2 The Triad of Medium, Substance, and Surfaces for the Theory of Further Scrutiny

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> Logic works perfectly well once mankind has developed adequate language. But logic is helpless if it has to develop this adequate language … As for the formulation of adequate logic, there must be a language which does not impoverish the real situation. It is terrible that in our technocratic age we do not doubt the initial basic principles. But when these principles become the basis for constructing either a trivial or finely developed model, then the model is viewed as a complete substitute for the natural phenomenon itself.
> (from the Kyoto Prize Lecture by Israel M. Gelfand, 1989, p. 19. Copyright 2009, Tatiana V. Gelfand and Tatiana I. Gelfand)

Charles Sanders Peirce (1955, p. 6) once remarked that every great work of science affords some exemplification of the defective state of the art of reasoning of the time when it was written. Perhaps one of the great services of *The Ecological Approach to Visual Perception* (Gibson, 1979/2015) to psychological science was bringing to the fore a set of fundamental assumptions which have long been, and perhaps still are, invisible to psychologists who live amidst them. For generations, we have been taught that the apprehension of the world depends on the perception of space and time, and that "perception begins in receptor cells that are sensitive to one or another kind of stimulus energy" (Kandel, Schwartz, Jessell, Siegelbaum, & Hudspeth, 2013, p. 445). Such a narrative is so deep in psychology as to be almost unquestionable: Fish don't talk about water. But what if these fundamental assumptions are irrelevant to the activity of perception that orients the organs of perception and explores the cluttered *environment*? What if our perceptual systems, through evolution, are coordinated to a particular scale of nature that is at a different level from the description provided by physics of atoms and objects in *space*? What if the level of the description of the world that our perceptual systems *fit into* is so unique that it deserves investigation in its own right?

Gibson suggested that psychologists can approach the problem of perception in an entirely different light, once an adequate description of the environment to be perceived which does not impoverish the real situation has been developed. In Chapter 2 of his 1979 book, "Medium, Substances, and Surfaces," Gibson attempted to develop a "new" description of the environment that our perception and behavior fit into. "It will be unfamiliar, and it is not fully developed, but it provides a fresh approach where the old perplexities do not block the way" (Gibson, 1979/2015, p. xi). The aim of this chapter is two-fold: to reflect on the development of a "new" description of the environment—the triad of medium, substances, and surfaces, and to highlight its significance to the study of perception and behavior.

Useful Vision

Almost immediately after the publication of *The Senses Considered as Perceptual Systems* (Gibson, 1966a), Gibson began working on the revision of *The Perception of the Visual World* (Gibson, 1950a), which, as we now know retrospectively, ended up in an entirely new book (Gibson, 1979/2015). In the James J. Gibson papers (#14–23–1832) at the Division of Rare and Manuscript Collections of Cornell University Library, New York, there is a folder entitled "Notes for Revision of Visual World," which contains over 50 pages of handwritten notes for the "new book" written by Gibson in 1967. One of the notes reads as follows:

> For New Book ("Useful Vision"?)
>
> The ability to distinguish *environmental substances*, the forms of *matter*, the material *composition of* the world around us, what things are *made of*—the ability to distinguish among the main types and to identify earth, clay, rock, vegetation, bark, leaves, fur, feathers, skin—this capacity is extremely important to animals and the pickup of such information does not depend on a single sense organ or perceptual system. These natural substances should not be thought of *chemically* but *ecologically*. They are important to animals for what they *afford*. They are specified (1) by the *texture* of the surface and the *pigment color* of it (even better than by the "shape" of the "object"). They are specified (2) by their *effluvia*, if volatile. And they are specified (3) by their specific gravity (density), by hardness-softness (resistance to deformation) roughness-smoothness, and thermal conductivity. Accordingly, they can be identified by *seeing* the surface, by *smelling* the substance, and by *palpating* ("feeling") the substance…
>
> (Gibson, 1967b)

Although this handwritten memo was probably not intended for publication, its message is clear. A theory of visual perception, first and foremost, needs to account for "useful vision." It must account for our remarkably veridical ability to deal with the surfaces and substances, objects and events of the environment that we are, like it or not, obliged to cope with and use as a species and as individuals (E. J. Gibson, 1994, p. 503). What different types of clay, rock, vegetation, bark, leaves, fur, feathers, or skin afford to us may not be distinguishable at first glance. But they can potentially be identified through the activity of perceiving—looking around, palpating, listening to, or sniffing them. Unlike neural signals converted from stimuli impinging on receptors, the activity of perceiving, involving adjustments of organs, is a function of a set of meaningful properties of the environment that are selectively attended to by animals. Naturally, an effort to study the activity of perception thus conceived demands the description of the functional referent of perception (Holt, 1915). Otherwise, it would be like watching a tennis match with half the court occluded from view. To study useful dimensions of perception, the next logical step would be to find out the adequate level of the description of the world that our perception and behavior fit into. An attempt to develop a "new" description of the environment, it seems, was a natural consequence of Gibson's effort at understanding useful vision.

