E. S. (1984). From action gestalts to direct actions. In H. Whiting (Ed.), *Human motor actions - Bernstein reassessed* (pp. 157-168). Amsterdam: North Holland.

Revonsuo, A. (1995). Consciousness, dreams and virtual realities. *Philosophical Psychology, 8*(1), 35.

Roberts, L., Birbaumer, N., Rockstroh, B., Lutzenberger, W., & Elbert, T. (1989). Self-report during feedback regulation of slow cortical potentials. *Psychophysiology, 26(4)*, 392-403.

Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction, and extent. *Journal of Experimental Psychology: General, 109*, 444-474.

Schandry, R., Sparrer, B., & Weitkunat, R. (1986). From the heart to the brain: A study of heart beat contingent scalp potentials. *International Journal of Neuroscience, 30*, 261-275.

Sekuler, R., & Blake, R. (1994). *Perception* (3rd ed.). New York: McGraw-Hill.

Shadlen, M. N., & Movshon, J. A. (1999). Synchrony unbound: A critical evaluation of the temporal binding hypothesis. *Neuron, 24*, 67-77.

Singer, W. (1999). Neuronal synchrony: A versatile code for the definition of relations. *Neuron, 24*, 49-65.

Smid, H. G. O. M., Böcker, K. B. E., van Touw, D. A., Mulder, G., & Brunia, C. H. M. (1996). A psychophysiological investigation of the selection and the use of partial stimulus information in response choice. *Journal of Experimental Psychology: Human Perception and Performance, 22*(1), 3-24.

Sporns, O., & Edelman, G. M. (1993). Solving Bernstein's problem: A proposal for the development of coordinated movement by selection. *Child Development, 64*, 960-981.

Sternberg, S. (1969). Memory scanning: Mental processes revealed by reaction time experiments. *American Scientist, 57*, 421-457.

Sternberg, S. (2001). Separate modifiability, mental modules, and the use of pure and composite measures to reveal them. *Acta Psychologica, 106*, 147-246.

Stoffregen, T. A. (2000). Affordances and events. *Ecological Psychology, 12*, 1-28.

Treisman, A. (1999). Solution to the binding problem: Progress through controversy and convergence. *Neuron, 24*, 105-110.

Treisman, A. M., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology, 12*, 97-136.

Turvey, M. T. (1977). Preliminaries to a theory of action with reference to a vision. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing* (pp. 67-82). Hillsdale, NJ: Lawrence Erlbaum.

Turvey, M. T. (1990). Coordination. *American Psychologist, 45*, 938-953.

Ulrich, R., Leuthold, H., & Sommer, W. (1998). Motor programming of response force and movement direction. *Psychophysiology, 35*(6), 721-728.

Van der Heijden, A. H. C. (1996). Perception for selection, selection for action, and action for perception. *Visual Cognition, 3*(4), 357-361.

van Gelder, T. (1997). The dynamical alternative. In M. D. Johnson (Ed.), *The Future of the Cognitive Revolution* (pp. 227-241). New York: Oxford University Press.

van Gelder, T. (1998). The dynamical hypothesis in cognitive science. *Behavioral and Brain Sciences, 21*(5), 615-665.

Weitkunat, R., & Schandry, R. (1990). Motivation and heartbeat evoked potentials. *Journal of Psychophysiology, 4*, 33-40.

Whitehead, A. N. (1925). *Science and the Modern World*. Cambridge, England: Macmillan Publishing Co.

Whitehead, A. N. (1930). *The Concept of Nature*. Cambridge, England: University Press.

Acknowledgment

I am grateful to J. Scott Jordan for fruitful discussions on the problems of perception and action.

*

Formatiert: Block