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Seeing what is not seen

Gabrielle Benette Jackson[1]

Abstract This paper connects ideas from twentieth century Gestalt psychology, experiments in vision science, and Maurice Merleau-Ponty's phenomenology of perception. I propose that when we engage in simple sensorimotor tasks whose successful completion is open, our behavior may be motivated by practical perceptual awareness alone, responding to invariant features of the perceptual field that are invisible to other forms of perceptual awareness. On this view, we see more than we think we see, as evidenced by our skillful bodily behavior.

Keywords Shape constancy · Isomorphism · Medial axis · Merleau-Ponty · Presence of absence · Perceptual awareness · Skill

1 Introduction

This paper weaves together topics from three distinct but overlapping discourses: Gestalt psychology, vision science, and phenomenology. After explaining Gestalt psychology's psychophysical isomorphism thesis as it pertains to the perceptual phenomenon of shape constancy, I present various models of visual processing that track invariant properties of shapes, with a particular emphasis on sensitivity to the medial axis of shapes. This sensitivity can be understood in terms of Maurice Merleau-Ponty's phenomenology of perceptual space—and that which is visible only through practical perceptual awareness. I propose that when a perceiver engages in a sensorimotor task whose successful completion is open, her behavior may be motivated by practical perceptual awareness alone, responding to features of the world that are unavailable (and, in that sense, invisible) to other forms of perceptual awareness. I also propose that practical perceptual awareness of the medial axis may be constitutive of the perceptual

✉ Gabrielle Benette Jackson
gabrielle.jackson@gmail.com

[1] Stony Brook University, Stony Brook, NY 11790, USA

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phenomenon of shape constancy. I present empirical evidence for these claims and discuss their implications for the psychophysical isomorphism thesis.

2 Gestalt psychology

Gestalt psychologists emphasized the idea that perceptual phenomena tend to have *good form*. "Good form" is a way of referring to the idea that many different spatiotemporal properties of the perceptual field come together in such a way as to generate a global effect that exceeds the aggregate—such are Gestalt psychology's principles of wholes (e.g., reification, invariance, multistability) and principles of grouping (e.g., proximity, closure, common fate) (Müller 1896; Wertheimer 2012; Koffka 1963; Köhler 1966). Wolfgang Köhler came to bemoan the mysterion slogan associated with Gestalt psychology—"a whole that is more than the sum of its parts"—but it was not entirely misleading. Perceptual experience has good form, a seemingly improbable emergent effect of the dynamic interactions of its manifold parts. In this sense, the properties of the whole do exceed the properties of the parts.

Of course, one can take an organized whole and, with some effort, perceive the parts as disorganized; as one can take a disorganized aggregate and, with some effort, perceive an organized whole. Consider the following example of invariance, given its relevance for this paper. Invariance is a basic principle of perceptual organization. It denotes the phenomenon whereby, under normal conditions, an object is perceived as retaining certain properties (e.g., color, shape, tone, texture) despite changing spatio-temporal perspectives (e.g., illumination, orientation, loudness). For instance, when I look at the three images below, through no apparent effort on my behalf, all the doors look to have the same shape—a door opening, in three acts (Fig. 1). In fact, it would be unusual to have a visual experience of a rectangular door, a slightly trapezoidal door, and a very trapezoidal door. I can do it, however, with some industry—that is, shift my perception of invariance into a perception of variance. So there is a phenomenological distinction of note between them, a difference at the level of perceptual experience. In ordinary perception, luckily, I do not labor over constructing good form. The principle of invariance names the fact that I simply perceive it.[1]

Gestalt psychology is perhaps less known for another of its commitments—the *psychophysical isomorphism thesis*. This is the view that there are spatial, temporal, and even functional similarities between perceptual phenomena and neural processes.[2] Early Gestalt psychologists such as Georg Müller, Max Wertheimer, Kurt Koffka and Wolfgang Köhler certainly held to the psychophysical isomorphism thesis, looking to ground their observations about good form in verifiable field effects at the cortical level (Müller 1896; Wertheimer 2012; Koffka 1963; Köhler 1966; see also Henle 1984 and Scheerer 1994). But it was not just early Gestalt psychologists who held this view. Vision scientists sympathetic to neurological explanations of the unique perceptual properties of

[1] There are documented case studies of neuropathological patients who do not simply perceive good form at all times. Gestalt psychologists Adhemar Gelb and Kurt Goldstein studied a patient who could describe the parts of a visual scene or the sequence of a verbal narrative, but could only guess at the whole they together formed. For instance, when looking at a line drawing of a duck, the patient reported, "there is a dark point, and big like a hand…an uneven circle, like a lung" (Gelb and Goldstein 1917, 15).

[2] Notably, psychophysical isomorphism was *not* meant to involve "substance" or "quality" (Köhler 1966).

organized wholes were influenced by some version of the psychophysical isomorphism thesis (e.g., Hochberg 1964; Neisser 1976; Gibson 1979).[3] Contemporary theorists too, even those with quite different philosophical orientations, have preserved the idea of isomorphism between phenomenal and cortical fields in more limited domains (e.g., O'Regan 1992; Stadler and Kruse 1994; Epstein and Hatfield 1994; Spillmann and Ehrenstein 1996; Pessoa et al. 1998; Lehar 2003; Crick and Koch 2003).[4] They all postulate that for a particular global effect of good form at the personal level—such as shape constancy, affordances, figure-ground structure, filling-in, pattern recognition, binding—there may be neurological processes similar in form, structure or relation at the subpersonal level.

How exactly does psychophysical isomorphism work? Let us return to invariance as an example. Recall that invariance is a principle of perceptual organization, which includes the phenomenon of *shape constancy*, or the experience of an object's shape as constant across changing spatiotemporal perspectives. Psychophysical isomorphism warrants the inference from certain aspects of this personal level phenomenon to subpersonal level processes. For instance, looking at a closed door (the image on the far left of Fig. 1) produces a rectangular projection on the retina. Looking at an open door (the image on the far right of Fig. 1) produces a trapezoidal projection on the retina. If shape constancy is a personal level emergent effect that exceeds aggregated individual perspectives, then for those who hold the psychophysical isomorphism thesis it follows that something similar is occurring at the subpersonal level—that even as retinal projections change from rectangular to trapezoidal, there are neurological processes taking these variant inputs and generating an invariant output.

