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Naturalizing Perception

Developing the Gibsonian Approach to Perception along Evolutionary Lines

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ABSTRACT. We believe that one of the most important aspects of Gibson's ecological psychology is his attempted naturalization of perception, that is, his attempt to place perception in the context of evolutionary theory. However, the dominant neo-Gibsonian approach to perception has been criticized for being inconsistent with evolutionary theory. We argue that a central tenet of this approach indeed runs counter to evolutionary considerations. Based on an evolutionary analysis of the use of information, we sketch an alternative development of Gibson's pioneering ideas. A truly naturalistic theory of perception, we argue, should recognize both suboptimalities in perception and variation among the members of a population in what informational variables are used. Like other variable organismal features, the use of information is a function of multiple factors. We will compare this naturalistic ecological approach with both Gibson's own perspective and more recent frameworks.

KEY WORDS: ecological psychology, evolutionary psychology, information, naturalism, perception

In the distant future I see open fields for far more important researches. Psychology will be based on a new foundation, that of the necessary acquirement of each mental power and capacity by gradation. (Darwin, 1859/1985, p. 458)

As is clear from the above quote, Darwin believed that his theory of evolution would have profound effects on psychology. In the century that followed the publication of his theory (in 1859), it did indeed have impact on thinking

about the nature and origin of many psychological functions, grounding them in biology (e.g., James, 1890/1950; see also Richards, 1987). However, Darwin's theory of evolution has had little effect on theorizing about perception. Many post-Darwinian theories of perception follow pre-Darwinian theories both in their conceptualization of perception and in their basic idea of how perception comes about (Glotzbach & Heft, 1982; Reed, 1982b). Among the exceptions was Gibson's (1966, 1979/1986) ecological approach. Gibson was clearly influenced by evolutionary theory and aimed at what we will call naturalizing perception—treating perception as an evolved, biological function (Lombardo, 1987).¹ In fact, he complained that “[t]he classics of vision were unaffected by evolutionary considerations or by knowledge of animal behavior but nevertheless they dominate the theories of perception” (Gibson, 1966, p. 155). To develop a naturalistic theory, Gibson therefore broke with a long tradition in psychology and introduced a radically new way of thinking about perception in the 1960s and 1970s. Although arguably Gibson did not succeed in completing the naturalization of perception, his theory of direct perception has long been conceived as “the only worked-out naturalistic theory of perception” (Meijsing, 1998, p. 89; but see Looren de Jong, 1995, and below).

Over the last few decades, ecological psychologists have systematized and developed Gibson's ideas and initiated a broad empirical research program the results of which have been impressive and are piling up (see, e.g., Fajen & Warren, 2003; Riley & Turvey, 2001; Runeson, Juslin, & Olsson, 2000; Turvey, Shockley, & Carello, 1999). However, different ecological psychologists have developed Gibson's ideas in different ways, yielding perspectives that are sometimes inconsistent with one another (e.g., Fajen, 2005; Goldfield, 1995; Heft, 2001; Jacobs & Michaels, 2002; Reed, 1996; Runeson et al., 2000; Shaw & Kinsella-Shaw, 1988; Stoffregen & Bardy, 2001; Turvey, 1990). Among the issues that separate contemporary developments of Gibson's theory is the relationship of ecological psychology to evolution: that is, the extent to which Gibsonian psychology is a naturalization of perception. Reed (1982a, 1985, 1996), for example, has taken this naturalization to be central to ecological psychology. He also claimed without evidence or argument that Turvey, the most prominent and influential neo-Gibsonian, is “far removed from evolutionary or selectionist thinking” (Reed, 1996, p. 187). Since Gibson's death, Turvey, in collaboration with Shaw and other colleagues (e.g., Michaels & Carello, 1981; Shaw, Turvey, & Mace, 1982; Turvey, 1990; Turvey & Shaw, 1999; Turvey, Shaw, Reed, & Mace, 1981), has developed an ecological theory of perception that continues to have a great impact on the thinking of researchers on perception and action (for a review, see Fajen, 2005; Tresilian, 1999). However, if this theory is indeed at odds with evolutionary considerations, the prominent neo-Gibsonians have developed an approach that runs counter to the naturalization of perception that Gibson aimed at.

This paper is about Gibson's naturalization of perception. After setting out both Gibson's own approach and the prevailing neo-Gibsonian perspective,

we will evaluate the biological plausibility of the latter. The reason for this evaluation is two-fold. First, Reed's sharp but entirely unsubstantiated critique of Turvey requires investigation. Although some authors have already briefly commented upon the biological plausibility of aspects of the dominant neo-Gibsonian tradition (e.g., Cabe, 2001; Meijer, 1998), a thorough analysis is still needed. Does the prevailing neo-Gibsonian theory of perception run counter to evolutionary considerations? Second, this examination will reveal criteria that a truly naturalistic theory of perception should meet. These criteria can be used both to evaluate the plausibility of theories of perception and to guide further theoretical and empirical research on perception. We will argue that a central tenet of the dominant neo-Gibsonian perspective is indeed at odds with the idea that perceptual systems have evolved. Based on our evolutionary analysis of the use of information, we will make a recommendation concerning what a more completely naturalistic theory of the use of information in perception should look like. Finally, we will compare our ideas with Gibson's approach and more recent perspectives.

Gibson's Approach and the Dominant Neo-Gibsonian Program

It is hard to imagine a theory of perception more elegant than Gibson's (1966, 1979/1986). However, partly because of its elegance, the significance of his work is not easily seen if you do not understand the tradition he opposed. In the 1960s and 1970s, Gibson took aim at the widely accepted view that perceptual experience is the result of inferential processes. Roughly speaking, most theories of perception (pre- or post-Darwinian) are based on the assumption that the stimulus information impinging on the senses is impoverished—the stimulus information does not contain a specification of the environment, but relates ambiguously to it. That is, different environmental conditions can yield the same stimulus information; and the same environmental state of affairs can result in different stimuli. Because of this many-to-many relation between stimulus and environment, the animal has to infer the cause of the stimulation in order to gain knowledge of the environment. This implies that animals do not have direct access to the environment. Instead, animals “form a conception of the properties of external objects, which may be relatively correct,” as the physiologist Müller put it in his seminal book *Elements of Physiology* (1838–1840/2007; as cited in Reed, 1982b, p. 749). This means that the objects of experience are constructed, reside in the head, and are relatively insulated from the environment. This conception of perception can be traced back to Descartes, perhaps even back to Augustine or Plato, and is central in most (cognitive) theories of perception.

