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ORIGINAL RESEARCH

Measuring up the World in Size and Distance Perception

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Abstract
An empirically based view of size and distance perceptual content and phenomenology is introduced, in which perceivers measure worldly size and distance against their bodies. Central principles of the formal, representational theory of the measurement of extensive magnitudes are then applied in framing the account in a precise way. The question of whether spatial-perceptual experience is "unit-free" is clarified. The framework is used to assess Dennis Proffitt's proposal that spatial setting is perceived in various "units," "scales," or "rulers", some of them non-spatial—distance in terms of calories burned to traverse and the like. The debate between Proffitt and Firestone about the commensurability of differing measurement scales held by Proffitt to be relied on by perceivers is then clarified and resolved. Finally, the measurement theory framed account of size and distance perception is used to illuminate Gibson's famous but elusive contrasts between "geometrical optics" and "ecological optics" and between the "physical world" and the "animal environment".

1 A Motivating Puzzle and an Overview

Comfortable as you are in the presence of your pet dog, imagine being shrunk drastically, as in the movie 'Honey I Shrunk the Kids'.

Now the same dog looms up, enormous. In seeing the dog in this new setting, one's experiences are informative about the dog's size—and, so, about the threat posed (Fig. 1). But how can this be? After all, the dog has throughout remained two feet high (let us say). How then can the new size experience—differing so dramatically—still be informative about the size of the dog? This puzzle motivates the development of an account of the content and phenomenology of size perception. This account is sharpened by appeal to core principles of the formal theory of measurement, and then applied in clarifying some widely discussed empirical projects and philosophical debates.

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The following principle is assumed as a working hypothesis about the perceptual experience of size:

P). Necessarily, one undergoes an experience with a certain size experience phenomenology just in case one represents a certain worldly size property in experience.

Views of this kind are perhaps more common for spatial experience than for color experience. However, this constraint has prominently been doubted for size/spatial experience (see especially, Thompson, 2010, and the response to Thompson in Bennett, 2011). Chalmers (2006, 2019) is more complicated to place; but Chalmers cites Thompson's arguments centrally and sympathetically, and flouts P if "worldly" is read as requiring that the size properties represented in size experience are familiar spatial properties that are or could be properties of viewed objects.[1]

Section 2 introduces an empirically motivated account of size and distance experience optical information, contents, and phenomenology that aligns with principle P. The root idea is that perceivers measure up the world against their bodies, assessing object size and distance in 'eye levels'. Section 3 refines this view of size and distance perception by drawing from the representational theory of the measurement of 'extensive' magnitudes. This spells out the kind of measuring perceivers achieve, including by specifying just what measurement units and scales consist in. Section 4 completes the basic framework, in part by clarifying the (debated) question of whether spatial experience is "unit free". The remaining sections of the paper apply the framework developed—elaborating an empirically supported account of size and distance perception by appeal to the representational theory of measurement—to a range of related questions about size and distance perception. Section 5 assesses

[1] The complex and inventive Chalmers account requires extended exploration. But for present purposes I will assume (pace Chalmers) that the size (here) properties represented in size perceptual experience are spatial properties—that do not somehow differ dramatically in character from familiar conception, and that viewed objects might or might not have. It is worth noting that even if length or spatial structure properties, as somehow ordinarily conceived, aren't fundamental properties on favored interpretations of modern microphysics (say), it doesn't necessarily follow that length and spatial structure properties aren't available to be perceived—or relied on by geologists, engineers, surveyors, and so on (here assuming, (partly) pace Chalmers, that length and spatial structure are not thought of as properties that play certain causal roles, e.g., prominently, in bringing about certain spatial experiences; see, Tsvetkov, ms). 'Being a cat' is not a fundamental property according to contemporary microphysics, but presumably I see and own a cat.

At a minimum, to represent a property in visual-perceptual experience in seeing an object is to *attribute* this property to the object seen. By contrast, on the Campbell (2002), non-representational, "relational" account of experience, the properties present in experience bear only an *instantiation* relation to objects seen. More of course needs to be said about what specifically *experiential* attribution of properties comes to, in order to draw a proper contrast with visually (say) based *beliefs* that attribute properties (see for example Hill, 2009, discussed in Bennett, 2016). But there is a good case to be made that a representationalist approach to perceptual experience allows for a much more natural and plausible account of the nature of perceptual-experiential illusion than is available to deniers (compare Byrne,2009). There is also a good case to be made that a representationalist approach to understanding perceptual experience allows for a smoother fit with much contemporary perception science (Hill, 2009).

P) is compatible with holding that there is an explanatory relation between experiential representation of size properties and size phenomenology, where the latter (or facts in which size-phenomenology properties figure) are present "in virtue of" or are "grounded in" the former. The examples presented below compellingly suggest that the phenomenology of object size experience reflects experiential attribution of certain (specified) kinds of object size properties or relations.

Fig. 1 Frame from the movie, *Honey I Shrunk the Kids*

the empirical researcher Dennis Proffitt's proposal that spatial setting is perceived in various "units," "scales," or "rulers", some of them non-spatial—e.g., distance in terms of calories or the like burned to traverse a viewed extent. Section 6 clarifies and resolves the dispute between Proffitt and Firestone about whether the perceptual system representations hypothesized by Profitt are "commensurable"—and thereby usefully relied on in planning. Finally, in Sect. 7 the measurement theory framed account of size and distance perception is used to illuminate Gibson's famous but elusive contrasts between "geometrical optics" and "ecological optics" and between the "physical world" and the "animal environment".

2 Body-Scaled Size and Distance Perceiving

Height relative to eye level can be determined by perceptually detecting where the horizon cuts objects arrayed on a ground plane shared with the perceiver (Mark, 1987; Sedgwick, 1986; Warren & Whang, 1987; Wraga, 1999a, 1999b; Fig. 2a). The horizon line can be optically specified, either explicitly (with a visible horizon), or in implicit extensions of rays associated with parallel borders (as in looking down an indoor hallway). Proprioceptive feedback about the posture of the body, combined with information about the orientation of the eye in its socket, can also play a role (see Warren & Whang, 1987, and Sedgwick, 1986, for discussion). The ratio to eye-level of non-height object dimensions, like width, can be recovered as well via horizon ratio optical-geometric information, provided the location on the ground surface that the width (say) expanse is directly over can be determined (Warren & Whang, 1987, p. 377).

Size relative to perceiver body dimensions can also be perceptually determined through a size-distance calculation. On this proposal, distance is first determined relative to eye-level through a simple trigonometric relation, working off detection of the angle of declination (illustrated in Fig. 2b below). The motivating observation is that more distant objects on a shared ground plane are presented higher in the visual field (Ooi et al., 2001; Wallach & O'Leary, 1982; Wu et al., 2004; see Fig. 2b). Size relative to eye-level is then gauged by combining this distance estimate with the sensed visual angle spanned by the viewed object, through another simple trigonometric relation (Sedgwick, 1986).