The Triad

It is likely that Gibson wrote the first draft of Part I of the new book—"The Environment to be Perceived"—between January and November in 1971, and came up with the title of the book, *An Ecological Approach to Visual Perception* (albeit beginning with "An" instead of "The") during this period. On January 12, 1971, Gibson (1971a) sent a tentative outline of the new book to the editor at the Houghton Mifflin Company that was quite different from the final version of the book: the book was then entitled *Everyday Visual Perception*, and the Part I of the book was "A New Theory of Perception," for which Gibson left notes that contrast a theory of sensation-based perception and that of information-based perception (e.g., Gibson, 1967c).

1971 seems to have been a key year in the development of ideas that culminated in Gibson's (1979/2015) final book. It was when a series of notes on affordances (Gibson, 1982a) and "Do We Ever See Light?" (Gibson, 1971b) that later constitute the important parts of the 1979 book were written, and the phrase "an ecological approach to visual perception" appeared in a note Gibson, 1971c). The use of the term "ecological psychology" by Gibson is also found in the note entitled "A Preliminary List of Postulates for an Ecological Psychology," written in June, 1971 (Gibson, 1971d). After writing a series of notes, by November 1971, Gibson had written up an early version of the new Part I, "The Environment to be Perceived," which included all the basic contents of the finished version of the part, including the triad of medium, substances, and surfaces and the nine ecological laws of surfaces (Gibson, 1971e).

Normal perception involves the possibility of further exploration, which we are aware of whether or not the possibility is taken advantage of (Gibson, 1978a). But, what makes us aware of the possibility of further exploration in the first place? What makes us aware of the layout of the environment in and *out of* sight? What makes it possible for animals to discover the potentially meaningful features of the environment that have not yet been taken advantage of? These are the questions that share the same fundamental issue which cannot be resolved without restoring the active observer to the world in a way physics never did (Gibson, 1973). Gibson's following thought experiment illustrates well what gets lost in the description of the world by physics in terms of space, time, matter, and energy: What if a wholly passive animal were in a wholly frozen world? Or, conversely, what if an animal were in "an environment that was changing in all parts and was wholly variant, consisting only of swirling clouds of matter" (Gibson, 1979/2015, p. 10)? In both cases, it would be impossible for the animal to disentangle a set of variables that are specific to the world out there (i.e., independent of the point of observation). These hypothetical worlds are not the environment for perceiving animals. But, note that "in both extreme cases there would be space, time, matter, and energy" (p. 10).

Restoration of the active observer that scrutinizes the environment requires a fundamental reworking of the description of the world, or in Gibson's (1971f) words, "the permutation of the orchard with Newton's apple!" The crux of this permutation was the replacement of matter and bodies in empty space with the triad of (1) medium (the gaseous atmosphere); (2) substances that are more or less substantial; and (3) surfaces that separate the substances from the medium (Gibson, 1979/2015, p. 27).

The Medium

The recognition of the air as a medium (for terrestrial animals) allows the distinction between potential and effective stimulation. Radiant energy, acoustic energy, and chemical energy are propagated through the medium, which provides the ambient sea of stimulus energy in which animals can move about. Instead of inquiring whether one model of inferring the causes of sensation aroused by stimuli is better than another, with the notion of medium, we can now begin to study activity before sensations have been aroused by stimuli, an activity that orients the organs of perception and explores the sea of *potential* stimulation for the information external to the perceiver (Gibson, 1982b, p. 398). Unlike points in space defined by an arbitrary frame of reference, the ambient energy array surrounding each potential point of observation is unique (Gibson, 1979/2015, p. 13). As the observer moves from one point of observation to another, the optical array, the acoustic array, and the chemical array are transformed accordingly (p. 13). This provides the opportunities for an active observer to move in the medium to detect invariants underlying the transforming perspectives in the ambient array surrounding a moving point of observation.

Among the recent advances that have furthered our understanding of the notion of medium for perceiving animals is the insight provided by Turvey and Fonseca (2014), whose research, probably for the first time since Aristotle (1907), brought to light the problem of medium in haptic perception. They hypothesized that interconnected structural hierarchies composed of tensionally prestressed networks of our bodies that span from the macroscale to the microscale—from muscles, tendons, and other connective tissues to various micro-elastic structures such as a network of collagen fibers—constitute the medium for the haptic sense organs of animals (Turvey & Fonseca, 2014). Like the air being the medium for sound, odor, and reverberating flux of light, despite being on the other side of the skin, the presence of isometric tension distributed throughout all levels of interconnected, multiscale networks make available the opportunities for an active perceiver to spontaneously transform the distribution of forces throughout the tensionally integrated system in such a way as to detect the invariant patterns that specify the source of mechanical disturbances.