Gibson (1966, 1979/1986) criticized this traditional theory of perception on several grounds, and developed a new theoretical framework. He adopted an evolutionary perspective and conceived perception as a biological function,

emphasizing the intimate connection between the animal and its environment. Indeed, Gibson conceived perception not as a mental state residing in the head, but as an epistemic relation between perceiver and environment. Although his work has been conceived as highly original (Reed, 1988), it is rooted in the naturalistic tradition in psychology (Looren de Jong, 1995). Gibson shared the biological approach and the allied emphasis on the animal–environment relation with earlier theorists like James, Heider, Brunswik, and Holt. Brunswik (1956) had argued that “[t]he basic fact of perception is distal focussing. No orientation in an organized ‘world’ would be possible without it” (p. 61). And Heider (1930/1959b) stated,

Everybody will concede that the perceptual apparatus belongs to an organism which is adapted to the environment; nevertheless, in discussions on perception the structure of the environment is often completely neglected, and only the proximal stimuli (for instance, the wave length of the stimuli impinging on the organs) are taken account of. (p. 35)

Heider (1927/1959a, 1930/1959b) was convinced that understanding perception requires a thorough examination of the relationship between the distal object and the energy patterns that might convey information about it. And Brunswik (1956) adopted this idea and tried to capture the relation between the proximal stimuli (e.g., the retinal image) and distal stimuli (the environment) in his famous lens model. Although the later Gibson rejected several central elements of Brunswik’s and Heider’s naturalistic approaches, he was sympathetic to and influenced by their focus on the environment and the stimulus in explaining perception (see, e.g., Gibson, 1957; 1966, p. 187; 1979/1986, pp. 2–3; see also Looren de Jong, 1995). However, in conceptualizing perception as an epistemic relation between animal and environment, Gibson was perhaps most influenced by Holt, his mentor at Princeton (Heft, 2001). Indeed, in his autobiography, Gibson (1967) called himself a Holtian. His mentor had argued that animals perceive the environment, not a representation thereof. That is, all things that animals perceive are “out there” (see, e.g., Holt, 1915). Gibson (1979/1986) adopted this idea from Holt—perception, he asserted, “is a keeping-in-touch with the world, an experiencing of things, rather than a having of experiences” (p. 239).

Gibson took the animal–environment relation to be central not only in his definition of perception, but also in his conceptualization of the environment. In fact, Gibson (1979/1986) developed a new perspective on what animals perceive. The primary objects of animals’ experience, he argued, are the action possibilities that the environment affords. He termed these *affordances*. “The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or for ill” (Gibson, 1979/1986, p. 127). Examples of affordances are climb-on-ability, grasp-ability, walk-on-ability. Note that the existence of an affordance implies a fit between the animal and its environment. Whether stairs are climb-on-able for an animal depends on the relation between the height of the stairs and the animal’s action capabilities. Hence, an environment consisting of affordances

is an animal-relative environment, which, according to Gibson, is permeated with meaning. To perceive what behavior an object or surface affords is perceiving what it means for you.

To explain how animals establish perceptual contact with affordances, Gibson (1966, 1979/1986) introduced a new theory of the stimulus information available to the senses. He argued that the assumption of impoverished stimulus information, on which most inferential theories of perception are based,² is fallacious. It is true, Gibson conceded, that the energy pattern that impacts the eye of a passive observer at any moment relates many-to-many to the environment. However, according to the later Gibson (1966, 1979/1986), the retinal image is not the stimulus to the visual system. Instead, he argued that perceptual information resides in the ambient energy arrays and flows. And this information is rich; it specifies the environmental properties. Gibson stressed the importance of the animal's movement in both the detection and creation of specifying information. In his view, perceiving animals are rarely passive: to detect information, perceptual systems scan the ambient arrays and extract information. Furthermore, by moving, animals can create spatiotemporal energy patterns that are specific to environmental properties. His conception of information and his allied theory of direct perception is generally regarded as the most important contribution of Gibson's ecological perspective. It contrasted not only with the previously mentioned traditional theories of perception, but also with the naturalistic frameworks of Brunswik and Heider (Looren de Jong, 1995; Vicente, 2003). Brunswik (1956) believed that the retinal image constitutes the input for the visual system. Furthermore, his theory of perception is based on the assumption that the world is probabilistic. According to Brunswik's lens model, the proximal stimulus (e.g., the retinal image) is correlated with the distal stimulus (an environmental property), but is not specific to it. It has a limited ecological validity; it can make the existence of the environmental property only (highly) probable. And because of this untrustworthiness of the stimuli, Brunswik's model posits inferential perceptual processes to explain the adaptiveness of perception. Gibson believed that his conception of information as specification renders such inferential processes dispensable, and allows for a new, direct theory of perception. Because animals exploit spatiotemporal energy patterns that are specific to the to-be-perceived or to-be-acted-upon properties of the environment, inferential processes can be discarded and direct perceptual contact is possible. That is, an animal can directly perceive an affordance by picking up information that is specific to it.

Gibson's theory of direct perception has proven to be a very powerful idea. It provides a new way of thinking about perception, one that contrasts in important ways with the widely accepted view that perceptual experience is the result of inferential or computational processes. Furthermore, in making the animal-environment relation central in the conceptualization of both perception and the environment, Gibson's work has been regarded as an important contribution to the naturalization of psychology (e.g., Looren de

Jong, 1995, 1997; Meijsing, 1998). And lastly, Gibson's ideas have inspired researchers working in the fields of embodied cognition (e.g., Clark, 1997; Kirsh, 1991), dynamical systems theory (e.g., Keijzer 2001; Kelso 1995; Kugler & Turvey 1987; Port & van Gelder 1995; Thelen & Smith 1994), and experimental research on perception and action. In the next section, we will focus on the work of the prevailing neo-Gibsonians.