The studies cited above present experimental evidence that human perceivers do rely on these kinds of optical-geometric information in perceiving size and distance.[2]

There is also ready phenomenological evidence that size is perceptually determined relative to perceiver body dimensions (Bennett, 2011). To the ant-sized, the molehill appears a mountain. Much as Gulliver loomed, titanic, to the Lilliputians (but not, say, to his English neighbors). Much as blood clots looked enormous to the adventurers in the movie Fantastic Voyage, miniaturized and sailing through blood vessels. Much as—in our motivating example—the pet dog looms up, huge, to the shrunk children.

Indeed, the answer to our opening puzzle is now evident. Size perceptual experiences do not represent the 'absolute' size or height of the dog—the (here) unchanging two foot expanse. Rather, size experiences represent the relative size or size ratio of the viewed object and the eye-level, body dimension, of the perceiver.

The specific, full contents of such size experiences presumably run something like, '*that* tree is twice *my* eye-height high' (similarly for distance). But you and I might undergo experiences with the same size phenomenology, with our different bodies and looking at different objects. This is presumably because we both represent the same abstract (i.e., non-object-involving), phenomenology-fixing, 'body-scaling measuring relation'—something like, 'object x is twice the eye-height of body y high'.[3]

[2] These are likely not the only sources of size information drawn upon in perceptually assessing the size of objects (Sedgwick, 1986; McKee & Smallman, 1998, are helpful reviews). But for present, exploratory purposes I will write as though these are the only sources of size information in play. Given the compelling phenomenological and experimental evidence that size experience is 'body-scaled' this may not be a great over-simplification. At least regarding viewing objects resting on ground plane within the 30 m or so that "action space" extends. (Wraga, 1999a, 1999b; see Wraga & Proffitt, 2000, for some preliminary determination of what Wraga calls "the zone of eye height utility"; the term "action space" is introduced in Cutting and Vishton 1995; see also, Bennett, 2016).

[3] This general proposal is compatible with a variety of fine grained views about the content of perceived object size experiences. So, perhaps such body-scaling size measuring relations figure in existentially quantified propositions that are elements of experience content. Or perhaps something like—and at least implying—such perceiver-to-object size measuring relations are 'self-ascribed' by perceivers. Maybe size experience contents are simply and only singular propositions in which both perceiving subjects and viewed object figure. Or what-have-you, provided body-scaling size measuring relations are attributed in perceptually experiencing object size.

In the vicinity: in resisting the label "Russellian" Prosser (2011) observes that "in order for represented…[subject and object] relations to have the right significance for the actions of the perceiving subject, they have to be represented in a distinctively first-person way". No doubt that in order to engage and guide action subjects must represent themselves to be related to the objects perceptually sized up in some "first person way". Whatever this comes to exactly; see Peacocke (2014) for discussion. But the point is that if—as I will assume—you and I can undergo experiences with the same size phenomenology, the represented properties or relations that fix this shared phenomenology are not tied to a particular perceiving subject. (I examine Prosser, 2011 more fully in footnote 22 below.).

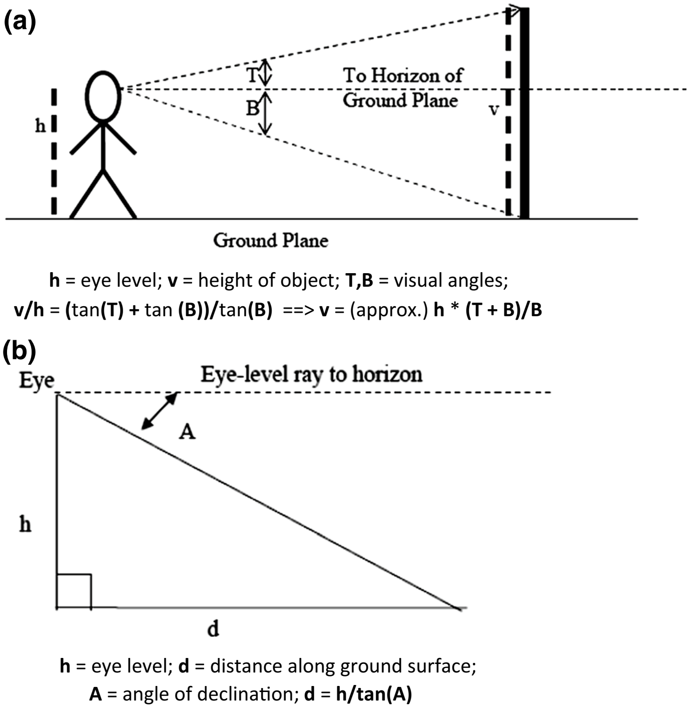


Fig. 2 **a** Size via horizon ratio scaling, **b** distance via angle of declination

I will assume that enduring, worldly object size is represented in experience. As a car pulls away from the curb it takes up a changing extent of sensed visual field. But in addition to these varying ‘size appearances’, enduring worldly size is also present in experience: the car in no sense looks in experience to be shrinking—that would be a different experience. The view that enduring object size (shape, slant, etc.) is represented in experience, in addition to shifting size (shape, etc.) appearances, is widely held in philosophy (cf., Bennett, 2016; Byrne, 2009; Green, 2021; Siegel, 2019) as well as in empirical vision science (cf., Palmer, 1999, pp 313–314, Morales et al., 2020). Framings can differ importantly in details, and this isn’t a universal view (on both, see footnote 4, next). But it’s a widely defended view, and I will assume it.[4] On the account of size (and distance) perception outlined, the

[4] Siegel (2019), for example, concludes, “…we can often easily form justified beliefs about how tall things are or what volumetric shapes they have on the basis of…experiences. The phenomenology of perceptual experience includes the constancies”. However, Siegel is here responding to Hill’s views, who has argued, to the contrary, that only shifting size (shape, etc.) appearances are present in what he details as “experiential awareness” proper (Hill, 2009), and that representation of worldly size (shape, etc.) only enter in judgments that such changing appearances lead to—a view with long historical precedent in both philosophy and psychology. However, Hill (2009, pp 133–134) does at one point suggest the amodal completion of the shape of a cat viewed behind a picket fence as a general model of perceptual constancy. I think this is a good model (see Bennett, 2016, which includes discussion of Hill’s exact use of this example). But this allows for worldly, enduring size (shape, etc.) to be present in experience in a way that Siegel (and others) can accept: in viewing a building behind a thicket of leaveless branches it is the ‘completed’ building wall that is present in experience, not (or not just) building fragments, that are only

phenomenology fixing contents of object size experiences are the just described body-scaling measuring relations (see also footnote 3 above).

It is an obvious consequence of this account of size experience that observers of different sizes relative to their surroundings will typically experientially represent the size of the same object to be different eye-levels high (say). Is this a sign that something has gone wrong? It seems not. While this might initially surprise, surely this *is* a discovery—one readily accepted as an immediate consequence of our opening 'Honey I shrunk the kids' illustration, for example. Moreover, the differing experiential size assessments across subjects will have no practical ill effects. For one thing, we have meter sticks and the like to serve as socially shared size *lingua franca*. It is also quite plausible that reports that a chair, say, "looks" or "appears" 3 feet high employ *epistemic* senses of "looks" and "appears," that describe learned associations of sizes in terms of culturally favored units and scales like feet, yards and the like—which may well not figure in the contents of perceptual experiences of size.[5]

Relevant as well to understanding how social coordination/communication about size is possible, is that experiential assessments of the *relative size* of visually present objects, based on (say) horizon ratio scaling, will be the same across different sized subjects. If I know that an object is *n* eye-levels high against your eye-level 'bodily ruler', this may not help me move to pick it up. But knowing that a fire hydrant, say, looks or appears half the height of a car to you—as gauged by you through a horizon ratio calculation—I can then infer that the fire hydrant will look half the height of the car to me, too, via my own visual-experience, body-scaling assessment, even if we differ in height.

