HEAVINESS OR MOVEABLENESS? IS PERCEPTION SENSITIVE TO HIGH-ORDER, ACTION-RELEVANT PHYSICAL VARIABLES?

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Abstract

Since Weber's initial investigations into heaviness perception, psychophysics has primarily focused on the mapping between low-order, behavior-irrelevant physical variables to sensations. An alternative strategy is to evaluate perceptual sensitivity to higher-order, physical variables of direct significance to the perceiver's activities. Research over the past 15 years on heaviness perception illustrates the advantages of the latter strategy and the significance of such a strategy in accounting for the richness of experience.

Psychophysics has historically focused on the mappings between simple (behavior-neutral) physical variables (e.g., mass, light amplitude/wavelength, sound amplitude/frequency) and their corresponding sensations (e.g., heaviness, brightness/color, loudness/pitch). This approach is motivated by the assumption that "such relations are fundamental for the apprehension of "secondary" properties" (Runeson, 1977, p. 175). Interestingly, humans are remarkably bad at judging simple physical variables and when perception does not reliably correspond to simple physical variables (e.g., when two different physical stimuli map to the same percept [metamers] or when two stimuli that are identical along a single physical dimension are perceived as different [i.e., illusions]) this is typically attributed to the subjective nature of perception (see Shockley, Carello, & Turvey, 2004, and Turvey, Whitmyer, & Shockley, 2001, for a more detailed discussion).

Gibson (1979) claimed that because simple physical variables do not capture behavior-relevant structure in our environment, they should not be the foundation of a theory of perception designed to account for the richness of behavior. He argued that perceptual systems must be sensitive to complex physical variables that are inherently meaningful with respect to the behavior of a perceiving-acting system (i.e., without interpretation or inference). In the spirit of this argument, Runeson (1977) suggested that perceptual systems should be conceptualized as "smart devices" that are directly sensitive to higher-order, behavior-relevant structure, rather that rote computational devices that operate over simple physical variables detected through the senses. He proposed a metaphor of the polar planimeter—a physical device that is designed to directly measure the higher-order variable surface area without any computation over lower order variables (e.g., extents). Implicit in Runeson's argument was the assumption that the typical psychophysical strategy of evaluating the mappings between simple, behavior-irrelevant physical variables and sensations undermines the possibility of discovering such smart perceptual devices. Evidence for direct sensitivity to higher-order, behavior-relevant structure will be discussed in the in the context of heaviness perception, the domain of perception in which Weber's (1834/1978) initial psychophysical investigations were conducted.

Heaviness Perception: The Size-Weight Illusion and Rotational Inertia

Heaviness perception has defied scientific understanding for over a century. Although Weber's (1834/1978) initial psychophysical investigations showed a systematic relationship between the mass of an object and perceived heaviness, subsequent investigations revealed that object mass is not sufficient to account for impressions of heaviness of wielded objects. A dramatic illustration of this can be found in the size-weight illusion (SWI) first identified by Charpentier (1891). In the SWI, two objects of equal mass will feel differentially heavy as their size (i.e., volume) changes—larger objects feel lighter than smaller objects.

The SWI phenomenon has historically been attributed to cognitive accounts such as variants of percept-percept coupling or cognitive expectations of mass based on size (see Amazeen & Turvey, 1996, for a review). However, Amazeen and Turvey (1996) proposed an alternative account based on the fact that heaviness perception via dynamics touch (i.e., via active wielding) is informed by deformations of the muscles and tendons involved in rotating an object about a joint. They considered an alternative physical variable to mass—rotational inertia. Rotational inertia (*I*) is a higher-order variable that captures the resistance of an object to rotational acceleration and is a function of both the mass of an object and its distribution about the point of rotation. In its simplest characterization, $I = mass \cdot d^2$, where *d* is the distance of the center of mass from the point of rotation (e.g., the wrist for an object wielded with the hand). Of particular significance is the fact that *d* changes as a function of changes in volume (i.e., size) for a given mass. Amazeen and Turvey (1996) reasoned that the changes in heaviness perception observed in the SWI may, therefore, be attributed to the changes in rotational inertia that accompany changes in size. They examined the mass distribution of typical SWI objects and found a distinctive pattern of changes in rotational inertia about the three intrinsically defined spatial axes of the objects. They reproduced this distinctive pattern using specialized objects of unchanging linear dimensions, but whose mass distribution could be manipulated. In other words, they reproduced the same patterns of *I* for objects that produce the SWI with no corresponding changes in object dimensions. The found the same pattern of results for heaviness perception as is observed in the SWI with no changes in the volume of the wielded objects. The implication is that the influence of mass distribution (i.e., *d*) in heaviness perception has historically been misattributed to volume (i.e., size) when the actual variable relevant to heaviness perception was rotational inertia.