The Dominant Neo-Gibsonian Program

In the decades since Gibson's death (in 1979), several psychologists have found inspiration in his ideas and tried to elaborate them. However, different neo-Gibsonians have developed Gibson's ideas in different ways. As mentioned in the introduction, the most influential approach has been developed by Turvey, Shaw, and colleagues at the University of Connecticut. However, they have developed Gibson's ideas in a very particular way. Indeed, Cutting (1982) has even talked about "two ecological perspectives": Gibson's and Turvey and Shaw's.

These prominent neo-Gibsonians have followed Gibson in claiming that the detection of specifying information is a necessary and sufficient condition for establishing a direct perceptual contact with the environment. All perception, that is, is the pickup of information specific to the aspect of the environment that is perceived. However, they have taken the concept of specificity as being more central to their approach than Gibson did. Although Gibson stressed that animals rely on information that is specific to the environment, to our knowledge the later Gibson did not posit a specificity relation between information and perception. In fact, arguing that the same environmental property can be specified by different sources of information, Gibson (1966, pp. 203–204) seems to allow that animals vary in what information they detect on different occasions (see also Cutting, 1991, fn. 1). The prevailing neo-Gibsonians, however, have asserted two specificity relations: one between the information and the environmental property, the other between the perceptual experience and the information. Thus, perception, they have claimed, is specific to information that is specific to a particular environmental property (Burton & Turvey, 1990; Turvey, 1990; Turvey & Carello, 1995).

This focus on specificity relations is perhaps due to the fact that these neo-Gibsonians are very much inspired by physics and have tried to model ecological psychology on it. They have explicitly stated that they are searching for psychological laws and symmetry principles analogous to physical ones (e.g., Shaw & Kinsella-Shaw, 1988; Turvey, 1990; Turvey et al., 1981). In their view, one of the merits of Gibsonian psychology is that "it promises to put psychology back on the track of seeking lawful relations" (Turvey et al., 1981, p. 237). And these to-be-sought-after laws are not probabilistic. To support specificity, laws must be exceptionless regularities that hold whenever appropriate conditions are met. Note that this is in stark contrast to Brunswik's probabilistic connections between proximal and distal stimuli, which were merely correlations. For the

prevailing neo-Gibsonians, environmental properties lawfully guarantee the presence of particular information, and vice versa. And if the animal intends to perceive an environmental property, there is also a lawful connection between information and perception (Turvey, 1990; Turvey et al., 1981).

This neo-Gibsonian law-based theory of perception is very elegant, perhaps even more elegant than Gibson's original framework. The lawful, specificity relations guarantee one-to-one connections. Thus, a specifying variable is a variable that relates one-to-one to an environmental feature in the animal's natural habitat. And the specificity between perception and information entails a one-to-one relation between what an animal perceives and an informational variable. Hence, the dominant neo-Gibsonian tradition holds that there is a one-to-one-to-one relation between the environment, information, and perception (see e.g., Burton & Turvey, 1990; Fajen, 2005; Michaels, 2000; Michaels & Beek, 1995; Turvey, 1990). As Burton and Turvey (1990) put it, "... our inclination ... is to pursue one-to-one mappings—between information and environment, and between perception and information" (p. 321). We will refer to this theory as the "one-to-one-to-one theory."

Note that by arguing for a specificity relation between information and perception, the one-to-one-to-one theory assumes an absence of variation in what information is exploited, both between animals and within animals over time. As Michaels and Beek (1995) put it, "... the basic idea that perception and action are specific to some particular information that is specific to affordances suggests to us that the theory of direct perception expects minimization of variability" (p. 270). In other words, all members of a species use the same information in their perception of a particular environmental property.

Although radical, these ideas have had a substantial impact on research on perception and action. Reading the current experimental literature about the use of information in perceiving and acting, one often encounters questions like: What is *the* informational variable that humans exploit to perform this task? As has been demonstrated by Fajen (2005), the assumption of a *single specifying informational variable* that is exploited by all members of a species in the performance of a task figures prominently in most studies on visually guided actions, including steering towards a goal, intercepting a moving target by either hand or foot, and braking to avoid an obstacle (see also Tresilian, 1999). Indeed, the assumption is dominant in many paradigms. For instance, Cesari, Formenti, and Olivato (2003) searched for a common informational variable used by children and young and old adults in the perception of climb-on-ability. And research on dynamic touch generally aims at an identification of *the* mechanical invariant that underlies the perception of a particular rod property (see, e.g., Burton & Turvey, 1990; Carello, Thuot, Anderson, & Turvey, 1999; Solomon & Turvey, 1988; Turvey, Burton, Amazeen, Butwill, & Carello, 1998; for exceptions see van de Langenberg, Kingma, & Beek, 2006; Withagen & Michaels, 2005). Hence, many researchers assume a one-to-one relation between information and perception (or action).

Although several psychologists take the one-to-one-to-one theory to be falsifiable by experimental data (see, e.g., Tresilian, 1999), it is important to note that Turvey and colleagues have explicitly argued that the theory of direct perception is not “an hypothesis to be tested as much as it is a point of departure for understanding some particularly difficult aspects of nature” (Turvey, 1990, p. 59). Indeed, in their approach, specificity between perception and information, and between information and environment, is assumed to exist; the scientist’s job is to discover it. That is, the one-to-one-to-one theory is treated as an axiomatic truth to be used as a research strategy—it is a methodological principle. Hence, according to Turvey and colleagues, the fact that studies do not reveal specificity relations (e.g., Cutting, 1991; Fajen & Devaney, 2006; Jacobs, Michaels, & Runeson, 2000; Jacobs, Runeson, & Michaels, 2001; Tresilian, 1999) does not disprove the one-to-one-to-one theory; rather it suggests that the researchers should continue their search for such relations. As Turvey and Shaw (1999) put it,

... any conclusion that a patterned energy distribution underspecifies the environment must be viewed with circumspection. ... failure [to find specificity] identifies an inadequacy or incompleteness in the physical and mathematical characterization of the patterned energy distribution. The failure implies the need for a deeper mathematical-physical analysis coordinate with a sharpening and refinement of the descriptors of the animal–environment system. (p. 103)

As an example, Burton and Turvey (1990) conducted an experiment on what mechanical invariant constrains the length perception of unseen, hand-held rods. When participants were asked to hold the rod stationary, their judgments were constrained by the first moment of mass distribution. When, on the other hand, the participants were allowed to wield the hand-held rod, their length judgments were primarily constrained by the second moment of mass distribution. Apparently, the same perception can be constrained by different mechanical variables. However, instead of taking these findings as evidence against the one-to-one relation between information and perception, Burton and Turvey surmised that in the haptic array (the structured arrays of tissue strains) there might be an informational variable that uniquely constrains the length perception. However, they remained silent as to what this variable is. As they put it,

... the structuring of strains by the torques of holding and wielding contain an invariant patterning specific to rod extent. That is to say, the first and second moment invariants of the mass distribution causally entail the same invariant of tissue deformation (an invariant whose identification must await developments in the mechanical and physical analysis of *haptic arrays*). (Burton & Turvey, 1990, pp. 321–322).