Footnote 4 (continued)

linked in a post perceptual inference. The Hill view that worldly size and shape are recovered by working from shifting size (shape, etc.) appearances—a claim which often accompanies the view that worldly size, shape, etc. aren't represented in experience—is also a contingent and empirical matter. And close examination of relevant vision science research reveals that it is probably not correct, though recording 'shape appearances' does play a role in object recognition (on both, see Bennett, 2016). Following Thouless (1931a, 1931b), Hill stresses as well that shifting size and shape appearances don't closely track visual angle quantities, but instead reflect the influence of perceptual constancy mechanisms. This poses a challenge to (widespread) views understanding size and shape appearances in terms of the representation of visual angle quantities. However, this is an observation about varying size and shape appearances. It isn't by itself an account of how worldly size (shape etc.) is visually (say) recovered, or of whether enduring size (shape, etc.) is represented in experience.

This is to only briefly engage rich topics. But the view that enduring worldly size, shape, and more, are represented in experience is widely held and defensible. The most straightforward readings of the proposals in this paper are as giving the contents of object size and object distance perceptual experiences, which determine object size and distance experience phenomenology.

5 Could, though, over-learned associations of (say) the size in feet (or yards, or meters) of familiar objects intrude into experiential content? This would complicate the over-all story of size perception. But I think such a proposal could be accommodated by treating such learned associations framed in terms of culturally specified scales as an additional source of size information, that is combined with other size assessments gained from other sources (e.g., horizon ratio optical-geometric information; see Bennett et al., 2013, Bennett, ms1, for approaches to "cue combination"). There is also evidence that familiar size associations have little or no effect on size perceptual *experience* (see Sedgwick, 1986 on "familiar size effects"). (This and the next paragraph follow Bennett, 2011 closely.)

The kind of perceptual measuring we have described is importantly like what the engineer does in reaching for a ruler. Only here the ruler is an ‘eye-level marked body’. The body is not literally laid off against the object. But that is the effect, given the viewing geometry. For help in sharpening the approach outlined it therefore makes sense to turn to the classical theory of the measurement of “extensive quantities”, like mass, duration—and length (Warren, 1984; Warren & Whang, 1987). The measurement theory apparatus will help us clarify proposals about size experience contents, in part by clarifying notions of size ‘units’ and ‘scales’. This approach will also help isolate certain differences as well between (say) the upshot size judgment reached about the width of a desk after laying off a yardstick, and perceptually experiencing the width of an opening in determining whether or how to rotate one’s shoulders in order to pass through (see Sect. 7 below).

Notice that in the tradition of empirical psychophysics shaped by Fechner, measurement theory apparatus has instead typically been invoked/developed in modeling perceptual system assessment of psychological/sensory states—say, the intensity of a ‘brightness sensation’ (see Gescheider, 1997 for an introduction; Marks & Florentine, 2011 provides more of the fine-grain). However, everyday perception is directed at gauging *worldly* size and distance, in determining where to sit, when to duck, and so on (compare Warren & Whang, 1987). The classical theory of the measurement of extensive magnitudes was developed in analyzing the core structure of the measurement of such worldly spatial extents.[6]

3 The Formal, Representational Theory of the Measurement of Extensive Magnitudes

Section 2 introduced an empirically well founded account of size and distance perception, in which viewed object size and distance are measured against perceiver body dimensions. Given the size and distance optical information relied on this amounts to ‘laying off’ the perceiver’s body, much as a ruler is laid off in measuring the height of a doorway. To render the account precise, and useful in clarifying

[6] In presenting this material in an interdisciplinary setting I have encountered the following challenge from empirical perception researchers: “You say the visual system is measuring out length against a ’body-ruler’. On your account comparisons of perceived lengths are transitive [see Bennett, ms1]. But perceptual comparisons of length are not transitive. So it is unclear how your account of perceptual measurement applies to human perceivers.” However, relations between the *worldly physical lengths* that objects can have presumably/arguably *are* transitive. This includes ratios of these physical lengths that physical objects do or can bear to each other, and that figure in the relational properties that are represented in size perceptual experiences on the present view. The complaint noted leaves these assumptions untouched. Compare the Krantz et al. (1989, p. 300), first of “Three Approaches to Non-transitive Data”: “A [non-numerical] relational statement [concerning quantities like length or mass], such as a = > b, is not considered to be the record of a particular observation or experiment but is a theoretical assertion inferred from the data, and is subject to errors of inference just like any other theoretical assertion. The problem of measurement theory [on this conception] is to represent such theoretical assertions by numerical ones, such as f(a) = > f(b); the problem of inference, leading from observed data to assertions of the form a = > b is interesting and important but is not part of the foundations of measurement per se” (compare also, Sider ms).

debated questions about size and distance perception, requires carefully specifying what measuring of this kind consists in. To anticipate, for example: we'll see that assessing the rather informal Proffitt claims about perceptual "units", "scales", and "rulers"—where Proffitt uses horizon ratio based size perception as an illustrative example—requires first getting clear about just what a measurement unit and scale is.

Helmholtz (1887) noted that key quantities familiarly measured in empirical settings: (1) admit of ordering in terms of more or less; (2) are combined or "concatentated" in ways that result in aggregates or combinations that also possesses the quantity being assessed. For example, familiar standard or "unit" masses—gram weights/masses, say—might be combined by placing them together in one side or the other of an equal-arm balance. Then the masses of the collection of elements in each pan might be compared by determining which side of the balance, if either, is lower. Similar observations about length can be illustrated in the example of laying off a standard or unit rod end to end (Falmagne, 1985).

Lengths and masses qualify as "extensive magnitudes" in meeting extensive magnitude axioms. These axioms govern a two place relation and an operation (a three place relation), intended as corresponding to the ordering and the combining/concatenating relations that Helmholtz noted hold between elements of certain familiar kinds of quantities. A key analytical/logical aim is to show that—given the arbitrary selection of a "unit" element that is to be mapped to the number, 1—there is a mapping from such quantities to numerical structures that preserves the ordering and concatenation relations governed by the axioms. As a result, the ordering of masses and lengths and durations is reflected in the arithmetic relation of less than or equal to; and the concatenation relation or operation between such quantities is reflected in the arithmetic operation of addition. On this approach, structure preserving mappings *are* measurement *scales*. An immediate consequence is that units of (say) length are themselves lengths or spatial expanses—the expanses selected to be mapped to the number, 1. Or, put in terms of measuring processes (and I will talk both ways[7]): standard or unit rulers that are to be laid off in directly measuring out length must *have* spatial extent. Similarly with mass and with time duration. We'll see that *some* of Proffitt's proposals about the contents of perceptual experience flout these principles (Sect. 5 below), which are at the heart of the representational theory of measurement (Fig. 3).