Turvey and Fonseca's (2014) rediscovery of the medium of haptic perception resonates with the recent surge of interest in the mechanical basis of information and pattern formation in a wide range of fields—mechanobiology, soft robotics, sensory ecology, and rheology (e.g., Hanke, 2014; Ingber, 2006; Iwamoto, Ueyama, & Kobayashi, 2014; Rieffel, Valero-Cuevas, & Lipson, 2010). Because the form of any structure, whether a vortex flow of water or a living tissue, is determined through a dynamic interplay of physical forces, the distinct pattern of forces characteristic of a mechanical disturbance may convey a physical form of information that constrains perception and the behavior of an agent (Ingber, 2005). One good example of this is the hydrodynamic perception by aquatic animals (Hanke, 2014). Harbor seals, for instance, are known to use their vibrissae to haptically discriminate the water movements left behind by prey or predator that have passed by at an earlier point in time, and perceive the motion path, size and shape of the object that caused the trail (Hanke, Wieskotten, Marshall, & Dehnhardt, 2013) (Figure 2.1). A point worth emphasizing is the fact that although the informative patterns of water movement are there to be perceived by an animal, there are many reasons that the animal may not attend to the information. The harbor seal running away from the white shark may not attend to a pattern of water movement that specifies the presence of salmon that can be preyed upon. Near the surface of clear water during daytime the animal may attend to optical information without taking advantage of hydrodynamic information. The notion of medium makes possible for us to recognize this distinction between the existing information available to the animal and the information selectively picked up by the perceptual activity of the animal.

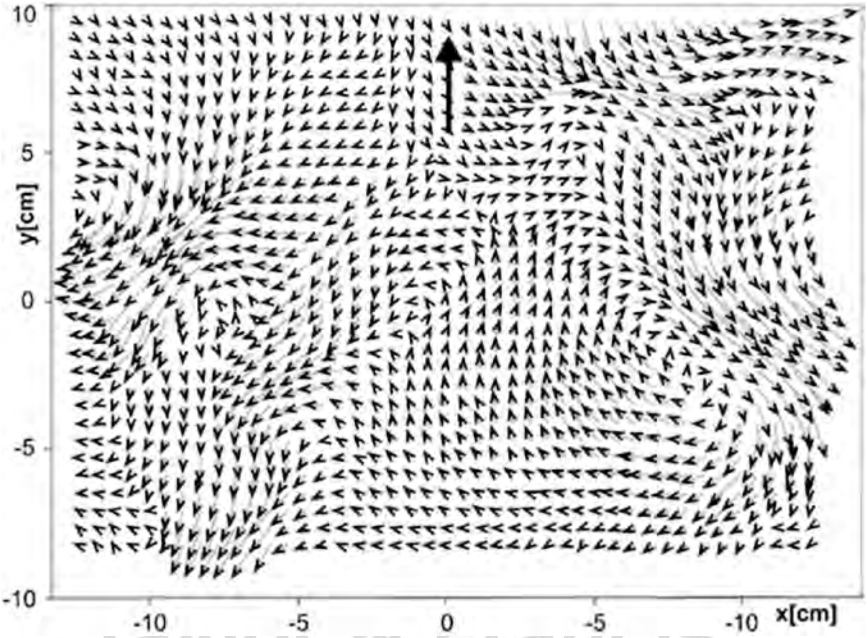

Figure 2.1 Water velocity 60 s after an 86 mm-long fish (*Lepomis gibbosus*) passed the area. Bold arrow indicates swimming direction.

Source: From Bleckmann et al. (2014): Figure 1.4a, adapted with permission from Springer-Verlag.

According to Gibson (1979/2015, p. 13), "if we understand the notion of medium, … we come to an entirely new way of thinking about perception and behavior." Recent years have witnessed a growing interest in the problem concerning the laws of variation in efficient exploratory behavior to obtain the information about aspects of the environment relevant to the task at hand (e.g., Boeddeker, Dittmar, Stürzl, & Egelhaaf, 2010; Nonaka & Bril, 2014; Stephen, Arzamarski, & Michaels, 2010; Viswanathan, Da Luz, Raposo, & Stanley, 2011). In general, exploration requires fluctuations, and fluctuations increase in time. A growing body of research suggests that the fluctuations in exploratory behaviors exhibit the property of superdiffusion, where the fluctuation grows faster than normal diffusion governed by a Gaussian probability density function (Nonaka & Bril, 2014; Stephen et al., 2010; Viswanathan et al., 2011).