Gestalt psychology's principles of wholes and groupings constitute a robust doctrine that still is used in study of perception (not to mention its use in art and design). But despite the efforts of a few ardent supporters, the equally foundational psychophysical isomorphism thesis has fallen out of favor. Taken as an analytic thesis, this abandonment probably was wise. It is clear that not all (or even most) psychological processes are isomorphic with physical processes.[5] But treated as an epistemic thesis—that is, as a principle that warrants positing token isomorphisms between perceptual phenomena and neural processes, until such time that empirical evidence either justifies the token or invalidates it—there may be a place for it. We cannot rule out the occasional token psychophysical isomorphism. It seems we may proceed, on a case-by-case basis, with a heavy dose of caution. As Daniel Dennett warns, "we tend to assume the isomorphism principle tacitly, and hence are driven to expect that there is more in the brain than there has to be" (Dennett 1998, 754). Point taken.

[3] For instance, James J. Gibson posited a psychophysical isomorphism between invariant visual structures of visual perception and invariant structures in the ambient optic array for ecologically situated perceivers (Gibson 1979).

[4] Francis Crick and Cristof Koch's work on perceptual binding of shape and color may be an instance of temporal psychophysical isomorphism: when a perceiver reports seeing a colored shape, they claim there are synchronous oscillations of neurons correlated with color and shape (Crick and Koch 1990).

[5] I have encountered various explanations for this shift: the rise of computational psychology and neuroscience; the corresponding functionalist theory of mind and its corollary of multiple realizability; the advancement of imaging technology, making "macroscopic" observations of the brain seem both quaint and arbitrary; the worry that looking for psychophysical isomorphs is effectively looking for a homunculus inside the person that entertains the same content as the person herself, making it a kind of Cartesian Materialism or "the view you arrive at when you discard Descartes's dualism but fail to discard the imagery of a central (but material) theater where 'it all comes together'" (Dennett 1991, 185). Thus, the psychophysical isomorphism thesis has come to be viewed as either empirically unnecessary (e.g., Sperry 1952) or philosophically suspect (e.g., Dennett 1991).

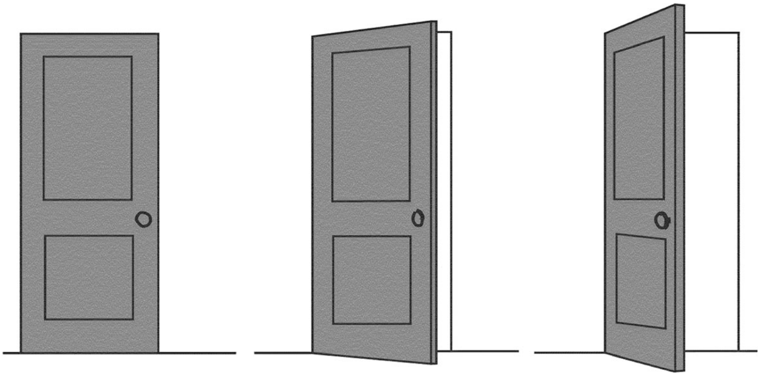

Fig. 1 Gestalt psychology's principle of invariance describes the perceptual phenomenon that, in spite of wildly different projections onto the retina, the door in the three images looks to be the same size

3 Vision science

Around the same time that Gestalt psychology came to America, a group of vision scientists were proposing that the phenomenon of shape constancy might be correlated with sensitivity to mathematical structures of shapes that are invariant across perspectives. These structures are defined algorithmically, and therefore are computable. For instance, in human vision, these scientists believed there are neurons in the visual cortex sensitive to some mathematical property of shape, such that these neurons generate the same or similar outputs from a wide variety of input from the retina. There were a number of promising proposals, many of which are still used to model shape constancy today.

In the 1947 article "How We Know Universals: The Perception of Auditory and Visual Forms," Walter Pitts and Warren McCulloch proposed two algorithms, both of which first generate outlines of objects based on their projection onto the retina. One algorithm they developed dilates and contracts these outlines, and then produces a generalization. Outlines whose generalizations are roughly equivalent over time are likely to be produced by the same object. For example, an approaching rectangle generates outlines whose generalizations have the same length-to-width ratio, which correlates with shape constancy at the personal level. A second algorithm they developed contracts these outlines, and then records the linear form generated by connecting the corner-forming joints. Outlines that produce roughly equivalent forms across perspectives are likely to be produced by the same object. For example, a rotating rectangle produces the form "X," which correlates with shape constancy at the personal level (see Fig. 2 on left). Pitts and McCulloch's proposal has been called the "size constancy" hypothesis.[6]

Harry Blum offered another proposal in his 1967 piece, "A Transformation for Extracting Descriptors of Shape." His insight was that any given shape has a computable medial axis (also called a "shape skeleton" or "grassfire transform"). The medial axis of a shape is generated when the outline of a shape is shrunk and every node of convergence is a point along the medial axis (see Fig. 2 on right). Blum himself

[6] Though related, Pitts and McCulloch's *size constancy hypothesis* should not be confused with the *shape constancy phenomenon* in Gestalt psychology.