[7] To say that measurement units for length (say) *are* spatial extents is a consequence of singling out a length or spatial extent to map to the number 1, in constructing a measurement scale. For extensive magnitudes selecting the unit length (or mass, or duration) entirely fixes the measurement scale. This point applies whether measuring is, in some specified way(s), direct or indirect.

The requirement that units or rulers used in "directly measuring out" a length must themselves *have* spatial extent only applies to cases of direct measurement. Think, for example, of laying off a meter stick; or, in measuring mass, think of placing a gram weight/mass on a pan of an equal arm balance. As noted below (this section), much measuring in the sciences is often quite indirect and theory based. But some measuring *does* proceed in a 'direct' way, in a fairly clear and intuitive sense that is illustrated by the foregoing examples. In these cases, this second reading of the stricture that 'measuring must be in units of the quantity measured' also applies, where the physical measuring 'unit mass' or 'unit rod/ruler' must (respectively) have mass and have spatial extent.

These principles of measurement are explored and established with precision in the development of the formal, representational theory of the measurement for (here) extensive magnitudes (Krantz et al., 1971; Luce & Suppes, 2002; Suppes & Zinnes, 1963; important precursors include, Helmholtz, 1887; Hölder, 1901; see Bennett, ms2, for an accessible overview). Here is a summary of further ideas and results that will be drawn on in the present paper.

For given systems of axioms, the theorem which shows that there is a structure preserving ("homomorphic") mapping or scale—of the kind described above—is called a "Representation theorem". The availability of such proofs gives this tradition and approach to measurement its name, because this descriptive label captures the usefulness of understanding measurement in this way: empirical science can draw conclusions about worldly quantities like length and mass through mathematical reasoning and proof because the structure of these worldly quantities is mirrored or represented in the structure of the mathematics employed in reasoning about them.

Uniqueness theorems for axiom systems show how all such mappings or scales for quantities meeting the axioms are related. For extensive magnitudes, all mappings or scales are related by a multiplication by a constant—a "similarity transformation". For example, in relating length assessed in feet to length assessed in inches we might have: 2, the number of feet $=(1/12)\times 24$, the number of inches. This result will prove crucial in clarifying and resolving the dispute between Proffitt and Firestone about whether the measurement units said by Proffitt to be relied on by perceivers are commensurable, and so useful to perceivers in planning (Sect. 6 below).

For extensive magnitudes, each such scale or mapping is entirely determined once a (say) mass or a length is selected as a unit mass or a unit length, to be assigned the number, 1.[8]

Such extensive magnitude scales are called "ratio scales" because similarity transformations preserve ratios of magnitudes. Focusing on lengths: the preserved, invariant ratios reflect underlying, non-number-involving, spatial relations (Field, 1980; Maudlin, 2012). Length or spatial-extent *ratios* are the same regardless of the specific unit, and so scale, selected. These magnitude ratios are therefore not themselves in any way the result of arbitrary social or cultural, decisions, preferences, or practices.[9] This observation will prove important in Sect. 4.2 below in clarifying debate about whether the perceptual experience of spatial extent is "unit free".

[8] Talk about "a mass" (for example) can be ambiguous, leaving it unclear whether the reference is to an object of a certain mass, or to a property that an object does or might have. My language will remain somewhat relaxed in this regard. See Bennett, ms2, where it is noted that the formal theory can be developed in either direction.

[9] To fix an initial picture you can think of such extents as carved out of a classical Newtonian substantival space (see Maudlin, 2012, chapter 1). Maudlin (2012, chapter 2) echoes our observation in the text in noting that it is size or length *ratios* that reflect the underlying, geometric, non-numerical, "metrical structure" of such a space.

Exactly how the earthly engineer's length-measurement assessments point to ground-truth physical properties/facts in a non-Newtonian world is a difficult question that I will not take on in the current paper. My assumption is that when the earthly surveyor carefully assesses local distances and angles, her upshot measurements are in some way accurate, or close. Measuring by a well trained and equipped surveyor is familiarly cited as a model of care and accuracy in measuring.

There are other kinds of scales (or "scale types"), that correspond to axiom systems yielding different uniqueness theorems. For example, Fahrenheit and Celsius temperature scales are related by an *Affine* transformation: deg-Farhenheit = deg-Celsius × (9/5) + 32. Affine transformations preserve ratios of *differences* or *intervals*. Such scales are therefore called "interval scales". However, while it is important to appreciate that there are different kinds of axioms, and correspondingly different types of scales, our focus is, appropriately, on extensive magnitudes. This is because we are out to understand the perception of size and distance. And length or spatial extent is a classical extensive magnitude, along with mass and duration.

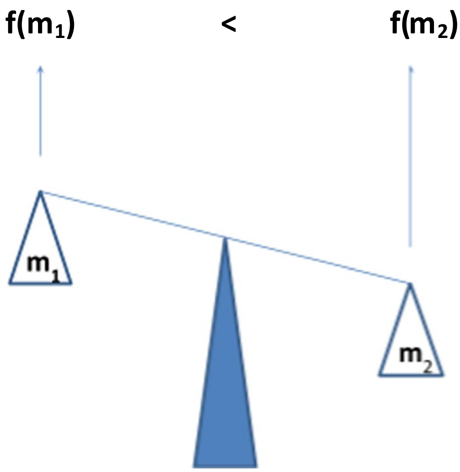
Much actual measurement in the sciences is more indirect than measuring via directly laying off a ruler, or by adding mass elements to equal-arm balance pans. Understanding the use of measurement instruments in science and elsewhere is a rich and complex project (cf. Chang, 2004, Chang & Cartwright, 2008, Tal, 2012, 2013; see also footnote 10 below). However, some basic observations about simple measuring devices will suffice for our purposes. For example, Proffitt and Linkenauger (2013) draw an analogy between perceiving size and distance and the operation of a car fuel gauge, which is a kind of pointer measurement, which is explained next. Noting this will underline that in their appeal to the fuel gauge analogy, the Proffitt and Linkenauger reasoning is mistaken in a key respect (Sect. 5 below).

Consider determining the mass of a Thanksgiving turkey via an old-fashioned spring-based mechanical device (Fig. 4). This is an instance of "pointer measurement" (Suppes & Zinnes, 1963). Intuitively, what is learned in placing the turkey on the tray is the mass or weight of the turkey, in units of mass or weight—grams, kilograms, what have you. Spelling this out: as we've noted, mass satisfies the axioms for extensive quantities, and so is associated with extensive magnitude representation and uniqueness theorems. The core principle behind pointer measurement is that device readings are linked by lawful relations to (here) mass, and so can mirror or indicate the mass of the (here) turkey that is placed on the device. With this kind of spring-based device, needle deflections are lawfully connected to the mass of the turkey via Hooke's law for springs, and the law of gravity. These lawful connections to the masses of objects allows measurement scales—structure preserving mappings of (here) masses to numerical structures—to be mirrored or represented in the deflections of the gauge needle. So, on one familiar choice of unit and scale, a deflection of the needle might indicate the mass of the turkey in kilograms.