Nonaka and Bril (2014) studied the exploratory movement of expert stone beads craftsmen in India who shape a bead by a series of hammer strikes on a stone held against the pointed tip of an iron bar (Figure 2.2). In the field experiment, the craftsmen shaped the ellipsoidal beads made of two different materials (carnelian stone—a familiar material, and glass—an unfamiliar, much more fragile material) in the workshops where they normally work. The use of the novel material must require the acute sensitivity to the properties of the material, where the finer the exploration, the better the probable outcome of the activities that follow. In the exploratory tapping movement of the craftsmen during the preparatory phase of the task, they found (1) the presence of long-range correlations where the variance of the displacement time series of the hand wielding the hammer grows superlinearly in time; and (2) underlying multiplicative interactions between fluctuations at different temporal scales indicated by the heterogeneity of scaling properties over time. When faced with the unfamiliar condition using unusual, fragile material, the exploratory hammer tapping movement of highly skilled experts who were able to cope with the situation exhibited a pronounced increase in the long-range temporal correlations. In contrast, the wielding behavior of less skilled experts—those who could not shape the glass beads—exhibited a significant loss of long-range correlations and reduced heterogeneity of scaling properties over time, which robustly discriminated the groups with different skill levels (Figure 2.2). Alterations in multiscale temporal structure of movement fluctuations were apparently associated with changes in the situation differently depending on the level of expertise (Nonaka & Bril, 2014).

The empirical evidence derived from this field experiment, albeit a special case of an unusually complex skill, may well serve the purpose of constraining the possible accounts of active touch. Traditionally, active touch is explained by the activity of neurons that compare central motor commands with peripheral sensory feedback during manual exploration (Kandel et al., 2013, p. 524)—an account which exclusively focuses on sensory receptors and the nervous system without reference to the architecture of the body where they are embedded. But the problem expert craftsmen face is unlikely to be that of associating central and peripheral signals. The presence of nonlinearity arising from multiplicative interaction across fluctuations at different timescales would greatly complicate such a process, with no simple correspondence between the central motor command, the generated movement, and the peripheral sensory feedback that arises as a consequence of the movement. Instead, the result is a much better fit to the alternative scenario of active touch that takes into account the medium for the haptic perceptual system (Turvey & Fonseca, 2014), in which efficacy of active touch depends on the tuning of the whole system including the multiscale tensile states of the body, the structures of which are transformed by exploratory behavior in such a way to discriminate the invariant patterns that specify the source of mechanical disturbances from all the other patterns that do *not* specify the source (Gibson, 1966a, p. 55).

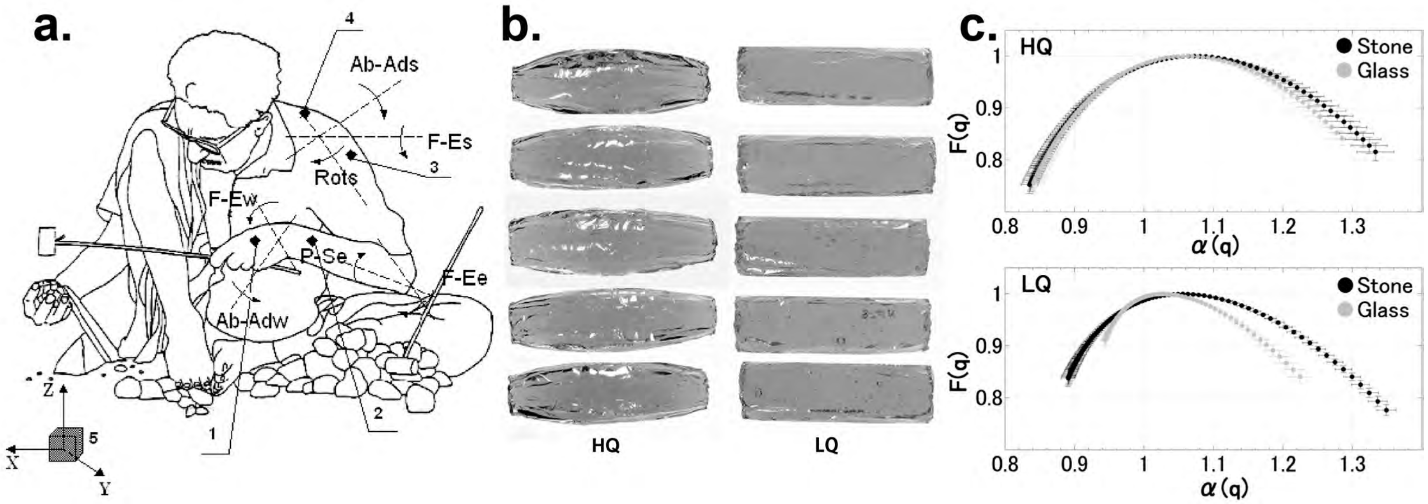

Figure 2.2 (a) Typical posture and movement of craftsmen during stone bead production. (b) Examples of ellipsoidal glass beads produced by expert (HQ) and non-expert (LQ) craftsman. (c) Singularity spectrum $f(\alpha(q))$ ($-1.4 \leq q \leq 3$) estimated for expert (HQ) and non-expert (LQ) craftsmen in the conditions using carnelian stone (black spheres) and glass (gray spheres) as raw materials. The vertical and horizontal bars are standard errors of the means for $f(q)$ and $\alpha(q)$, respectively, of multiple realizations of each condition.