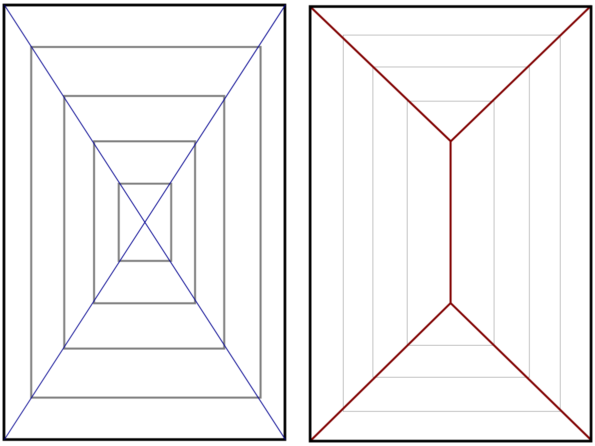

Fig. 2 Two mathematical models for shape constancy. For a rectangle, the algorithmically generated form is highlighted in blue for the Size Constancy hypothesis (*left*) and in red for the Medial Axis hypothesis (*right*)

described the medial axis in this provocative way: imagine lighting a fire on the borders of a shape laid out on a field of grass; wherever one line of fire meets another, a quench point is determined; the totality of the quench points constitutes the medial axis (Blum 1973).[7] Remarkably, the medial axis remains constant when perspective changes in two-dimensions. And similarly, in three-dimensions, the medial axis stays the same when objects hinge and revolve, just like your bones stay the same when you bend or rotate your arm. Blum's proposal can be called the "medial axis" hypothesis.

The algorithms offered by Pitts and McCulloch and Blum give the same result for certain basic shapes (e.g., a circle, a square). But they generate different results for other shapes (e.g., a rectangle, a trapezoid). Insofar as both are equally plausible models of how neurological processes compute shape, how could these competing hypotheses—*size constancy* or *medial axis*—be tested?

Some remarkable evidence of which algorithm is operative came from vision scientist Josef Psotka. In his 1978 article, "Perceptual Processes that may create Stick Figures and Balance," Psotka described his approach in this way:

> Intrinsic structures could be made visible using a technique called *constrained free choice* (Kubovy and Psotka 1976). If a person is asked to place a dot anywhere inside an outlined form in the first place to come to mind, there is nothing inside the form to constrain his choice except the stick figure structures that are postulated to arise from the interaction of the outline with itself through field processes. (Psotka 1978, 102–103; *emphasis added*)

[7] For two-dimensional shapes, the medial axis also can be visualized with water, as border perturbations that produce the medial axis where ripples collide. You might also see the medial axis aesthetically displayed in the converging lines raked into the gravel of a Japanese rock garden. For three-dimensional shapes, the medial axis is best visualized as the ridge formed by a union of cones whose bases sit on the original contour. There are many diverse applications of the medial axis transformation, from collision detection programs to generation of ridgelines for rooftops (Aurenhammer 1991).

In other words, Psotka presented subjects with simple shape outlines, and then asked them to place a dot anywhere inside the shape. "They were not informed about the purpose of the experiment. They were just told to 'carefully place a dot anywhere on the figure below in the first place that comes to mind,' in a caption at the top of each page" (Psotka 1978, 103). Psotka's insight was that the placement of the dot might be guided by whatever algorithm the neurons are sensitive to—size constancy or medial axis—without the subjects knowing that this is the case. It is also possible, Psotka acknowledged, that the placement of the dot might be guided by other factors independent of the postulated algorithms, such as aesthetics, balance, orientation in the environment, or even social factors, like the desire to please or to outsmart the experimenters (Kubovy and Psotka 1976, 294; Psotka 1978, 103; see also Rock 1956). The results might even be random. But this is the genius of constrained free choice. It is an experimental method that gives subjects a simple clearly defined sensorimotor task ("place a dot…") whose successful completion is open ("…anywhere you like"). The aggregate of what subjects freely choose is evidence of what is guiding their performance. In this case, the results were remarkable. *Subjects repeatedly affixed dots along the medial-axis of the shapes* (see Fig. 3).

Psotka's initial findings had a sample size of 150 subjects pulled from the summer school community at Yale University. Were his results biased by the sample population: college students with an extensive background in mathematics? Might less mathematically sophisticated populations perform differently? Psotka gathered similar results when he conducted his experiment with elementary school children who lacked training in geometry (see Fig. 4).

Psotka's remarkable experiments were rediscovered and reproduced (with some additions) in 2014 by Chaz Firestone and Brian Scholl, psychologists at the Yale

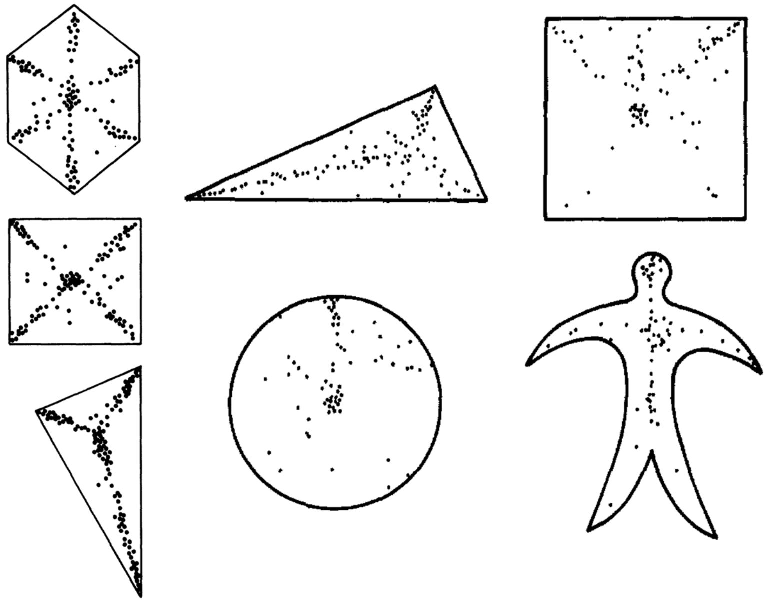

Fig. 3 Psotka's initial findings (Psotka 1978, 103; 105). Subjects are drawn to the medial axis of shapes. (Note: subjects did not see the results of previous trials)