Of course, as we've hinted, measuring in the sciences can be still more indirect, with corresponding complexities introduced in the *epistemology* of measurement (again, see Chang, 2004, Chang & Cartwright, 2008, Tal, 2012, 2013; see also Suppes & Zinnes, 1963, on calibrating a measuring device).[10] Measurement readings are sometimes connected to the quantities measured by intricate causal connections, with the measurements only gained by applying a fair amount of physical-science

[10] To give the flavor of the richly complex epistemological issues, here are Chang and Cartwright (2008): "For example, does the standard mercury thermometer measure temperature correctly? In common conception (though not in modern expert practice), the mercury thermometer is a mercury-filled cylinder of uniform bore, calibrated at the freezing and boiling points of water to read 0 °C and 100 °C, with the scale divided up uniformly in-between and extrapolated beyond the fixed points. Such an instru-

Fig. 3 Measuring with an equal-arm balance



theory. Consider, for example, the astronomer, measuring interstellar distance via redshifts, luminosity, or triangulation (and likely more). This observed—and bracketing the corresponding complex questions about the epistemology of measurement—key underlying principles may still be shared with our homey spring-scale example. So, device readings of luminosity may also ultimately constitute a kind of pointer measurement, turning on the lawful link between star luminosity and interstellar distance.

4 Two Final Preliminaries

4.1 Size Representation Content Implies 'Being a Body'

What is given in, for example, horizon-ratio optical-geometric information (Fig. 2a) is, strictly, the *ratio* of object size dimensions to eye-height (compare Warren, 1984).[11] In keeping with our observations in Sect. 3 above: these size ratios are independent of the assessment of object size, or the dimensions of the organism's body, in any particular unit or units—body-based ('eye-levels') or otherwise. However, as

Footnote 10 (continued)
ment would give correct temperatures only if the mercury expands uniformly with temperature. How can we test that assumption? We need to monitor how the volume of mercury varies with real temperature; if the volume is a linear function of temperature, then our mercury thermometer is correct. But how can we get the real temperature values without already having a thermometer that we know we can trust, which is just what we are trying to obtain?".

[11] The ratio is typically taken to be determined by standing eye-height. If, say, the perceiver is sitting, it is straightforward to determine object size relative to standing eye-level, provided the organism has some record of how changes in posture change eye-level relative to standing eye-level. For example, if sitting eye-level is assumed to be half standing eye-level, and horizon ratio geometry specifies that a viewed object bears a 4:1 size ratio to current eye-level, then size relative to standing eye-level is 2:1 (see Wraga 1999a for data and discussion).

we have characterized (Sect. 2) the ‘body-scaling measuring relations’ represented in size experience, object size is compared to dimensions of an organism *body*. So, some property of ‘being a body’ is implied by the relational property represented in the perceptual experience of size. There is as yet still no implication in this about the use of a spatial unit, body based (e.g., ‘eye levels’) or otherwise.

The thought is that such ratio-involving measuring relations are among the key organism/environmental relations that perceptual systems are sensitive to in guiding action (Bennett, 2009; see also Sect. 7 below).[12]

It does seem correct that some sort of non-geometric property of ’being a body’ is represented in size experience. The dog looms over my comparatively tiny, shrunk body. The presence of some such body-involving content allows size perceptual experiences to serve their affordance-indicating role (see Sect. 7 below)—size experiences thereby reveal the fit of the perceiver’s body to (say) prospective openings or passage ways.

That said, the observation that ’being a body’ figures in the content of size (and distance) perceptual experience leaves open just how this body-involving element should be characterized in detail. The current framing provides a place-holder, to be filled, one hopes, by work deriving from the burgeoning empirically oriented philosophical literature on the sensing of perceiver bodies (cf. Gallagher, 2005, De Vignemont, 2006, 2010).

[12] An alternative would be to take body-scaling measuring relations as properties that *fix reference* to spatial lengths that are attributed to objects. I have explored such a view in Bennett (2011). One way to see that this is not a promising interpretation of Proffit’s proposal is to write out the relevant description invoking relative size. This does not correspond well to Proffitt’s use and presentation: “To Gulliver, the Lilliputians and their artifacts seemed tiny, whereas to the Lilliputians the reverse was true. Each perceived extents and size relative to the size of their own bodies” (Proffitt & Linkenauger, 2013). I have also argued that the reference-fixing story is problematic on several grounds just considered as a proposal about size perception content and phenomenology (Bennett, 2009, 2011). In this sense, too, attributing such a view to Proffitt would be uncharitable.

To anticipate: it might be suggested that Proffitt’s talk of representing perceived distance (e.g.) in “units” of energy-expenditure—calories or the like—should be interpreted as proposing that viewed distance is picked out by perceivers via a reference-fixing description like, ‘the spatial expanse that burns such and such calories to traverse by walking’. This proposal is difficult to square with Proffit’s central use, and characterizations of, the case of perceiving size via horizon ratio information. But as a final i-dot, suppose that *all* of the Proffitt claims invoking “units”/“scales”/“rulers” are read as pertaining to ’modes of presentation’ of the sizes and distances of viewed objects—including horizon ratio scaling by eye-height, as well as claims of alleged scaling of size and distance by non-spatial energy/calorie units (and the like). Essentially the same challenges concerning appeals to coding in terms of non-spatial, energy (and the like) “units”/”scales”/”rulers” will reappear, reframed as a challenge to whether such non-spatial units do or could characterize perceptual ‘modes of presentation’. (At least if ‘grasping a mode of presentation’ consists of representing a property in a way that guides reference—which, in a philosophy of perception setting, is allowed by Chalmers (cf., Chalmers, 2006) though denied by Thompson (2010). See Bennett (2011, 2016) for relevant discussion.)

Fig. 4 Spring-based kitchen device

4.2 Clarifying the Question of Whether Spatial Experience is "Unit Free"

A complicating caution: there are grounds to question whether perceptual representation of size (and distance) is in fact entirely in terms of *unit-free size ratios*. Noting this clarifies how to approach the question of whether experience is "unit free".

It can be proved that combining perceptual estimates of size (or distance, slant, etc.) from different sources by taking certain weighted averages, carries computational advantages. For example, a haptic estimate of the width of a tennis ball might be combined in a weighted average with an estimate of the width of the ball gained from stereo visual information. If the individual estimates are weighted inversely proportional to the variability of the source of the estimates (so, if haptic estimates of size are noisier they are weighted less) this maximizes the precision (minimizes variability) of upshot estimates. There is evidence that perceivers do combine estimates in this way (Landyet al., 2011; Bennett et al., 2013; Bennett, ms1). However, 'taking' a weighted *average* requires that the individual estimates that are averaged are framed in a shared unit and scale. It doesn't make sense to talk of taking an "average" of bare ratios.[13]

[13] Here is the point illustrated with a worked example. Suppose that stereo vision yields an estimate that the width of a ball bears a 2:1 ratio relation to perceiver eye-width. Suppose haptic exploration yields an estimate that the width of the ball stands in a 3:1 ratio relation to palm width. On a "linear cue combination" scheme an upshot estimate is arrived at by taking a specific kind of weighted average of these estimates (Bennett et al., 2013). If eye-width and palm width stand in a 1:1 size ratio to each other—i.e., they are the same size—then an average of these differing estimates is meaningfully taken. This is because what amounts to a shared length unit is available in specifying that eye-width and palm width are the same.