Source: From Nonaka and Bril (2014). Adapted with permission fromthe American Psychological Association.

Substances and Surfaces

Substances refer to the portions of the environment that are in the solid or semisolid state, which are structured in a hierarchy of nested units—such as rock, soil, sand, mud, clay, oil, tar, wood, minerals, metal, and the various tissues of plants and animals (Gibson, 1979/2015, p. 15). Unlike the medium, the substances differ in all sorts of ways—in hardness, resistance to flow, mass per unit volume, resistance to breaking, the tendency to regain the previous shape after deformation, the tendency to hold the subsequent shape after deformation, or the degree to which they absorb light (p. 16). Different substances have different biochemical, physiological, and behavioral effects on the animal. For example, the affordances of a substance for human behavior, such as making useful things, depends on these properties of substances. The ability to distinguish among the different substances is extremely important to us, and we often succeed in picking up the relevant information through the process of scrutiny.

The central question is: *where is the action* in our scrutiny of the substances of the environment (E. J. Gibson, 1994, p. 503)? Brick, for example, can be visually or haptically inspected. But no one has ever seen or touched the inside of a brick (Feynman, 1985). Every time you break the brick, you only see or feel its surface. Nevertheless, the surface of a brick has a characteristic texture that specifies what it is made of, and can be distinguished from other substances by seeing and touching its surface. Likewise, "the surfaces of the substances from which primitive men fashioned tools have different textures—flint, clay, wood, bone, and fiber" (Gibson, 1979/2015, pp. 21–22).

The surface is something of fundamental importance to our perception, especially to visual perception. It is not only because we cannot see the inside of a thing, but also because our vision fails without the illuminated surfaces of a thing. In fact, all we ever see is the surfaces of substances, and the only way we see illumination is by the way of "the surface on which the beam falls, the cloud, or the particles that are lighted" (p. 48; see also Carello & Turvey, Chapter 4, in this volume). There is experimental evidence that seeing the surfaces depends on the structure of the ambient array which has different intensities in different directions (Gibson, Purdy, & Lawrence, 1955). There is also evidence that the eye would be unfocusable in homogeneous ambient light (i.e., in the unusual case where light that surrounds a point of observation would not be different in different directions). In consequence, "the possessor of the eye could not *fix* it on anything, and the eye would drift aimlessly" (Gibson, 1979/2015, p. 47). Our visual system can *only* be adjusted to and oriented to surfaces, and this ability relies on the fundamental fact that "all persisting substances have surfaces, and all surfaces have a layout"—the first of the nine ecological laws of surfaces proposed by Gibson (1979/2015, p. 19). Furthermore, "the surface of a substance is where a mechanical action like collision is located, where chemical reactions take place, where vaporization occurs, or solution, or diffusion into the medium" (p. 86). Then, the answer to the question raised in the beginning of the foregoing paragraph has to be as follows: The surface is *where the action is*—where the activity of perception is focused, adjusted to, and oriented toward.

We pay great attention to the layouts of substantial surfaces and what they afford. To paraphrase Reed (1996b, p. 122), for many centuries, human beings have been chopping, cutting, tying, molding, sharpening, honing, dyeing, shaping, etching, washing, scrubbing, brushing, sweeping, raking, shaving, ironing, mowing, polishing, scraping, grinding, and much more. These are operations that modify the layout of a substantial surface so as to alter its affordance for human life—its utility or function—which turn rough into smooth, and make available the edge or the vertices that affords cutting or piercing. The general problem of how we perceive the meaningful features of the substances and surfaces of the environment is an important problem of psychology. There is, however, a lack of experiments that investigate this rich behavioral repertoire involving the scrutiny of substantial surfaces of the environment. While experimental testing of behavior with virtual surfaces displayed in the monitor are becoming increasingly common, it is still rare to discuss the ways in which our perception and behavior differ depending on the reality of the surfaces involved (i.e., real, material surfaces vs. virtual surfaces).

In what follows, drawing on the research on the ancient skill of stone tool-making that takes advantage of fracture mechanics exhibited by a specific type of brittle substance, I hope to illustrate how the focus on substances and surfaces could shed light on the important problem of human cognition, and how it could expand the intellectual horizons of ecological psychology by connecting with other relevant developments in understanding human ways of life.

Flaking Stone

The earliest known evidence of the alteration of a surface layout by humans to change its affordances is the modification of a natural, hard, and rigid mineral material (cobbles, pebbles, and rock fragments) by means of percussion with hard stone hammers (Režek, Dibble, McPherron, Braun, & Lin, 2018). Thanks to its excellent durability, hard stone records very old traces of physical actions applied to it (Pelegrin, 2005). The archeological records clearly show that by around at least 2.6 million years ago (and likely much earlier, e.g., Harmand et al., 2015; McPherron et al., 2010), early human species were already habitually fracturing stones so as to alter their utility or function—stone knapping, as archeologists call it. From the very beginning, the aim of stone knapping was to obtain a specific layout of surfaces—the razor-sharp edges—that afford a function which is absent or extremely rare in the natural world: the *cutting* function (Roche, Blumenschine, & Shea, 2009). This is inferred from the fact that stone fragments (called *flakes*), detached from a block of stone (called a *core*) found in the old archeological sites, unequivocally display the characteristic layout of surfaces resulting from the specific fracture mechanism called a conchoidal fracture. This mechanism leaves razor-sharp cutting edges and conspicuous bulbs of percussion on the fracture plane that are unlikely to have been formed naturally (Roche, 2005; Semaw et al., 1997) (Figure 2.3a).