Proper Function

Although inertia models neatly account for heaviness perception, they raise the question: Why *should* heaviness perception map to rotational inertia? Rotational inertia is not heaviness and, therefore, appears to offer a theoretical account that is no more parsimonious than traditional cognitive theories based on mass and size. It is important to recognize, however, that invoking the term “heaviness perception” presumes that heaviness is the relevant phenomenological variable. The fact that perceivers report on a certain variable designated by a scientist does not prove that this is what is actually perceived (Runeson, 1977; Shockley et al., 2004; Sjöberg, 1968; Turvey et al., 2001). What is more likely is that perceivers are reporting on a variable to which they are sensitive in order to conform to the task imperative to best of their ability. To borrow from Runeson’s (1977) polar planimeter example, if one is asked to measure length using a polar planimeter (which is designed to measure surface area and functions poorly as a ruler), he or she can use the tool to measure length, however inaccurately their measurement may be. At issue is what Millikan (1984) described as the proper function of the perceptual system in question. In the present context, what is the function of the dynamic touch perceptual system that that it has executed successfully in the history of one or more species to warrant reproduction? A reasonable guess is that the system was designed to register variables that are informative for wielding objects effectively (Shockley et al., 2004; Turvey, Shockley, & Carello, 1999). I, by definition, is just such a variable. The rotational inertia of an object about its three spatial axes specifies what forces must be applied and in what directions to wield an object in a particular way. The implication is that what is perceived when wielding an object is its maneuverability or moveableness, which corresponds directly to I. Shockley et al. (2004) addressed the hypothesis that heaviness perception is more properly the perception of maneuverability by asking for perceptual reports of both heaviness and moveableness of wielded objects. They found dimensions of heaviness and moveableness to be perceptually equivalent and both to be a function of the patterns of I.

Complex, Action-Relevant Variables versus Subjectivism in the Lived Experience

Importantly, I is not only a complex, higher-order physical variable that is behavior-relevant, it is also a function of how an animal interfaces with the object. For example, an object of a given mass and mass configuration will feel differentially heavy depending upon where it is grasped. At first glance, this phenomenon appears to exemplify the subjective nature of perception because the same physical object is perceived differently under different circumstances. However, this conclusion only follows if we assume that the simple variable mass is the relevant physical variable. If, however, the dynamic touch perceptual system is sensitive to a higher-order, complex variable that specifies how forces must be patterned to effectively wield the object, then an object should feel different depending upon the point of grasp because grasp changes d and, therefore, I. In spite of the fact that the same object is perceived differently depending on how it relates to the animal does not reflect perceptual error or subjective experience. Rather, it reflects a change in a legitimate complex, physical variable whose structure is a function of both the physical properties of the object and how the animal interfaces with the object. As illustrated by the misleading consequences resulting from the assumption that a simple, physical variable (mass) is the variable relevant to heaviness perception, the classical assumption of the mapping between simple physical (and by implication, animal-independent) variables to sensations as the proper basis of perception often precludes consideration of complex, action-relevant variables to which we may be directly sensitive. The latter possibility offers the opportunity to discover direct mappings between physical variables and behavior.

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References

Amazeen, E., & Turvey, M. T. (1996). Weight perception and the haptic size-weight illusion are functions of the inertia tensor. *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 213-232.

Charpentier, A. (1891). Analyse experimentale de quelques el¬ements de la sensation de poids [Experimental study of some aspects of weight perception]. *Archives de Physiologie Normales et Pathologiques*, *3*, 122-135.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Millikan, R. (1984). *Language, thought and other biological categories*. Cambridge, MA: MIT Press.

Runeson, S. (1977). On the possibility of “smart” perceptual mechanisms. *Scandinavian Journal of Psychology*, *18*, 172-179.

Sjöberg, L. (1968). When can the subject be trusted not to think? *Scandinavian Journal of Psychology*, *9*, 274-276.

Shockley, K., Carello, C., Turvey, M. T. (2004). Metamers in the haptic perception of heaviness and moveableness. *Perception & Psychophysics*, *66*, 731-742.

Turvey, M. T., Shockley, K., & Carello, C. (1999). Affordance, proper function and the physical basis of perceived heaviness. *Cognition*, *73*, B17-B26.

Turvey, M. T., Whitmyer, V., & Shockley, K. (2001). Explaining metamers: Right degrees of freedom, not subjectivism. *Consciousness and Cognition*, *10*, 105-116.

Weber, E. H. (1978). *The sense of touch* (H. E. Ross Ed. and Translator). London: Academic Press. (Original work published 1834).