If, instead, the ratio of eye-width to palm width is 2:3, then to meaningfully average these estimates a 2:3 'transformation ratio'—relating eye-width to palm-width—must be applied. This amounts to translating the two estimates into a shared unit and scale prior to the weighted averaging. Since length admits ratio scales, we know that this can be done through a multiplication by a constant (Sect. 3 above). So: multiplying, (2/3) × 3 palm-widths transforms the palm-width estimate into the needed, shared, eye-width units.

It is true that Field (1980) has argued that it is possible to do "Science Without Numbers"—in essence, sticking purely to geometry (compare Peacocke, 2015, who works from Scott, 1963). There may be a

This observed, even if there is assignment of measurement units in performing perceptual system computations like averaging, it does not strictly follow that perceptual experience contents traffic in measurement units or scales, as opposed to ratios only. My treatments of the Proffitt and Gibson projects allow for size experience contents to involve body-based units and scales, but are for the most part not committed to this thesis.[14]

5 Proffitt and Multiple Perceptual Units or Scales

Proffitt and collaborators have reported many studies that they interpret as showing that distances experientially look greater, and slopes experientially look steeper, if subjects are burdened and/or if they are fatigued (and—much—more, in a similar vein).[15] A key element of the theoretical apparatus presented in Proffitt and Linkenauger (2013) is that perceivers are held to "scale" the spatial world in terms of multitude different "units" or "rulers"—some determined by organism body structure ("morphological"), others determined by (for example) physiological state, concerning how tired or energized the perceiver is ("physiological" or "behavioral" units).

The central, illustrative example deployed by Proffitt—in this paper with Linkenauger and also in talks—is horizon-ratio based perception of object size relative to perceiver eye-level or eye-height (Fig. 2a above). Such eye-height scaling is, for Proffitt, an example of a "morphological" measuring "unit" or "scale". Perceptual measuring in terms of arm length and grip expanse are also offered as examples of "morphological" scaling—with (the idea is) differing such scales or "rulers" invoked depending upon behavioral aims and needs (to pass through an opening, to pick an object up, and so on).

The summary assessment about such morphological units is straightforward: in a traditional measurement theory framework, such morphological measures are

Footnote 13 (continued)
specifiable sense in which this is possible in principle (see Greenberg, 2008, pp. 169ff, who points to Hilbert, 1899/1971, and to contemporary refinement in Hartshorne, 2005). But what is relevant to understanding perceptual system aims and contents is not what is possible in principle, but how perceptual systems do operate. The preceding worked example suggests that natural and efficient perceptual processing requires a shared unit and scale.

[14] As pointed out to me by Jeremy Goodman, unfortunately Bennett (2011) slid incautiously back and forth between claims that size experience content involves object to eye-level size ratios, and claims that (standing) eye-level is a privileged unit in perceptually assessing object size. These are not the same, even if it is granted that (say) eye-level or standing eye-height would be a convenient choice of unit if there is to be coding in a specific scale. The distinction becomes clear with the measurement theory apparatus in place, as this clarifies just how to understand measurement 'units' and 'scales'.

[15] There is at times some ambiguity in Proffitt-group presentations about whether they are proposing views about size/distance/slant perception or views about (claimed) 'direct' perception of affordances (passability, climb-ability, and the like). However the participants in the empirical studies conducted by Proffitt and collaborators are probed about the former—for example, "how steep is the hill?" (compare Firestone, 2013). As noted in Sect. 7 below, there is good reason to think that the relevant affordances are recovered through perceptually recovering spatial size and structure relative to body-dimension(s).

perfectly coherently in the running as possible measurement “units” in perceptually assessing size and distance. This is because such units are or have spatial extents—the same quantity being measured. As we saw in Sect. 3 above, this reflects a basic feature of the measurement of extensive magnitudes, including spatial extent.

However, the same cannot be said of the Proffitt-group proposals about perceived spatial expanses in terms of “physiological” and “behavioral” “units” or “rulers” (their terms)—e.g., distances in terms of the calories or the like to be burned in traversing. On the Suppes, Luce, and others measurement theory approach, these claims reflect an apples and oranges category mistake. Spatial expanses are held to be gauged relative to “units” or “rulers” that are not—or do not have—spatial extents. But for extensive magnitudes like spatial extent (and mass, and duration) a measurement scale is a mapping between lengths (or masses or durations) and numbers, that is fixed in associating the number ‘1’ with a “unit” spatial extent (or mass or duration). This might be observer eye level, in which case the measurement unit would be observer ‘eye levels’. But it could in principle be perceiver eye width or grasp size, for example. However, whatever the extent selected to be mapped to 1, spatial extents will be measured in spatial extent units—inches, eye levels, eye widths, or what have you.

This observed, proposals covering the same Proffitt-group research projects that motivate their claims of non spatial units can be reformulated in ways that don’t flout central measurement-theory principles. And that are still interesting, if less daring-sounding. So, it might be proposed that when perceivers are tired things look farther away, on a body-scale representation of distance (compare, indeed, Proffitt, 2006).[16] Or perhaps it will proposed that energetic state shapes the perceptual representation of affordances, like ‘walkability’. These are interesting and coherent empirical theses, if controversial.

Proffitt and Linkenauger (2013) do draw an analogy between the use of fuel gauges and the perceptual scaling of distances in terms of calories or the like. While this analogy might be apt in understanding function serving aspects of perceptual response (see below), pace Proffitt and Linkenauger this analogy does not show that perceived sizes and distances can be coded in non-spatial units.

Of course in planning actions organisms might well usefully determine how much energy would likely be used in traversing the distance to a viewed object. Recognition of this bit of scientific common sense might give the Proffitt and Linkenauger claims about fuel gauges, calories, and visual-perceptual measuring some initial plausibility. However, such a blandly sensible general hypothesis is to be sharply distinguished from the proposal that spatial extents are represented in perceptual experience in terms of non-spatial units. It is important to see that the fuel gauge analogy is of no help establishing this conclusion.

Car fuel gauges indicate fuel level. Assessment of fuel expended could figure in the construction of an *odometer*, detailing distance *traveled*. But that is not what is wanted (this would also not yield distance traveled in non-spatial units). It is true

[16] See, though, Firestone (2013) and Firestone and Scholl (2014,2015) for doubts that any such proposal is correct.

that information about fuel level can be combined with distance information to arrive at assessments of 'what a driving setting affords'—whether Topeka is accessible by driving, say. This is a pretty good model of how some affordances are likely determined (Sect. 7 below). But this assumes that distance has been gleaned already. No insight is provided into how the needed distance assessment is arrived at, or what form it takes.[17]

There are, moreover, reasons of general principle for thinking a fuel gauge model isn't going to help explain how calories or the like can be used to perceptually scale size or distance. Measuring using fuel gauges is a form of pointer measurement (Sect. 3 above). Recall that pointer measures of the weight or mass of a turkey placed on a spring-based kitchen device are in units of *weight* or *mass*. The underlying principle at work is a general principle of the measurement of extensive magnitudes, including pointer measurement: pointer measures of size or distance will yield assessments of size or distance in terms of spatial-extent units.