Although the persistence in the search for specificity relations seems based on little more than faith in one-to-one relations between environment and information, and between information and perception, it has yielded interesting

discoveries (e.g., Amazeen & Turvey, 1996). This has led several neo-Gibsonians to conclude that “embracing the assumption of specificity acts as an engine of discovery: Variables participating in many-to-one mappings must be reformulated to reveal uniqueness” (Carello & Turvey, 2004, p. 28).

The Biological Plausibility of the One-to-One-to-One Theory

Now that we have briefly spelled out Gibson’s ecological approach and the prevailing neo-Gibsonian perspective, let us turn to an evaluation of the latter. As a methodological principle, the merit of one-to-one-to-one theory should not be evaluated on the basis of empirical data alone. After all, one can argue that any study that does not find specificity relations suggests that the researchers should continue their search for one-to-one relations, as described above.³ Hence, a theoretical analysis is needed. Starting from Reed’s (1996) unsubstantiated claim that the prevailing neo-Gibsonian program is biologically implausible, we will address the question of whether a one-to-one-to-one path from environment to information to perception is to be expected from an evolutionary perspective. We will answer this question in the negative, implying that the exclusive neo-Gibsonian search for specificity relations is indeed at odds with evolutionary considerations.

The Use of Information from an Evolutionary Perspective

As discussed above, Gibson’s theory was intended to place perception in the context of evolution. Indeed, many of his most original claims reflect this. For instance, Gibson’s idea that perception is primarily of affordances is especially attractive when considered in the context of evolutionary theory. Perceiving affordances can allow adaptive behavior without complicated inferential processes intervening between perception and action. After all, perceiving the environment in terms of action possibilities renders dispensable those cognitive processes that transform action-independent perceptions into action-oriented perceptions. It is easy to imagine that evolutionary processes would typically prefer careful perception to complex cognition, especially when it comes to vital and time-sensitive activities such as food finding, mate selection, and predator avoidance. Yet this quite natural combination of evolutionary theory and ecological psychology is, we will argue below, not consistent with the one-to-one-to-one view of the use of information. To evaluate the biological plausibility of the one-to-one-to-one theory, we will scrutinize the two suggested specificity relations in turn. First, we will analyze the one-to-one relation between information and perception. Then, we will examine whether animals rely exclusively on specifying information, that is, the one-to-one relation between the environment and the detected information.

As mentioned above, the suggested specificity relation between information and perception entails that different members of a species rely on the same information in their perception of a particular environmental property. This claim, however, is inconsistent with one of the basics of evolutionary theory: variability. After all, evolution occurs in populations; it is the change in the frequency of traits in populations over time. Thus variability in traits in a population is a necessary condition for evolution to occur. As Mayr (2001/2002) has put it, the availability of variability is the “necessary prerequisite for evolution” (p. 96). This need for variability is central, of course, to Darwin’s theory of evolution, and is central as well to the effect of Darwin’s thinking on the nature of species. This aspect of Darwin’s thought is often called “population thinking” (Hull, 1965, 1978; Mayr, 1975/1994; Sober, 1980). “The populationist stresses the uniqueness of everything in the organic world. ... All organisms and organic phenomena are composed of unique features and can be described collectively only in statistical terms” (Mayr, 1975/1994, p. 158). The main consequence of Darwin’s population thinking is that there is no essence of a species; rather, there is variation among the members of a species so that every member of a species is different from every other member of that species.

This focus on populations and the variability in populations is central to Darwinian evolution by natural selection. In Lewontin’s (1970) well-known formulation, evolution by natural selection occurs whenever three conditions are met (see also Endler, 1986):

1. There is variability in a population.
2. Variability is heritable.
3. There is differential reproduction based on variability.

Imagine a population in which there is variability in some trait, say leg length. If there is differential reproduction based on leg length, individuals with, say, longer legs will be more likely to reproduce. If leg length is heritable, if the offspring of long-legged parents tend to have long legs, then the next generation will have a higher proportion of individuals with long legs. Thus the frequency of longer legs in the population will change and, typically, the average leg length in the population will change.

Although we have been discussing the necessity for variability in the context of Darwinian evolution by natural selection, we would like to stress that variability in a population is implicated in evolution of any kind, not just evolution by natural selection, but also random drift, meiotic drive, migration between subpopulations, and so on. If evolution is change over time of the frequency of traits in a population, there must be variability in the population. The only exception is a catastrophic change from a situation in which all members of a population have a trait to one in which no members have that trait in a single generation. Such changes, all thinking in biology indicates, must be vanishingly rare in the history of life on earth. Even the evolutionary “punctuations” of Eldredge

and Gould's (1972) punctuated equilibrium theory—vast, comparatively rapid changes in populations—happen over hundreds or thousands of generations, and rely on background variability in the populations. Variability, then, is necessary for evolution, full stop.

Although variation among the members of a population has generally been regarded as being essential to evolution by natural selection, its existence has not always been taken seriously in explaining current animal behavior. The neo-Gibsonian search for *the* information that animals use to perform a particular perceptual task is just one example of approaches that search for general rules that govern animal behavior and, thereby, neglect individual differences. As an example, the prominent evolutionary psychologists Tooby and Cosmides (1990, 1992) argued for a universal human nature. The human mind, they surmised, can be conceived as a Swiss army knife with different modules, each of which performs a particular function. And this cognitive architecture is basically the same for each and every human being. Individual differences, then, spring from this architecture and can be explained primarily in terms of phenotypic plasticity—that is, they are generally the result of different environmental factors operating on the same cognitive architecture. As Tooby and Cosmides (1990) put it, “If one believes in a universal human nature, as we do, one observes variable manifest psychologies, traits, or behaviors between and across cultures, and views them as the product of a common, underlying evolved innate psychology, operating under different circumstances” (p. 23).