Conchoidal fracture refers to the phenomenon producing a Herzian cone. It arises from the fracture of a specific type of brittle substance—a homogeneous and isotropic crypto-crystalline structure (e.g., flint, fine-grained silicified sandstone) or glasses (e.g., obsidian) with no preferred planes of weakness (Pelegrin, 2005). Conchoidal fracture requires loading at a point near the angular edge of the block of raw material with its

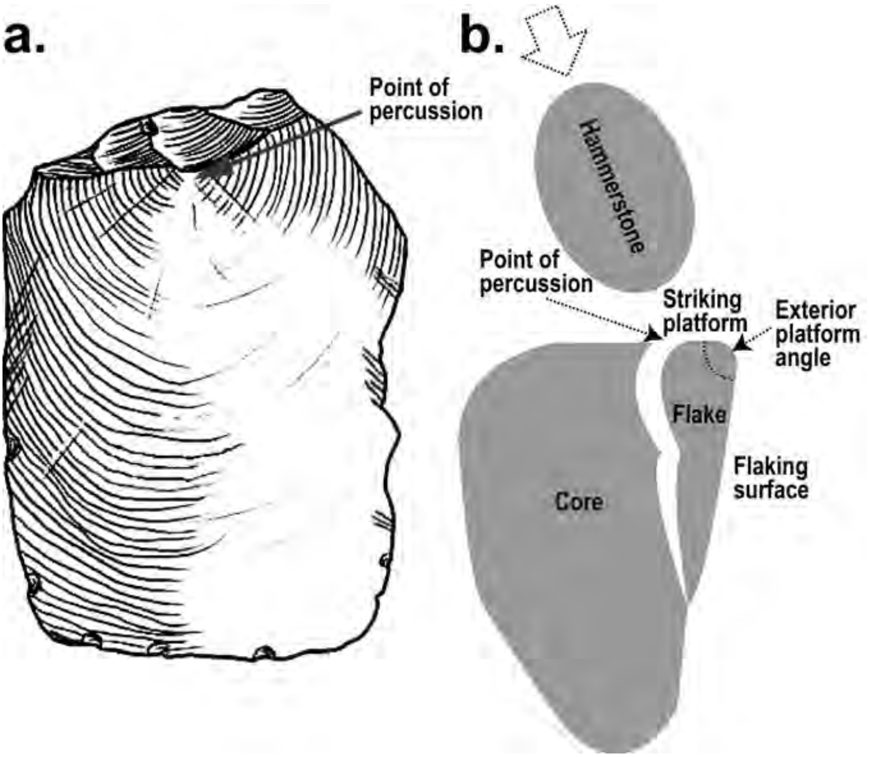

Figure 2.3 (a) Ventral surface of a flake detached by conchoidal fracture. (b) Flake terminology.

Source: (a) Adapted from “Lithic flake on flint, with its fundamentals elements for technic description,” Copyright 2006, José-Manuel Benito Álvarez. ~~(b)~~ From José-Manuel Benito Álvarez, Wikimedia (https://creativecommons.org/licenses/by-sa/2.5/legalcode).

exterior angle (called the *exterior platform angle*) less than 90° (Figure 2.3b), and the to-be-flaked exterior surface (called the *flaking surface*) needs to be flat or slightly convex to allow for the propagation of the energy transmitted by the loading event (Pelegrin, 2005).

Imagine you are a prehistoric human. What would you do to obtain precious cutting tools by fracturing stones? First, you need to look for natural homogeneous, isotropic, and brittle material that can be fractured conchoidally to obtain razor-sharp cutting edges, and the hammerstone that is suitable for aimed striking. In addition, the raw material needs to have a peculiar natural layout of surfaces with angular edges and a more or less flat surface (e.g., cobbles with a flat surface as opposed to a convex one) required for conchoidal fracture. Then, in order to make the most of the precious raw material (i.e., to produce as many usable flakes as possible), you need to make sure that the specific layout of surface of the core that allows further flake removals is preserved after each flake removal.