6 Ratio Scales and Commensurability: the Proffitt and Firestone Debate

Firestone (2013) notes that if we grant that spatial quantities can be assessed in terms of radically different "units"—say, caloric units, along with eye-levels—there will be a question of how options about how to act are weighed in deciding what to do. One might similarly worry about how estimates from different sources could be pooled in improving the precision of perceptual assessments of size and distance (Sect. 4.2 above). Ruling out calories and the like as determining size and distance units and scales at the least narrows worries. But it remains that size is said to be yielded in a number of different body-based units—eye levels, eye-width (in using

[17] Around this point in the discussion/dialectic the proposal is sometimes encountered that coding of the perceived distance of (say) a visually present tree is in terms of the estimated number of steps required to walk to a viewed object. Step number is (the idea goes) associated with the traverse via past experience. Somehow this suggestion is supposed to help rescue the Proffitt proposal that spatial expanse can be perceptually represented in non-spatial units.

There are several ways to make such a proposal more precise. None serve to rescue the Proffitt proposal. It is, first, possible that distance is in fact perceptually represented in terms of step lengths. Empirical plausibility aside, this is a coherent hypothesis because a step length unit is a spatial unit. But this observation provides no support for holding that distance is perceptually represented in non-spatial (caloric, etc.) units.

Perhaps organisms come to associate perceived traverses with likely energy expended in part by counting steps. But this is not a claim about the content and phenomenology of experience, and there is no evident way to turn it into one.

Tracking the number of steps already taken might serve as a kind of *odometer*. Again, this has no bearing on the question of experience content and phenomenology.

Finally, I have heard it proposed that coding in terms of step number might somehow figure in a pointer measurement of perceived distance. I have no clear idea how this idea might be unwound. But given our Suppes inspired treatment of pointer measurement (Sect. 3), there is no rescue on offer here for the Proffitt proposal that perceived size and distance are sometimes represented in non spatial units, like calories.

stereo information, say), perhaps also grip size, reach length, or step size.[18] And if any such variety of units and scales are employed,[19] one might wonder how these different measures could be combined in pooling estimates and coordinating actions.

The way forward lies in the observation that measurement of length (like mass) admits of ratio scales. Recall that one ratio scale can be transformed into another by a—ratio preserving—similarity transformation, consisting of multiplication by a constant. In this setting, translating from eye-levels to (say) grip-widths is achievable in principle simply through multiplication by a constant. How the organism might gain and store such 'transformation constants'—and update them as the organism grows—is not an easy matter to determine. But there is at least no in-principle challenge in making such transformations, and thereby making needed combinations and comparisons.

7 Gibson: the World of the Geometer-Physicist and the Perceived World

Gibson (1979) distinguished the world of the geometer-physicist from the perceived environment. So, in his (1979) Gibson contrasts the "physical world" with the "animal environment," and "geometrical optics" with "ecological optics". The proposed distinction can seem perplexing—don't we live in and perceive the world that is studied by the physicist?

I won't here attempt a detailed, scholarly-obedient unpacking of Gibson's meaning in making these distinctions.[20] Drawing upon the framework developed and applied in preceding sections, I note a way of marking a contrast between the contents of size perceptual experience and the contents of certain judgments about spatial extent that result from measurement. The proposed contrast fits the spirit of Gibson's remarks, and is a possible precisification of them.

Stepping back, we can distinguish questions about the contents of:

(i) Size (and distance) perceptual experiences.
(ii) Introspective assessments of size phenomenology.
(iii) Measuring judgments—say, after measuring out the width of a desk using a yardstick.

[18] Here assuming coding in size units, and not just in terms of size ratios (see Sect. 4.2 above).

[19] In some sense, grasping and reaching must be appropriate to size and extent relative to grip size and arm length. But note that it does not follow that either is reflected in the contents of perceptual experiences.

[20] This would not be straightforward. Gibson (1979) does introduce, qualitatively, the idea of horizon ratio scaling (pp. 162–164; see especially Fig. 9.6); Gibson (1979) also cites the 1973 dissertation of his student Hal Sedgwick ("The visible horizon: A potential source of information of the perception of size and distance"; see Sedgwick, 1980). However, empirical research specifically exploring whether/how horizon ratio information is used in perceiving object size mostly came later. See especially Warren and Whang (1987), Marks (1987), and Wraga (1999a, 1999b).

(iv) Assessments in perceptual judgment of the sizes and distances of objects as one looks out across a scene.

I will have nothing to say, here, about (ii) contents, a difficult issue. Basically, I will be proposing we understand Gibson as suggesting, in his contrasts, that contents of sort (i) and contents of sort (iii) contrast in an interesting and illuminating way.

As briefly noted earlier, Gibson and Gibson-influenced researchers have stressed that organisms are importantly geared to extract information about ecologically significant relations between perceivers and environments (Bennett, 2009). These relations include direction of heading (Warren & Hannon, 1988), time to contact (Lee & Reddish, 1981)—and body-scaling size or distance measuring relations (Sect. 2 above). The Gibsonian idea is that perceptually detecting such organism-environment relations serves centrally in determining what a setting offers or affords the perceiving organism. For example, in assessing whether an opening is a passable expanse relative to the perceiver, width of the opening relative to body-dimensions must be determined.[21]

It might seem that Nanay (2012) doubts whether the perception of affordances runs through the perception of size or other spatial properties or relations. However, Nanay distinguishes between perceiving, which he holds can be unconscious, and perceptually *experiencing* (compare, Burge, 2010, Kanwisher, 2001; see Bennett, 2022, for discussion). This allows that the spatial properties or relations whose presence underlies what the environment affords might be detected unconsciously. And Nanay argues that in neurological cases of "neglect" perceivers can perceptually *experience* affordances—say, 'passibility' in confronting an opening—without perceptually *experiencing* underlying spatial structure, like the width of an opening (which on the account of size and distance perception presented in Sect. 2 above would be represented relative to perceiver eye level). That said, Nanay's claim that these neurological subjects perceptually experience affordances without perceptually experiencing underlying spatial structure is surprising and may be false (see Yamamoto, 2017). But even if it is granted that these neurologically compromised patients recover affordances without experiencing the underlying worldly spatial structure, the centrality to everyday perceiving for *normals* of the perceptual experience of worldly size, distance (slant, and so on) suggests that Nanay's generalization to normals is, very, shaky.[22]

[21] Compare Gibson (1966, p. 285): "When the constant properties of constant objects are perceived (the shape, size, color, texture, composition, motion, animation, and position relative to other objects) the observer can go on to detect their affordances". However, Yamamoto (2017) discusses other passages, mainly from later work, in which Gibson does appear to maintain that affordance content is at the least more salient and more readily perceptually recoverable than the associated, underlying spatial properties.

There is also the question of whether affordance properties are themselves represented in experience, as opposed to, say, only represented in spontaneous but post-experiential judgment. Gibson is not quite explicit on this issue. However, the Gibson (1979) language quite strongly suggests that at least by the time of his last book, Gibson felt that perceptual experience is saturated with affordance content.