However, in line with other authors (e.g., Lewontin, 1984; Looren de Jong & van der Steen, 1998; Mayr, 1975/1994, 2001/2002, 2004/2007; Wilson, 1994), we believe that contemporary evolutionary thinking does not warrant this assumption of a universal human nature. Although generally speaking the process of natural selection eliminates the non-adapted animals and thereby reduces the amount of variation, it does not guarantee minimal variation among the members of a species. In fact, several studies have revealed that evolution by natural selection can establish and maintain (genetic) variation (e.g., Wilson, 1994; see also Endler, 1986, on frequency-dependent selection). In addition, the reduction of the amount of variation in the evolutionary process is partly determined by the intensity of the selection pressures. Although their intensity should not be underestimated in the animal's natural environment (Endler), it is not likely that they destroy all variation available in the evolving population. Indeed, as Mayr (2004/2007) argued, if the selection pressures are weak, only the most inferior are eliminated, leaving room for abundant variation in the population. Hence, given the myriad functions of perception and their different degrees of importance to the survival and reproduction of the animal, it is quite improbable that there is minimal variation in what information is exploited for each and every perceptual task. And indeed, several empirical studies on perception have searched for and demonstrated individual differences in what information is exploited (e.g., Jacobs et al., 2000, 2001; Michaels & de Vries, 1998). Individual human perceivers rely on different sources of information that differ in degree of

usefulness. Hence, there is no uniform perception of the environment among the members of a species.

Studying the learning process, these studies provide even further evidence for individual differences in perception and perceptual systems. Gibson (1966) had argued that perceptual learning is a process of differentiation. Animals can improve the accuracy of their perception by learning to exploit the more useful informational variables. This learning process has been demonstrated in several experimental paradigms—provided with feedback on their perceptual performance, many participants changed in what information they detected over time (Jacobs et al., 2000, 2001; Michaels & de Vries, 1998; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). Importantly, considerable individual differences in the learning trajectory were found as well—participants varied in how fast they learn to exploit the specifying information. In fact, several participants even did not succeed in detecting specifying information after extensive practice (Jacobs et al., 2000, 2001; Michaels & de Vries, 1998; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009). Using a large sample size, Withagen and van Wermeskerken (2009) recently showed that the individual differences in perceptual learning are indeed rather substantial. This suggests that the between-subject variation in what information is exploited is not the result of a universal mechanism that is differently exposed to feedback. Rather, it is indicative of individual differences in perceptual learning capacities, that is, variation among the participants' cognitive apparatuses. Humans vary in how well and quickly they can learn a perceptual task, implying variation in what information is exploited at any moment in time. Hence, the ubiquitous variation among the members of a species that proponents of Darwin's population thinking emphasize (Hull, 1965, 1978; Mayr, 1975/1994, 2001/2002, 2004/2007; Sober, 1980) is also present in the perceptual realm. This means that population thinking needs to be taken seriously in the study of perception. In other words, the suggested specificity relation between information and perception and the allied search for *the* information that members of a species exploit in a particular perceptual task are biologically unsound.

We believe that the other suggested specificity relation, the one-to-one relation between the environmental property and the detected information, is also implausible from an evolutionary perspective. Granted, animals sometimes rely on specifying information, but it is unlikely that they rely exclusively on such information. After all, that would only be the case if and only if two conditions are met:

1. Animals that detect only specifying information evolve.
2. Natural selection is so powerful that animals that rely on variables that relate ambiguously to environmental properties will not survive and reproduce.

It is, we believe, improbable that these two conditions are met. As suggested above, not all perceptual tasks are of great importance to survival

and reproduction. This means that a considerable degree of perceptual inaccuracy is possible (e.g., Cabe, 2001; Meijer, 1998; Withagen, 2004). Hence, animals need not always rely on the optimal information variables (i.e., the specifying variables)—variables that are “good enough” (i.e., correlate highly with the relevant environmental feature) often suffice. And, indeed, as has been demonstrated by empirical studies, animals are often opportunistic and detect variables that correlate highly with a to-be-perceived or to-be-acted-upon environment property, but are not specific to it (e.g., Jacobs et al., 2001; Michaels, Zeinstra, & Oudejans, 2001; Tresilian, 1999; van der Kamp, Savelsbergh, & Smeets, 1997). Hence natural selection is not so powerful that only animals that rely exclusively on specifying information are selected. That is, Condition 2 is not met.

Condition 1 is also unlikely to be met. It is quite improbable that animals that detect only specifying information evolve. After all, it might be that the system required to detect specifying information has not evolved or even cannot evolve. As many evolutionary biologists have stressed, the variation on which natural selection can operate is not “limitlessly rich” (Sober, 1993, p. 121). There are many constraints on the evolutionary process, which set severe limits on what systems can evolve (e.g., Dawkins, 1982; Gould, 1997; Gould & Lewontin, 1978; Mayr, 2001/2002). Hence, the *best possible* biological system might not be available in the evolving population. Indeed, evolution often yields suboptimal solutions (Dawkins, 1982; Mayr, 2001/2002), and there is no reason to assume that this does not hold for perception. In fact, it is possible that the constraints on evolution render many specifying informational variables undetectable by the animal (Withagen 2004; see also Reed, 1996, p. 48). This is because the detection of a specifying informational variable might require very particular anatomical structures or a configuration thereof, and it is far from certain that the required structural basis for the detection is available in the evolving population. Just as winged flight is extraordinarily unlikely for descendants of primates, given current primate body shape and bone density, there will be cases in which current constraints make it all but impossible for perceptual systems to evolve to take advantage of the optimal informational variable. Hence, from an evolutionary perspective one can expect that at least some specifying informational variables are not detectable by a given animal.