The foregoing is what has been found in the in-depth analysis of the traces of stone tool-making behavior by early humans who lived near the western margin of present-day Lake Turkana in Kenya—the archeological site of Lokalalei 2C—around 2.34 million years ago (Delagnes & Roche, 2005; Roche et al., 1999). Surprisingly for stone fragments that are so old, it was possible to re-fit many of these pieces found in in Lokalalei 2C back together into an original cobble. By re-fitting the flakes, Roche and her colleagues examined the sequence of flake removals—the order by which these flakes were originally removed (Delagnes & Roche, 2005). An early stone knapper who fractured the cobble in Figure 2.4, for example, selected a fine-grained phonolite cobble that has a flat surface (Face A) as opposed to a highly convex surface (Face B) resulting in edges with acute angles around the flat side of the cobble (indicated by the gray dotted line around Face A). Roman numerals in Figure 2.4 present the order of a series of flake removals, and the arrows show the direction of strike with a hammerstone. Even to a novice's eyes, it is obvious that the knapper obtained these flakes not randomly but by following a certain set of rules. For example, the knapper carried out all the flake removals on the flat face (Face A) but the final attempt (V on Face B), and aimed the blows at the edges with acute angles shown by the gray dotted line. In addition, after a series of flake removals, the knapper switched to the opposite edge on the same face, and alternately struck flakes from the two opposing edges (Figure 2.4). Had flaking been carried out from one direction, the flat surface would have been quickly lost and the remaining core would have been wasted just after a couple of flake removals. In this example, the knapper maintained the surface flat by alternating the direction of strike, thus providing the opportunities for further flake removals to the very end. It was also found that the cores and flakes in Lokalalei 2C do not show any impact damage from failed percussions, such as might be caused by faulty estimation of the opportunities for flaking (Delagnes & Roche,

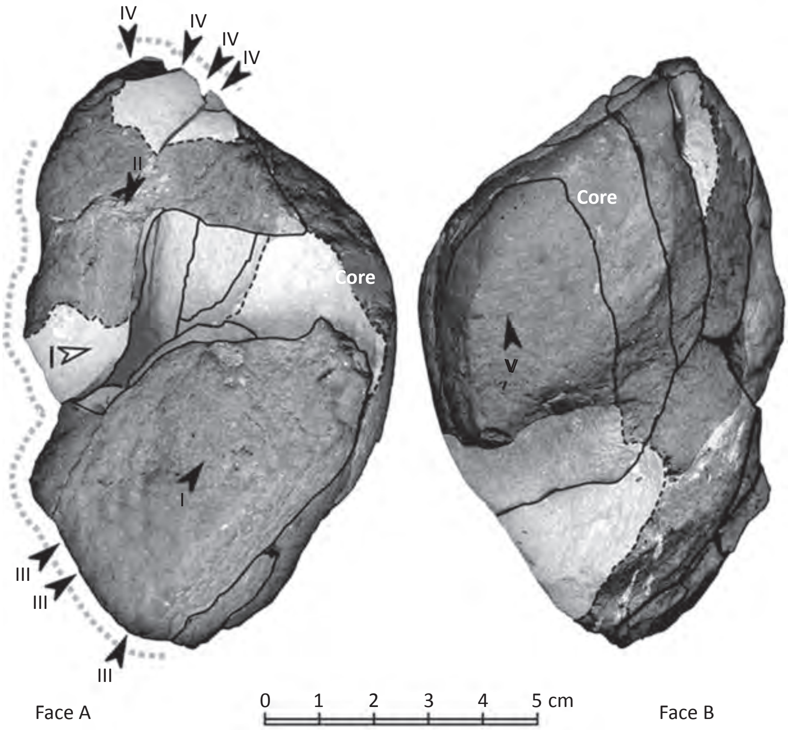

Figure 2.4 Re-fitted elongated ovate fine-grained porphyritic phonolite cobble from Lokalalei 2C. Flaking was carried out on a large and relatively flat natural face (Face A) from the longest available edge and a shorter adjacent edge, which are the only portions of the perimeter of the core with suitable natural striking angles (gray dotted line). The series of flakes were alternately struck from these two edges.

Source: From Delagnes and Roche (2005), Figure 8. Adapted with permission from Elsevier.

2005). Such systematic flake production, seemingly following a certain set of rules (called débitage), was not the result of trying out multiple ways to flake stones and at last succeeding in some way.

Seeing the Outcome at the Outset

How might we understand such regularity apparent in the archeological record of flake removal? Delagnes and Roche (2005, p. 465) wrote, “the débitage of successive series clearly hinges upon conscious planning.” But even if such an operational sequence was consciously planned in detail, if the outcome of each strike was unpredictable and out of control, it would have been impossible to carry out such an orderly sequence as shown in Figure 2.4. The French archeologist Texier (1995, p. 652), addressing this point, once wrote, "if the knapper is able to organize a débitage, he has already a good skill and knows exactly the consequences of a strike given to such a core." The fundamental question, then, is not so much how the early tool-makers consciously planned the order of the core reduction sequence, but how they foresaw the outcome of each hammerstone strike at the outset. Without this ability to foresee and control the path of fractures that would result from each strike, a phenomenon such as organized débitage could never have been realized.