[22] Prosser (2011) defends a view where affordance properties like 'passability' figure in experience phenomenology. It is not straightforward to compare Prosser's proposals to the account we've developed, as Prosser does not discuss the relevant empirical literature in any detail (he does claim—without argument—that studies by Warren and by Mark provide support for the view that affordances are represented

In any case, compare the recovery of body-scaling size measuring relations in perceptual experience with the contents of size judgments reached in laying off a yardstick that a desk is, say, ‘3 feet wide’, or ‘36 inches wide’, or what have you. In this assessment in judgment there is no reference to live bodies or the like; whatever the physics/metaphysics of the spatial extents attributed are, presumably they do not consist in relations borne to live human bodies. Nor, for that matter, is there any evident sense in which the width property attributed in such measuring judgments implies anything about specific measuring operations. Diagnostic of this: the length properties attributed in (here) judging the width of a desk in applying a yardstick can be assessed and attributed across endless differences in measuring tools and methods (compare Suppes & Zinnes, 1963; Luce & Suppes, 2002; see also Bennett, ms2).

Of course, it is no simple matter to say just what the nature is of the ‘lengths’ or ‘spatial extents’ that are thereby attributed. This issue is an object of study for physicists and philosophers of physics. As with physical mass, such spatial extents are likely not essentially number involving (cf. Maudlin, 2012; Sider, 2011)[23]—if, however, picked out under ‘guises’ or ‘modes of presentation’ that are number involving (say, as ‘3 feet’ or as’36 inches’). For our purposes, we don’t need to take a stand about exactly what such ‘guises’ consist in, and the exact role they play in judging (and perhaps communicating) that desks and tables and so on have certain spatial dimensions. To capture the Gibson contrasts we can rest with the plain-fact observation that such yardstick, etc., applying judgments just do pick out lengths or spatial

Footnote 22 (continued)

in experience). It is important to distinguish the claim that body-scaling size measuring relations fix size experience phenomenology, from the question of whether corresponding affordances like passability are represented in experience. The former is likely; we’ve remained non-committal about the latter. Prosser appears to collapse this distinction, perhaps due to a very wide official conception of what an affordance is: “An affordance, as I shall use the term, is a relation between a subject and an object that depends on the causal powers of the subject and, in many cases, the causal powers of the object”(p. 479).

The following passage is also revealing:

"…We can assume that Max’s and Min’s experiences continue to be veridical. Consequently each subject’s experience represents a tree of the same size at the same distance, subtending the same visual angle…" (Prosser, 2011, p. 488; here, Min is a much smaller than Max, and is viewing the same object as Max from the same distance.).

On our account, it may well be true that both experiences are veridical. This is so when both experiences correctly represent the viewed object as standing in the size ratio that it bears to each of the perceiver’s eye-levels (say). However, the size ratios correctly represented will be very different given that Min and Max’s bodies differ in size. As a result their size experiences will also differ phenomenologically.

This as background, Prosser’s argument in the following is to be resisted:

“…Max and Min will have experiences with different phenomenal characters when looking at objects of the same size at the same distance, and therefore the same visual angle…Consequently, …it [is] clear that spatial phenomenal content is not made up of purely spatial properties such as sizes, distances, or visual angles.”

This is a non-sequitur. Applying the account we have developed in the way just sketched, explains how and why size experience phenomenology differs, just because each perceiver represents differing spatial properties, in the form of differing relative sizes.

[23] See also Sects. 3 and 4 above.

extents and attribute them to desks and doorways. And that the spatial-extent properties attributed do not consist in relations to the bodies of perceivers.

This observation is enough to draw a contrast between the contents of such measuring judgments and—on the account developed—the contents of size perception experiences. The contrast seems to correspond to Gibson's distinction between the "world" of the engineer-geometer and the "world" of the animal environment. On the view we have developed, in undergoing size experiences perceivers attribute body-scaling measuring relations, like 'object x is twice the eye-height of body y high'. These size relations attributed in size perceptual experiences concern ratios between the sizes of viewed objects and dimensions of the body of the perceiving subject. Unlike the spatial extents attributed in measurement judgments, the body-scaling measuring relations attributed in size experiences *are* body involving. For one thing, such perceptual, body-scaling size measuring relations imply the property of 'being a body' (see Sect. 4.1 above). In representing such body-scaling measuring relations in experience, the affordance-determining fit of the world to subject body dimensions is assessed.

In measurement judgments the engineer thus makes contact with a cold, hard, world that exists beyond human interests and purposes. By contrast, in perceptual size-scaling the organism experientially assesses ongoing fit to its ecological niche.

8 Summing Up

We began with a puzzle: why the dramatic and seemingly informative shift in experienced object size with changes in perceiver body size, even though (in our opening example) the object seen—the family dog—remains the same two feet high? The best explanation is that experienced size does not reflect the unchanging, two feet, 'absolute' object size, but instead the relative size of the object viewed to perceiver body dimensions like eye-height. This kind of size ratio is specified in available optical-geometric light information. And such relative size is ecologically important to determine: the two foot high dog poses an existential threat to the shrunk kids, but not to the dog's normal-size masters.

An innovation in the current study has been to draw from the formal representational theory of the measurement of extensive magnitudes in spelling out the kind of measuring achieved in such size and distance perception (see also Peacocke, 2015). In developing our measurement theory informed framework we clarified the debated question of whether spatial experience is "unit free". Applying the framework, we were able to clarify, assess, and—where needed—reframe, Proffit's interpretation of empirical studies as indicating that perceivers represent spatial extents in terms of a range of differing "units", "scales", and "rulers". The Proffitt claims about "morphological" "units", "scales" or "rulers"—eye-levels, arm lengths, and so on— make cohering sense as hypotheses to explore about the perception of spatial extents. The Proffitt claims about non-spatial ("caloric" or what have you) "units", "scales", or "rulers" do not, as they flout core principles of the (Suppes, Luce, etc.) formal theory of measurement in claiming that measurement of spatial extents can be in non spatial units. These latter Proffitt claims can, however, be recast in ways that are compatible with measurement theory principles, and are still interesting (if controversial) empirical hypotheses. The foregoing lessons established, a response is also available to the Firestone concern that Proffitt posits representation of "units" and "scales" that are incommensurable, and so can't be relied on in planning actions: the *spatial* units relied on in perceiving size and distance, as ratio scales, are in principle related by a multiplication by a constant (that is, by a similarity transformation). Finally, in turning to Gibson's famous but elusive contrasts between the "physical world" and the "animal environment," and between "geometrical optics" and "ecological optics," our measurement theory informed framework suggested an interesting difference between the contents of size experience and the contents of size judgment, that captures the spirit of Gibson's contrasts. In representing size and distance relative to body dimensions, perceptual experiences reveal whether and where there are need-serving fits of perceiver body to environmental setting—and so the "animal environment". By contrast, the craft-person laying off a yard-stick, as well as the engineer checking the structure of a bridge, lead to measuring judgments that only immediately concern coldly geometrical spatial expanses. These bear no inherent relation to the aims and needs of embodied perceivers. If a connection is made to such needs and aims through measuring judgments it is as a result of reflective and sometimes theory-involving calculation.

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