Extending Gibson’s Naturalization of Perception

We have seen that an evolutionary analysis of the use of information in perception casts doubt upon the one-to-one-to-one theory. From an evolutionary perspective, a one-to-one-to-one path from environment to information to perception is not to be expected. Instead, evolutionary theory suggests both variation in what information is used and the exploitation of informational variables that are not specific to the environment. This implies that the exclusive neo-Gibsonian search for specificity relations is inappropriate. The fact that studies

do not find one-to-one-to-one relations between environment, information, and perception (e.g., Cutting, 1991; Fajen & Devaney, 2006; Jacobs et al., 2001; Tresilian, 1999; van de Langenberg et al., 2006) does not indicate that researchers should continue their search for such relations, as the prominent neo-Gibsonian program dictates. Rather, non-specific relations are to be expected.

To formulate a naturalistic theory of perception, then, Gibson's ideas have to be developed along different lines. In the remainder of the paper, we set out some ideas on what we think such a theory should look like. We will compare our sketch with both Gibson's pioneering ideas and more recent perspectives.

A Truly Naturalistic Theory of Perception

To sketch what a truly naturalistic theory should look like, we need to start with some ideas about information. Proponents of the one-to-one-to-one theory typically classify a spatiotemporal energy pattern as information about an affordance if and only if it is specific to it (e.g., Turvey & Kugler, 1984). This conception of information is not appropriate for a naturalistic theory of perception. As we have seen, an evolutionary perspective indicates that at least in some cases animals are also informed by variables that correlate (highly) with the environment. Further, animals are likely to vary in what variables they exploit to perceive a particular environmental property. A naturalistic theory of perception, then, should be built on a conception of information that captures this.

In the philosophy of information, such conceptions are available. Chemero (2003, 2006, in press) has developed a theory of information specifically for ecological psychology, drawing on earlier work by Barwise and Perry (1981, 1983) and Millikan (2000).⁴ According to this view of information, information is present whenever there are *constraints* connecting two types of situation. For example, a situation in which a step affords climbing will, in virtue of the laws of physics and optics, also be a situation in which the light available from some point of observation has a particular structure. Because climbable steps cause particular optical structures, situations that have these optical structures will be situations in which there is a climbable step. So the presence of this optical structure carries information about the presence of a climbable step. The information is here because the law-like causal connection between the two situation types, a specifying connection in this case, is a constraint. But not all constraints between types of situation are specifying. In setting out her conception of information, Millikan (2000), for instance, presented the example of the flying predator and the shadow moving across the ground. She argued that the shadow carries information about the predator, but the constraints are not specifying. That is, there is no one-to-one relation between the shadow and the predator. On a cloudy day, the flying predator will not result in a shadow moving across the ground. Furthermore, flying objects or animals of the same shape can yield the same shadow. Hence, as Millikan argued, the correlation that supports the relation between

the flying predator and the shadow, “though it persists for good reason, may not be particular strong” (p. 237). This means that prey whose escape behavior is guided by the shadows often show adaptive behavior. However, sometimes they flee from nonpredators; or do not escape while they should.

Ecological psychologists have coined the term ‘nonspecifying variables’ for those spatiotemporal patterns in the ambient array that correlate with the to-be-perceived property but are not specific to it (e.g., Michaels & de Vries, 1998). However, it is important to point out that such variables differ greatly in their degree of usefulness. As Millikan (2000) emphasized, the correlation may be weak or strong (see also Michaels & de Vries, 1998). Recently, Jacobs and Michaels (2007) nicely portrayed the degree of usefulness of informational variables with their conception of information space. It shows that in the ambient energy arrays there is a myriad of variables, some of them not particularly useful, others moderately useful, some almost as useful as the specifying variables. In principle, all these variables carry information about the environment and can be used to establish and maintain perceptual contact with it. However, the ensuing strength of the perceptual contact and the likelihood that the behavior will be adaptive are different for the different variables.

Now that we have sketched a naturalistic conception of information, we can take the next step in developing an evolutionarily plausible theory of perception. To be consistent with the above evolutionary analysis of the use of information, a theory of perception must meet two criteria. First, a truly naturalistic theory should recognize suboptimalities in perception. Although specifying information is most useful, the constraints on evolution render it probable that at least in some cases the animal’s perceptual system is not capable of exploiting it. This means that a nonspecifying informational variable sometimes constitutes the best information available to an animal. Second, to be consistent with population thinking, a truly naturalistic theory should hold that different members of a species might rely on different informational variables. Because informational variables generally differ in their degree of usefulness, this also means that there is gradation in the adaptiveness of the perception of the different members of a species. Some members of a species, that is, will perceive the world more accurately. And, as we have seen, such variation is to be expected from an evolutionary perspective.

Of course, the amount of variation is likely to differ for different tasks. As mentioned above, there is a relationship between the reduction of variation and the intensity of the selection pressures. Hence, for varieties of perception that play little role in survival, one might expect more variation in the degree of usefulness of the detected variables than in varieties of perception that are essential to survival and reproduction (e.g., predator avoidance, food finding). But if there are many variables that correlate highly with the to-be-perceived property, one might still expect variation in what information is used even in the latter case, with different members of a species detecting different but very useful informational variables. To repeat, from an evolutionary perspective it

is very unlikely that each member of the species exploits exactly the same (specifying) informational variable.

In recent years, some ecologically inspired authors have suggested theoretical frameworks that are capable of dealing with variation in what information is exploited. These authors did not take the one-to-one-to-one theory to be a methodological principle. Instead, based on empirical findings of, among other things, variability, they rejected the one-to-one-to-one theory and proposed alternative frameworks (e.g., Cutting, 1991; Fajen, 2005; Jacobs & Michaels, 2002; Tresilian, 1999). The two most elaborated perspectives are perhaps Cutting's and Jacobs and Michaels'. Although these approaches are more in line with evolutionist thinking, we believe that they are insufficiently naturalistic. Cutting (1986, 1991) stressed that animals rely on different information in different contexts. His theory of *directed perception* is, however, still grounded in the concept of specificity. Cutting (1991) argued that "the physics of almost any given natural situation allows for many different patterns of stimulation, each specifying uniquely a given object or event" (p. 27).⁵ Our everyday perception, Cutting argued, is informed by these multiple sources of specifying energy patterns, either by selecting different variables on different conditions or by integrating these multiple sources of information. Cutting put great emphasis on the flexibility of animals to detect different information in different contexts, and used evolutionary arguments to defend his position.