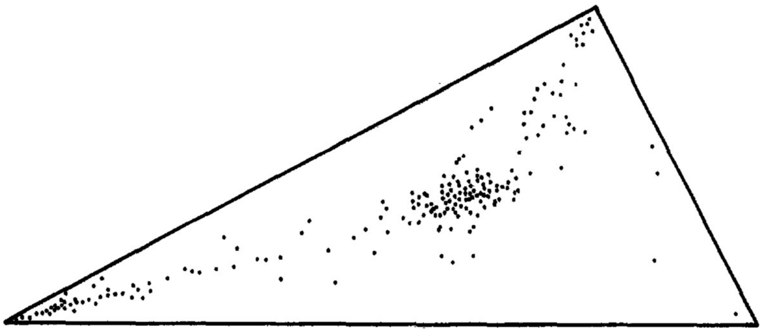

Fig. 4 Psotka's findings with children (Psotka 1978, 109). Subjects are still sensitive to the medial axis of the triangle

Perception and Cognition Lab. Describing the phenomenon of shape constancy, and what would be required for a visual system to generate it, Firestone and Scholl write, "views, positions, lighting, and other contextual factors ensure that objects and shapes rarely appear in just the same way across viewings, and so a challenge facing any prospective recognizer is to describe shapes flexibly enough to allow for generalizations over instances" (Firestone and Scholl 2014, 377). Expanding the sample size, and testing nearly 1500 subjects in Times Square, Firestone and Scholl confirmed that when viewing a two-dimensional shape on a touch-sensitive tablet, and instructed to "pick a spot anywhere inside the shape, and just gently tap that spot," subjects were drawn to the medial axis. In Firestone and Scholl's words, "the aggregated touches formed the shape's medial-axis skeleton" (Firestone and Scholl 2014, 377) (see Fig. 5).[8]

But there was still some question as to whether subjects' responses conformed better to the medial axis hypothesis or the size constancy hypothesis. For example, Firestone and Scholl illustrate how the taps falling on a rectangle might be consistent with either the medial axis hypothesis (the solid lines inside rectangle 5c above) or the size constancy hypothesis (the dashed lines inside rectangle 5d above). This led them to run additional experiments in which shapes had minor border perturbations that produced major divergent effects for the interior forms predicted by the medial axis hypothesis and the size constancy hypothesis. Here again, Firestone and Scholl found that subjects were amazingly sensitive to the medial axis (see Fig. 6).

Firestone and Scholl also addressed the issue of occluded shapes. The phenomenon of shape constancy is often described in terms of invariance across many perspectives. But an equally common way in which invariance is preserved involves occlusion, or the interposition of an opaque object between the perceiver and the perceived. Two-dimensional shapes can be occluded, and three-dimensional shapes are always in some

8 Firestone and Scholl chose a different quantitative display of their results than Psotka. Touches appear 'raw' in Fig. 5a (similar to Psotka's presentation) and then as 'heat maps' in subsequent figures (Firestone and Scholl's preferred display). Unlike the raw presentation, heat maps are better at depicting multiple touches in the same location. Firestone and Scholl also added interior lines afterwards, for effect. But just as in Psotka's experiments, subjects were shown only outlines when asked to tap the shape, and the screen was wiped clean after each trial, so to not reveal any previous touches.

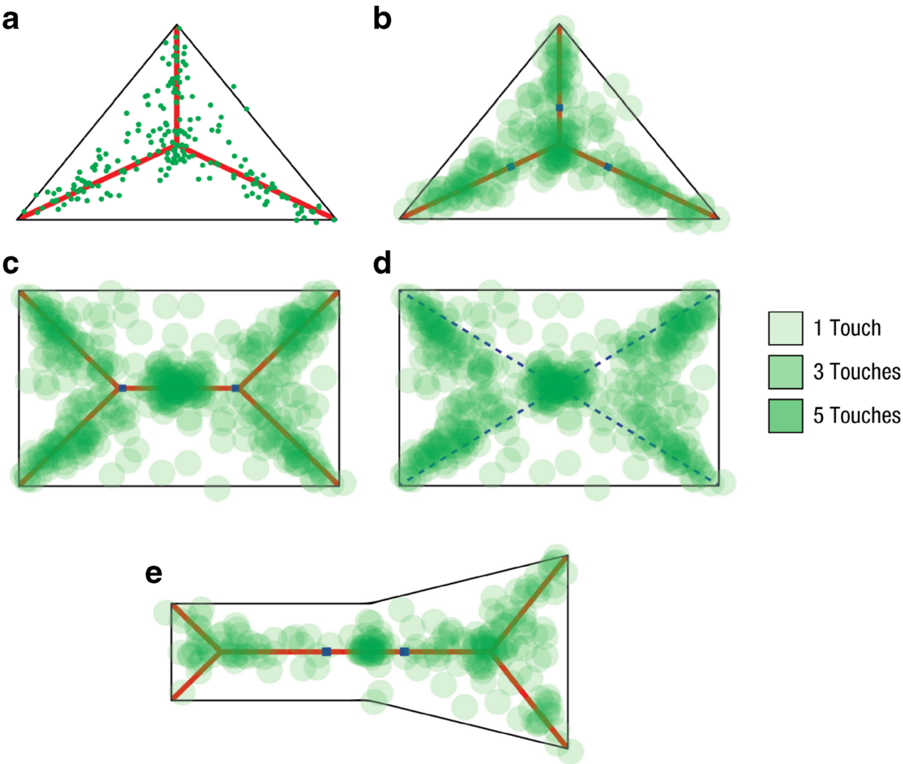

Fig. 5 (**a**) Firestone and Scholl's initial findings (Firestone and Scholl 2014, 380). (**b**-**e**) Heat maps show sensitivity to the medial axis of shapes. (Note: subjects did not see any of the previous results or interior lines depicted here)

way occluded.[9] Thus, the phenomenon of shape constancy also involves wholeness in spite of potential occlusion. Returning to the experiments, if subjects are sensitive to the medial axis of non-occluded shapes, then what will happen when presented with occluded shapes? To answer this question, Firestone and Scholl showed subjects an ambiguous shape (see Fig. 7b). It could be seen either as a stand-alone trapezoid with a triangular red sticker sitting above it, or as a trapezoidal subsection of a partly occluded full-sized triangle. As before, subjects were instructed to tap the shape anywhere they liked. The results may be less visually striking than in previous experiments, but they were still probative. Firestone and Scholl found an absence of concentrated touches on what would be the upper branches of a trapezoid's medial axis and the presence of concentrated touches on what would be the