Nonaka, Bril, and Rein (2010) systematically tested the skill of modern stone knappers to foresee and control the path of fracture that would result from their own flaking actions. Nonaka et al.'s hypothesis was that expert knappers could foresee and control the outcome by tuning their actions to the lawful regularities that exist in a conchoidal fracture. Previous conchoidal fracture experiments using a protocol in which a steel ball is dropped on plate glass documented an invariant relation among particular variables (Dibble & Pelcin, 1995): The size of the flake depends on the combination of two variables—the angle of the edge and the distance between that edge and the point of the percussion (see Figure 2.3b). The force with which the hammer strikes the core does not affect the flake size once it is above the threshold of fracture initiation (i.e., the minimum amount of force needed to remove a flake of a given size). The threshold of fracture initiation depends on flake size, which in turn depends on the striking location (Dibble & Režek, 2009). Although they are by no means the only variables that affect the outcome of conchoidal fracture, importantly, these variables are all under the direct control of the knapper. Do knappers, prior to the detachment of a flake, attend to such lawful relations so as to foresee and control the consequence of a strike given to a core?

In the experiment, participants—including prominent replica craftsmen—were asked to draw the outline of the fracture path on the surface of a flint core expected to result from the blow they would deliver at the core (Nonaka et al., 2010). After drawing the outline of the fracture path, the participants were then asked to proceed to actually fracture the stone as they had expected. The result of the experiment indicated that the task was surprisingly difficult. Most knappers who could produce usable flakes could not control the path of the fracture resulting from the strike given to a core. But there were a few expert knappers who proved capable of controlling the fracture path almost exactly as they had expected. Confirming the aforementioned hypothesis, it turned out that the outline of the fracture path drawn prior to the flake removal by those experts who succeeded in the task already exhibited the lawful relation among the three variables—the angle of the exterior edge, the distance between the point of percussion to the exterior edge, and the flake dimensions that reflect the constraints of conchoidal fracture (see Figure 2.3b). In contrast, no such relation appeared in the outlines drawn by the other knappers. The result suggests that those who are able to control conchoidal fracture are focusing their attention to specific salient features of the layout of stone surfaces that are lawfully related to the constraints of fracture mechanics. Simply put, novices intended to detach rather impossible flakes, while experts intended to detach feasible flakes from the outset.

It was further found that the experts hit the core with a lower kinetic energy of the hammerstone at impact than the nonexperts, and that only experts varied the kinetic energy of the hammerstone at impact in relation to the to-be-detached flake size (Nonaka et al., 2010). Experts were aware of the properties of a core and the mass of the hammerstone at hand in the sense that they detached flakes without excessively overshooting the required kinetic energy at impact. This means that those who controlled the conchoidal fracture were tuning their action into yet another higher-order functional relation among the relevant variables of surface layout of the core, potential flake size, and the required kinetic energy determined by these variables, which also depended on the mass of the hammerstone.

In summary, foresight in the control of stone flaking was shown to depend on the continuous participation of the knapper's behavior in the lawful regularity of conchoidal fracture. This participation, in turn, is made possible by the perceptual attunement of the knapper to discriminate a specific layout of surface of the core that has a consequence on the future fracture event, which is observable but not easily attended to by everyone (Nonaka et al., 2010). The path of fracture resulting in a flake is entailed by the natural unfolding of the system of which the behavior of the knapper is a component part (cf., Stepp & Turvey, 2010). In other words, foresight in this ancient skill is a matter of focusing the perception and behavior of an actor on the informative structure that specifies the inevitability of the environmental event in which the actor takes part. This study directs us to reconsider the primacy of the rich opportunities provided by the substances and surfaces of the environment, toward the use of which our perceptual and action systems continue to evolve and develop (Nonaka, 2012).

Epilogue

A "new" description of the environment to be perceived—the triad of medium, substances, and substances that allows for both persistence and change—provides a principled way to frame the existing possibility of further exploration, of scrutinizing, or of looking more carefully to extract invariants (Gibson, 1978a). Without taking this possibility into account, the activity of perceiving would easily get confounded with the activity of guessing which occurs in a rather atypical situation where further scrutiny is wholly prevented. This confusion, in turn, would lead to the reduction of the laws of perception to those of guessing.

Luminous, mechanical, or chemical energy is structured by the substantial environment and becomes *ambient* in the medium. The ambient sea of energy around each of us is usually very rich in what we call pattern and change, which provides the inexhaustible reservoir of potentially informative invariants that lies open to further scrutiny (Gibson, 1979/2015, p. 233). At this level of description of the environment, what has been known tacitly is made explicit: The activity of perception is "open-ended," and you can keep discovering new features and details about the environment by the act of scrutiny (p. 245). Unlike guessing based on a few cues or clues, normal perception is not based on "going beyond the data," as long as one can look again, or go back and look again (Gibson, 1978a). What the triad of medium, substances, and surfaces offers us is a theory of unlimited further discovery for perception. We will have to make a fresh start.

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