However, his directed perception theory recognizes neither suboptimalities nor within-species variability. First, Cutting's (1986, 1991) theory allows animals to vary only between specifying variables. Hence, this theory does not recognize the suboptimal solutions that evolution by natural selection often yields. And, as we have seen above, animals indeed sometimes rely on informational variables that are not specific to environmental features, but are merely correlated with them (cf. Tresilian, 1999). Second, although Cutting stressed that animals often use different information in different contexts, he did not put emphasis on the variation among the members of a species (in the same context). Thereby, his directed perception theory is not in line with population thinking, which we take to be a central element of any naturalistic theory of perception.

In contrast, Jacobs and Michaels do take the variation among the members of a species to be central (2002; Jacobs et al., 2000, 2001; Michaels & de Vries, 1998). As mentioned above, in their empirical studies of perceptual learning, Jacobs and Michaels found that participants rely on nonspecifying variables and differ in what information they exploit. In their view there is no such thing as *the* specifying variable that all members of a species use. This is both a significant departure from the prominent neo-Gibsonian framework and a big step towards a naturalistic theory. However, in Jacobs and Michaels' view, animals rely on nonspecifying variables only over a short time-scale. They believe that the process of perceptual learning is a fast process that "guarantees that [specifying] information will be detected on the long term"

(2002, p. 136). Thus, Jacobs and Michaels did not recognize constraints on evolution and the ensuing suboptimalities. Again, it might be that the system that is required to (learn to) detect the specifying information has not evolved or even cannot evolve. Furthermore, we believe that in their theorizing, Jacobs and Michaels insufficiently recognized individual differences. To reiterate a point made earlier, contemporary evolutionary thinking does not warrant the assumption of a universal human nature. This means that it is improbable that there is a unique perceptual learning mechanism among the members of a species. And as we have seen, studies on perceptual learning do indeed show individual differences in learning—some participants did not learn to detect the specifying variable after feedback (Jacobs et al., 2001; Michaels & de Vries, 1998; Withagen & Michaels, 2005; Withagen & van Wermeskerken, 2009).⁶ Hence, as mentioned above, over both the short term and the long term animals vary in what information they exploit.

The ubiquitous variation in the information that is used, then, implies that a naturalistic theory of perception should not make any universal claims about what information members of a species exploit in the performance of a task. Instead, such a theory should explain the variation in what information is used. As Tresilian (1999) has argued, researchers should try to reveal the principles that govern the use of information.⁷ In this sense, a theory of the use of information should follow theories of such other variable organismal features as stamina, height, muscle strength, and so on. Theories of these features do not include universal claims about the presence of a feature in animal kingdom (e.g., human beings are 1.81 m tall). Instead, they try to explain the variation in the population in terms of multiple factors that jointly determine the feature (the height of human beings depends on hygiene, birth order, nourishment, genetic factors, the amount and type of exercise, etc.; see, e.g., Beard & Blaser, 2002). Recent work on developmental systems has suggested that organismal features are always the result of the interplay of numerous organismal and environmental factors (e.g., Gottlieb, 1998; Oyama, 1985, 2000; Oyama, Griffiths, & Gray, 2001). None of the factors is in control; rather they mutually constrain and even define one another (Oyama, 1995, 2000). We believe that a naturalistic theory of perception should follow this line of thinking. That is, a naturalistic theory of perception must explain the individual differences in what information is exploited in terms of the interplay of multiple organismal and environmental factors.

Because the neo-Gibsonians have been concerned primarily with the search for *the* information that members of a species use in the execution of a perceptual task, the factors that are involved in determining what information is detected have received scant attention thus far (Tresilian, 1999). Nevertheless, we have seen that some factors have already been revealed. Cutting (1986, 1991) stressed that animals use different information in different environmental contexts (see also van de Langenberg et al., 2006; van der Kamp et al., 1997); and examining the role of feedback in different environments, Jacobs,

Michaels, and Runeson demonstrated that feedback can result in a change in what information is exploited (Jacobs et al., 2001, Michaels & de Vries, 1998; Runeson et al., 2000). To develop the theory, however, all factors (e.g., neural, genetic, environmental) that are likely to determine what information is used need to be scrutinized. What is more, a theoretical framework that is capable of explaining how all the factors jointly determine what information is detected needs to be developed.

Is Our View Gibsonian?

We have sketched in broad strokes what we think a truly naturalistic approach to perception should look like. Further, we have suggested that other recent ecologically inspired approaches are not naturalistic enough. But how does our sketch relate to Gibson's pioneering ideas? In general, our sketch is intended as a Gibsonian view, one that respects the core of his ecological approach, and puts it firmly in the context of current evolutionary theory. First, our sketch is consistent with the idea that perception is primarily of affordances. The primary objects of animals' perceptual experience are the action possibilities that the environment affords. Second, in line with Gibson, we assert that perception is the result of the exploitation of information. Third, our approach is surely consistent with Gibson's attempts at naturalizing perception. In fact, we try to extend his naturalization of perception.

However, our sketch is in one way a significant departure from Gibson's. After all, our approach is not grounded in the concept of specificity. For Gibson, however, this concept was central. As mentioned above, he developed his theory of direct perception by distinguishing specifying information from impoverished stimulus information. However, as we have seen, an evolutionary analysis indicates that animals are not likely to rely exclusively on specifying information. Hence, a truly naturalistic theory should not define perception in terms of specificity. Individual animals sometimes use specifying variables; sometimes they do not.

This assertion that animals sometimes rely on informational variables that are not specific to, but merely correlate with, environmental properties might seem to make us Brunswikians instead of Gibsonians. As mentioned above, Brunswik's (1956) approach posits probabilistic laws between stimulus information and environment, implying that the information is not trustworthy. However, we believe that our approach is not consistent with several central tenets of the Brunswikian approach to perception. First, in line with Gibson (1966, 1979/1986), we believe that perceptual information resides in the ambient array, not in the proximal stimuli (e.g., retinal image), as Brunswik argued. Second, and more importantly, we believe that the detection of information in nonspecifying variables is fully compatible with perception being direct (Chemero, 2003, 2006, in press; Withagen, 2004). That is, to claim that animals sometimes rely on nonspecifying information does not imply that inferential

processes are involved in perception (see also Michaels & de Vries, 1998). Consider, for instance, the bird's perception of clear flight paths. The informational variable used by birds to perceive such paths may have been specifying throughout most of the course of the evolution of flight. However, the trustworthiness of this variable changed when humans invented nearly transparent glass, entailing that birds now sometimes crash into windows.⁸ Although the presence of windows changed the adaptiveness of the bird's flying behavior, we believe that it is quite improbable that it implied a significant change in the nature of the perceptual process. That is, the abundant use of windows did not entail that the bird changed from a direct perception to an indirect perception of flight paths, meaning that the bird all of a sudden made inferences on imperfect information. Instead, the bird's perception is, we believe, still the result of a direct pick-up of information.