[9] For instance, Edmund Husserl observed that a cube viewed from everywhere—all six sides and twelve corners seen all at once—is impossible. In *Cartesian Meditations* he wrote, "from my body's point of view, I never see the six faces of the cube as equal, even if it is made of glass" (Husserl 1999, 209–211). To see a cube is for parts of it to be occluded from view, both in time and in space. Maurice Merleau-Ponty repeated this point in *Phenomenology of Perception*. "To be able to conceive of the cube, we take up a position in space, sometimes on its surface, sometimes inside it, and sometimes outside of it, and from then on we see it in perspective. The cube with six equal sides is not merely invisible, but is even inconceivable; this is the cube such as it would be for itself; but the cube is not for itself, since it is an object" (Merleau-Ponty 2012, 210).

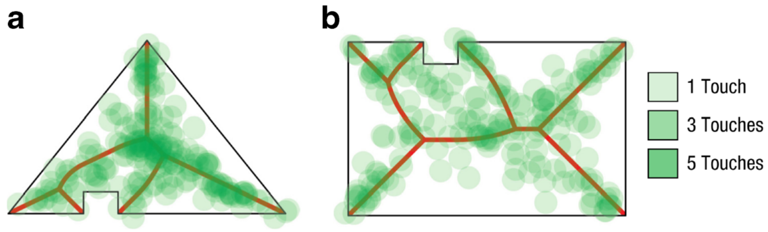

Fig. 6 Firestone and Scholl's findings with unusual shapes (Firestone and Scholl 2014, 381). Heat maps show responsiveness to the medial axis of the perturbed shapes

vertical branch of a triangle's medial axis. They concluded that the subjects' touches were more consistent with the medial axis of a triangle.

In sum, subjects not only are sensitive to the medial axis of shapes, but they know how to differentiate between the medial axis of un-notched and notched shapes, and between the medial axis of non-occluded and partly occluded shapes. Their sensitivity appears to be both specific and robust.

I would now like to look closer at these experiments and what they assume. We have read Psotka's description about how "intrinsic structures could be made visible" via constrained free choice. Firestone and Scholl say something similar. "[This] demonstrates (in an unusually direct way) how deep and otherwise-hidden visual processes can directly control simple behaviors, even while observers are completely unaware of their existence" (Firestone and Scholl 2014, 377). And again, "the reason touches of the shapes formed their medial axis, then, may be rather innocuous: arbitrary and 'unthinking' tasks with no obvious answer are precisely the contexts in which latent mental representations can subtly exert their influence" (Firestone and Scholl 2014, 385). These quotations, and others like them, communicate a particular view about perceptual space—how it is structured, what it contains, and our awareness of it. It is a view that treats the placement of dots and the locations of taps as a sort of reflex. It is a view that treats the medial axis of shapes as invisible. It is a view that understands perceptual awareness as a cognitive activity—its contents amenable to attention, introspection, reflection, and articulation. It is a reasonable view, but it is not the only one. In the next section, I will present Merleau-Ponty's account of *the practical perceptual awareness of presence of absence in bodily space*.

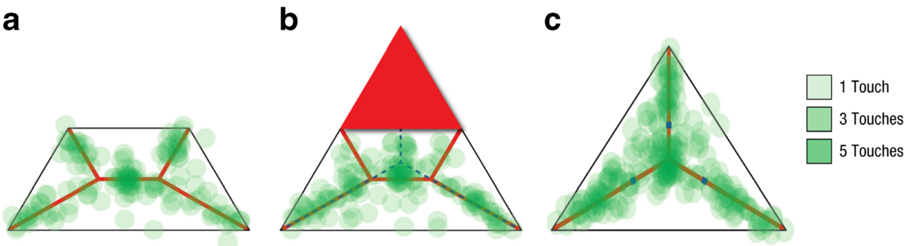

Fig. 7 Firestone and Scholl's findings with occluded shapes (Firestone and Scholl 2014, 380; 382). On the left (**a**), subjects respond to a trapezoid. On the right (**c**), subjects respond to a triangle. In the middle (**b**), heat maps show greater sensitivity to the medial axis of a triangle than of a trapezoid

4 Perceptual space

According to Maurice Merleau-Ponty, when we perceive an object, we experience both "its irrecusable presence and the perpetual absence into which it withdraws" (Merleau-Ponty 2012, 242). Here he was naming (among other things) the phenomenon of *perceptual presence of absence*.[10] This refers to those aspects of perception that are apparently present to us—that structure perceptual experience in a positive way—but that do not, or even could not, register as sensory stimulation.[11] Perceptual presence of absence arises in at least two different ways in Merleau-Ponty's writing. In what follows are two examples in relation to vision, noting that Merleau-Ponty described presence of absence for other sense modalities as well.

First, the phenomenon of presence of absence includes the fact that my perception of any object is always partially blocked or occluded by the constraints of four-dimensional space-time. For example, when looking at me head on, you see my face, not the back of my head. Certain aspects of visual objects are always, necessarily, hidden in space or time (or both).[12] But, in spite of this, Merleau-Ponty wrote that even "what is behind my back is not without some element of visual presence" (Merleau-Ponty 2012, 6). There is a clear sense in which you see not just my face, but my whole voluminous head, even though the back of my head is occluded (consider your surprise if I turned to reveal that I didn't have a whole voluminous head). The occluded sides of objects are present-as-absent in the visual field. We see whole objects existing in space and persisting in time even though we only ever have occurrent access to their spatiotemporal parts. This phenomenon can also be called "reification" or "amodal completion" (although Merleau-Ponty never used these terms).

Second, the phenomenon of presence of absence includes perceptual absences that, in principle, never could be perceptual presences; and yet they are still perceptually present-as-absent: witness the positive perceptual presence of empty space. When you step onto the crowded subway car, you don't just see the commuters, seats, and poles. You also see the spaces between the commuters, the open seat on which to sit down, the vacant pole around which to wrap your arm. Or consider Merleau-Ponty's well-known example of the soccer player on the field. She doesn't just see the grass, the people, and the ball, but also the spaces between them—"articulated in sectors (for example, the 'openings' between the adversaries)" (Merleau-Ponty 1963, 168). In Merleau-Ponty's words, "the perceived is composed of lacunae that are not merely 'non-perceptions'" (Merleau-Ponty 2012, 11). Rather

[10] Perceptual presence of absence appears repeatedly in the phenomenological tradition (e.g., Husserl 2001; Sartre 1943; Merleau-Ponty 2012). Samuel Todes (2001), Alva Noë (2004), and Sean Kelly (2005) have recently developed views of perceptual presence of absence influenced by these early phenomenological accounts, and especially by Merleau-Ponty's work.

[11] In *Gestalt Psychology*, Köhler criticized a view he called (somewhat confusingly) "the constancy hypothesis." Not to be confused with the *size constancy hypothesis* or the *shape constancy phenomenon*, the constancy hypothesis posits a one-to-one relation between sensation (which is directly correlated with sensory stimulation) and perception (which is not) (Köhler 1975). Notably, Merleau-Ponty took up Köhler's criticism of the constancy hypothesis in *Phenomenology of Perception*. The two theorists agreed that the content of perception outstrips the content of sensation, but for each for different reasons (e.g., Merleau-Ponty rejected both the existence of "sensations" and the determinacy of "perception") (Merleau-Ponty 2012).

[12] As already mentioned in footnote 9, we can see an entire two-dimensional object in space but never an entire three-dimensional object in space. We might call this occlusion by *space*. Occlusion by *time* is another matter, and altogether unavoidable, insofar as our perception of all objects occurs within a moving horizon of past, present, and future.

"our perceptual field is made of 'things' and 'gaps between things'," both of which are equally part of our experience (Merleau-Ponty 2012, 16).

We now have a brief introduction of perceptual presence of absence in Merleau-Ponty's work, or again, the aspects of perception that are apparently present to us but that do not, or even could not, register as sensory stimulation. The perceptual presence of absence can seem like a puzzle, because how is it that there are aspects of perceptual experience that are not, strictly speaking, within the sensory array but that still show up for us, having some degree of positive perceptual presence? In the case of vision, Merleau-Ponty observed that "what we do see is always, in some respect, not seen" (Merleau-Ponty 2012, 289). How is it that we see what is not seen?

There have been many solutions to this puzzle, both before Merleau-Ponty and since, solutions having to do with inference, judgment, imagination, expectation, probability, even illusion. But Merleau-Ponty's answer was this: the absence of sensory stimuli can nevertheless constitute richly detailed perceptual experience thanks to skillful bodily movement. You see my whole voluminous head because you know how (in a tacit, practical, bodily way) to see all of it—move a little to the side or walk around me; I see the empty space between two subway passengers because I know how to sit down there; the soccer player sees the opponents and the spaces between them because she knows how to maneuver around them—they "call for a certain mode of action and which initiate and guide the action as if the player were unaware of it" (Merleau-Ponty 1963, 168). In other words, for Merleau-Ponty, perceptual experience outstrips what is registered by the sense organs, at least in part, in virtue of the ability to move skillfully around in the world.

Merleau-Ponty's point was not just that the perceptual field is *revealed* by bodily movement (indeed, we constantly explore and inspect our environments), but also that the perceptual field is *structured* by bodily movement.[13] This difference is important. To understand it, we have to consider his account of perceptual space. According to Merleau-Ponty, the structure of perceptual space is actually an ambiguous concept, as there are multiple ways to conceive of it.

There is the more familiar idea of "*objective space*," in which the perceptual field is mapped out in <x, y, z > coordinates, often with the perceiver at the zero point <0, 0, 0> and objects located at <a, b, c>. Size, shape, height, distance—these all can be determined with a certain mathematical precision. If there is more than one answer to the question, "how far is the coffee cup from my hand?" then it is only because there is more than one system of objective measurement (e.g., allocentric versus egocentric).

Then there is Merleau-Ponty's more radical idea of "*bodily space,*" in which objects are situated by the actions required for the perceiver to engage with them—for instance, <graspable by doing A>. In his words, "the position of objects is given immediately by the scope of the gesture that reaches them…the radius of action" (Merleau-Ponty 2012, 144). And furthering the sentiment, "places in space are not defined as objective positions in

[13] Husserl claimed that because the body occupies space (and moves through it), the body is the condition of *possibility* of the spatiality of objects in the perceptual field (e.g., Husserl 1973). Though Merleau-Ponty agreed, he also seemed to be making a different point—that skillful bodily activity *structures* the spatiality of the perceptual field. Whether Merleau-Ponty also wished to make the Husserlian point is not an issue I address here. We may look instead to Dan Zahavi for discussions of Husserl's view on the relation between the body and perceptual space in his book *Self Awareness and Alterity* (Zahavi 1999) and Merleau-Ponty's understanding thereof in "Merleau-Ponty on Husserl: A Reappraisal" (Zahavi 2002).

relation to the objective position of our body, but rather they inscribe around us the variable reach of our intentions and our gestures" (Merleau-Ponty 2012, 144). That is, the perceptual field is structured—formed and deformed—by the perceiver's skillful bodily movement.[14]

Perceptual awareness is crucially different, too, on each conception of perceptual space. To know where an object is in objective space is to be able to identify its coordinates (for example, to measure its distance from the perceiver or to respond to a request to point to it). This awareness is *theoretical*, open to introspection, reflection, and articulation. And even if the spatial location of an object is not immediately accessible to the perceiver, it can be made explicit—it can be brought under the scope of perceptual awareness, for instance, through attention.