Relatedly, we think that the detection of nonspecifying information is also compatible with Gibson's conception of perception as a direct epistemic contact with the environment. Although Gibson (1959, p. 464) assumed that perceptual contact is all or nothing, we think it is better conceived of as a continuum (see Withagen, 2004). The informational variable that the bird uses to perceive flight paths may no longer specify that property. However, that does not mean that the bird is deprived of a direct perceptual touch with the environment, perceiving it via a representation. Rather, the bird's grip on the environment is weakened. Still, its connection with the environment is better than a bird that is blind or uses other variables. This allows a continuum of cases of direct contact with the environment: the bird that uses a variable that is specific to actual open flight paths to guide its flying behavior has better contact with the flight-relevant features of the world than the bird that uses a variable that is ambiguous between open paths and windows; both birds will be in better contact than is a bird that flies into brick walls when it uses a variable to try to perceive paths.

The extent to which one considers our view Gibsonian, then, will depend on how heavily one weighs the parts of Gibson's overall view. Taking the one-to-one-to-one theory to be the heart of Gibsonian ecological psychology will make us non-Gibsonians. Weighing Gibson's naturalism, theory of direct perception, and theory of affordances as being on a par with his views on specificity will make us Gibsonians. At the end of the day, of course, how our view is labeled does not matter.

Concluding Remarks

Gibson is generally conceived as a naturalist, and perhaps one of the most important naturalists in theorizing about perception (Lombardo, 1987; Looren de Jong, 1995, 1997; Meijnsing, 1998). Gibson indeed took evolutionary theory seriously and tried to develop a theory of perception that is in line with evolutionary considerations. In the present paper, however, we, following Reed

(1996), have argued that the prevailing neo-Gibsonian program runs counter to Gibson's naturalism. More specifically, the neo-Gibsonian search for specificity relations between perception and information, and information and environment is at odds with evolutionary considerations. First, this approach does not leave room for individual differences in what information is exploited and, thereby, is inconsistent with population thinking. Further, suggesting that animals rely on specifying information, the approach runs counter to the now widely accepted idea that evolution often yields suboptimal solutions. Hence, if one desires a naturalistic theory of perception, one that is consistent with and inspired by evolutionary theory, the neo-Gibsonian one-to-one-to-one theory and the allied experimental program of searching exclusively for specificity relations must be rejected.

Based on our evolutionary analysis of the use of information, we sketched an alternative development of Gibson's pioneering ideas. Of course, our naturalistic view is more a series of claims about the nature of the use of information than a full-fledged theory, but it has considerable implications for what such a theory should look like. Perhaps our most important claim is that a truly naturalistic theory of the use of information should not be grounded in the concept of specificity. This is a significant departure from Gibson and the dominant neo-Gibsonian tradition. We argued that instead of postulating specificity relations, a theory of the use of information should follow theories that explain other variable organismal features such as muscle strength, height, and so on. That is, a theory of the use of information should reveal how multiple environmental and organismal factors interact over time to determine what informational variable(s) particular animals exploit in particular perceptual and action tasks. At present this is a largely unexplored field of research in the study of perception. Hence, it will require much experimental and theoretical work to sketch only the outlines of such a theory. However, in our view, this is the track naturalistically inclined perceptionists should be on.

Notes

1. It is important to emphasize that the term "naturalization" has been used in different but often related ways in psychology and philosophy (see Hatfield, 1990). Fodor (1980) used the term to refer to approaches in psychology that take animal-environment interactions to be central (see also Looren de Jong, 1995, 1997). Hatfield (1990) used it to refer to theories that eliminate normative issues from psychology. Other authors use it to refer to approaches that try to bring psychology within the scope of the life sciences, for example by placing psychological functions in the context of evolutionary theory (e.g., Meijnsing, 1998). As mentioned in the text, we adopt the latter conception of naturalization.
2. Marr's (1982) theory of visual perception can be conceived as an exception. Marr argued that Gibson was right about the variables that animals rely on, but argued that the detection of specifying variables still requires computational/inferential processes.

3. We should point out, though, that the empirical evidence against the one-to-one theory is quite substantial. (For reviews see, e.g., Fajen 2005; Jacobs & Michaels, 2002; Tresilian, 1999; and below).
4. Barwise and Perry's (1983) work has also inspired the ecological psychologist Runeson (e.g., 1988) in his thinking about information. However, he was primarily concerned with how constraints (e.g., laws, local regularities, conventions) grant informational variables to be specific to the environment. We, on the other hand, focus here on how variables that relate ambiguously to the environment can carry information.
5. The idea that the same environmental property can be specified by different informational variables has also been defended by several neo-Gibsonians (e.g., Pittenger, 1989; Todd, 1981) and, as mentioned earlier, by Gibson (1966, pp. 203–204) himself.
6. It is important to emphasize that in their empirical studies Jacobs and Michaels stressed the fact that some individuals did not learn to exploit the specifying variable (e.g., Jacobs et al., 2001; Michaels & de Vries, 1998). However, in their theorizing, they generalize their finding that many participants learn to exploit the more useful information. Primarily because they are to be expected from an evolutionary perspective, we believe, however, that these individual differences in learning are important and should be taken into account when developing a theory of perception. It suggests, among other things, that individuals vary in their perceptual learning capacities and, thus, that also in the long term one can expect variation in what information is detected.
7. It is important to note that we do not subscribe to Tresilian's (1999) theory of perception. He defended a theory of cue-integration, in which perception is the result of the selection and combination of cues. As argued later, we, on the other hand, believe that perception is the result of the detection of spatiotemporal patterns in the ambient array. That is, in the process of perception, there is no integration and combination of cues involved.
8. See Runeson (e.g., 1988) on how constraints grant informational variables to be specific to environmental properties.

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