Conversely, to know where an object is in bodily space is to engage with it (for example, to tap it). "Bodily space can be given to a grasping intention [*une intention de prise*] without being given to an epistemic one [*une intention de connaissance*]" Merleau-Ponty wrote (Merleau-Ponty 2012, 106). In other words, this awareness is *practical*, not accessible to introspection, reflection or articulation, perhaps necessarily so. It is a species of know-how. The spatiality of an object is manifest in the actions of the perceiver, making practical perceptual awareness something the perceiver does (as when grabbing, touching, flicking, stepping, lunging, turning, scratching, sniffing, etc.).

Merleau-Ponty repeatedly harkened back to this distinction between types of perceptual awareness in his writings. Here is just one example of which there are many:

> One can know how to type without knowing how to indicate where on the keyboard the letters that compose the words are located. Knowing how to type, then, is not the same as knowing the location of each letter on the keyboard, nor even having acquired a conditioned reflex for each letter that is triggered upon seeing it. But if habit is neither a form of knowledge nor an automatic reflex, then what is it? It is a question of a knowledge in our hands, which is only given through a bodily effort and cannot be translated by an objective designation. The subject knows where the letters are on the keyboard just as we know where one of our limbs is—a knowledge of familiarity that does not provide us with a position in objective space. (Merleau-Ponty 2012, 145)

The experienced typist at work perceives her surroundings in bodily space. The paper, the individual lettered keys, the keyboard, even her body are situated in a perceptual field that is structured by her typing. For instance, her perceptual awareness of the keys, and therefore her knowledge of where the keys reside in the perceptual field, is manifest when her finger strikes down in the course of typing a word. Hers is a practical perceptual awareness.

[14] Egocentric space should not be confused with bodily space. For example, in egocentric space, a perceiver standing in front of two equidistant objects would represent them differently in terms of right/left or up/down. In contrast, in bodily space, a perceiver standing in front of two equidistant objects may see one as closer or larger than the other, depending on her motor intention to grasp one but not the other. In "Skillful Action in Peripersonal Space," I describe Merleau-Ponty's distinction between objective space and bodily space in greater detail (Jackson 2014).

Let us take stock. I have introduced three distinctively Merleau-Pontian themes: perceptual presence of absence, bodily space, and practical perceptual awareness. The connection among them is this: there are phenomena in the perceptual field that do not correspond to any actual or even possible sensory stimulation; we can do justice to these phenomena that are present-as-absent, if we understand the perceptual field as structured by our bodily activities; within this bodily space, perceptual awareness is practical, in which *visibilia*, including those which are present-as-absent, guide our behaviors, regardless of whether we are (or precisely because we are not) theoretically perceptually aware of them.

5 Seeing what is not seen

To review: (1) Gestalt psychology tells us that perceptual phenomena tend to have good form—like shape constancy, where invariant shape emerges out of variant perspectives—but also that this good form is isomorphic with field effects at the cortical level. (2) We make "intrinsic structures visible," in Psotka's words, by marking the medial axis of shapes. Firestone and Scholl made a parallel discovery too, that while we may be unaware of the "deep and otherwise-hidden visual processes" computing the medial axis of shapes, they are manifest in our bodily behavior. And (3) Merleau-Ponty described a practical perceptual awareness of that which is present-as-absent in bodily space. To recall his words, "what we do see is always, in some respect, not seen," as evidenced by our skillful bodily activity. How are we to understand the connection among these three discussions?

Let me begin by acknowledging that, strictly speaking, the medial axis of shapes produces no sensory stimulation. In this sense, it is not at all like the outline of shapes in the perceptual field. And yet subjects in the experiments know how to engage with the medial axis, quite well, as measured by their marks and taps. Without the ability to attend to this invariant feature (or introspect, reflect, or report on it), it appears their perceptual awareness of the medial axis is entirely practical. My first proposal, then, is that *the medial axis of shapes is present-as-absent in bodily space, and therefore is visible only in the mode of practical perceptual awareness.*

Is this practical perceptual awareness of the medial axis connected to the ability to grasp objects? To their center of gravity? Or to the ability to navigate between objects? I admit being curious about the relation between this invariant feature and these other abilities and properties. But I wish to make a different kind of claim about the purpose of this practical perceptual awareness. Recall that invariance is a principle of perceptual organization described by the Gestalt psychologists, which includes the phenomenon of shape constancy. My second proposal is that *the experience of an object's shape as constant across changing spatiotemporal perspectives is constituted (at least in part) by practical perceptual awareness of its medial axis.*

I now want to link these two proposals to the experimental method of constrained free choice. In the research presented, Psotka hoped that subjects would be "responsive to an underlying perceptual structure" when they placed a dot (Psotka 1978, 108). But he allowed that they might be "engaging in some cognitive activity that guides their responses in terms of experiences and rules generated in other circumstances," for example, practices developed in math class (angle bisection) or art class (aesthetic balance) (Psotka 1978, 108).[15] There may even be a desire to "appear to be in compliance" with the experimenter's request for a spontaneous response (Kubovy and Psotka 1976, 294). Or the opposite. In Firestone and Scholl's work, a few subjects tapped the screen outside of the shape outlines, as an act of rebellion. Or the aggregate might be random. In an experimental situation involving constrained free choice, the results indicate what (if anything) is motivating the subjects, whether or not they are aware of those motives. This is the brilliance of Psotka's method.

Firestone and Scholl write admiringly about Psotka's work—that it was "ahead of its time, both methodologically and theoretically"—and are hopeful that their experiments will introduce constrained free choice back into experimental psychology (Firestone and Scholl 2014, 378). Here we agree on the power and promise of this method. And yet we seem to disagree over what it does. Because Psotka, Firestone and Scholl limit themselves to a concept of perceptual awareness that is theoretical, the medial axis of shapes is invisible to the perceiver, and constrained free choice *as a method* points to subpersonal processes correlated with the perceptual phenomenon of shape constancy (or, on another interpretation, to behavior influenced by latent mental representations). Constrained free choice *as a method* does something quite different, however, if we adopt a concept of practical perceptual awareness, in which the medial axis of shape is visible to an embodied and embedded perceiver.

On this understanding, constrained free choice becomes a uniquely well-suited method for discerning perceptual features of our environment that we are aware of theoretically from those we are aware of practically. Rather than providing subjects with several predetermined choices of how to respond in an experimental situation (e.g., "which linear form do you prefer?"), subjects can rely on any drive, motive or reason when given a simple sensorimotor task whose successful completion is open (e.g., "place a dot anywhere on the figure below in the first place that comes to mind"). Constrained free choice makes it possible to bypass theoretical perceptual awareness—and potential distortions created by attention, introspection, reflection, and reporting. What remains are a different set of skills that constitute practical perceptual awareness. From within this embodied and embedded paradigm, salient features of the perceptual field can be identified by the aggregated sum of what subjects freely do. By observing this behavior, phenomena visible only in bodily space become discoverable and transposable into phenomena recorded in objective space. Also, on this understanding, constrained free choice becomes a way of putting enactive theories of perception to the test. In other words, Merleau-Ponty's curious adage "what we do see is always, in some respect, not seen" can become an experimental question to be answered. Just how much of what we do see is not seen? Please tap the shape, anywhere you like!

The discussion so far has been guided by Gestalt psychology's commitment to the idea that perceptual phenomena tend to have good form—specifically, that shape constancy is indeed an aspect of perception that requires further explanation. But where

[15] It is possible to imagine a subject who, through some cognitive activity, dependably identifies the medial axis of shapes—perhaps someone preternaturally good at visualizing grassfire transformations. Further suppose her reliability never diminishes, even as the shapes become increasingly complex or occluded. Nevertheless, her cognitive way of identifying the medial axis would not be the same as the way that subjects in these experiments responded to the medial axis.

does the discussion leave us with regards to Gestalt psychology's other major commitment, to the psychophysical isomorphism thesis? First, I would like to point out that the experiments presented here do not provide any *direct* evidence of a psychophysical isomorphism between the personal level and the subpersonal level. What was actually found is direct evidence of a surprising connection between two personal level entities: visual shape constancy and bodily sensitivity to a particular invariant structure of shapes (viz. their medial axis). Behavior, like perception, is a personal level phenomenon (Dennett 1969). We not do have to leave the realm of person to interpret these results.

Do the experiments presented here produce any *indirect* evidence of a psychophysical isomorphism—perhaps, in a very circumscribed domain, between visual shape constancy and neurological processes that compute the medial axis of shapes? After all, something must be figuring out this geometry. And it is certainly not the subjects themselves, at the personal level. Here I think it is reasonable to conclude two things.

First, it is likely that there are neurons computing the medial axis of shapes. In addition to Psotka's and Firestone and Scholl's work, other research indicates that the medial axis plays a role in shape perception in human vision (e.g., Kovács and Julesz 1994; Siddiqi et al. 1996; Wang and Burbeck 1998). There is abundant evidence of early-phase sensitivity to shapes generally, but it has proven difficult to distinguish whether this sensitivity is driven specifically by the medial axis of shapes or some other feature. That said, there is some recent evidence of medial axis sensitivity in early visual processing (e.g., Hung et al. 2012; Lescroart and Biederman 2013). There is also some evidence of late-phase sensitivity to the medial axis (e.g., Lee et al. 1998). This suggests there are neurological processes sensitive to the medial axis in earlier stages of visual processing (V1 through V2), in brain areas associated with dorsal stream processing (after leaving V2), or both. Either way, this is consistent with the medial axis of shapes being accessible through practical perceptual awareness.

Second, while there are many possibilities for how neurological processes realize the medial axis of shapes, it comes down to two general hypotheses: *computational transformation* or *topographical transformation*. To explain the difference, most of us cannot do the mathematics involved in the computational transformation of a simple shape into its medial axis (the formulae are daunting). But this is not to say that our neurons cannot 'do the math.' There may be neurons realizing the overall functional state of producing the medial axis as output given the retinal projection and other states as input. The topographical transformation of a simple shape into its medial axis takes a different approach. In much the same way that we might use Blum's grassfire visualization to generate the medial axis of shapes, it deploys a similar trick. There may be an actual location in the brain where shapes are represented and the quench points are determined—cortical fields where tiny analogue grassfire transformations are taking place.

Which of these two transformations do the empirical data support? As already noted, there are only a few experiments aimed specifically at discovering medial axis sensitivity in visual processing. So far as my research has taken me, there are no experiments supporting a computational transformation and only one experiment supporting a topographical transformation, on two rhesus monkeys (Hung et al. 2012).[16] It seems that there is not yet

[16] Even Hung, Carlson and Connor wish to qualify their findings: the areas involved in possible medial axis transformations are "so small that they require fMRI-based targeting for neural recording experiments, so it is unlikely that we sampled extensively from them" (Hung et al. 2012, 1110).

enough data to answer the question of which particular medial axis transformation is being realized by neurological processes. It is still, as they say, an open empirical question.

Gathering together the psychological, behavioral, and neurological data, there appears to be good initial evidence for a token psychophysical isomorphism between visual shape constancy and neurological processes, with practical perceptual awareness of the medial axis of shapes linking these two levels.

6 Conclusion

In this paper, I have presented topics ranging from the phenomenon of shape constancy to medial axis transformation, from constrained free choice to practical perceptual awareness, from psychophysical isomorphism to grassfires in the brain. And I have offered a view on what we see that creates a unified whole out of these aggregate parts. Insofar as subjects are responsive to the medial axis of shapes, they are manifesting a practical perceptual awareness of *visibilia* that are present-as-absent in bodily space, which constitutes (at least, in part) the perceptual phenomenon of shape constancy. We see more than we think we see, as revealed by constrained free choice, as evidenced by our skillful bodily behavior.

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