SHORT AND SWEET

When can an object feel heavier than itself? Perceived heaviness of a wielded object depends on grasp position

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Received 7 October 2011, in revised form 8 November 2011

Abstract. Perceived heaviness is a function of how an object resists being moved, and such resistance is determined by the object’s mass and how that mass is distributed relative to the wrist. Therefore, perceived heaviness should vary with how that mass is distributed relative to the wrist. Therefore, perceived heaviness should vary with grasp position. Blindfolded participants wielded internally weighted objects while grasping them at different distances from the centre of mass. They rated how heavy each object felt at each location relative to a standard object. The results show that objects felt heavier as they were grasped farther from the centre of mass, highlighting the role of the touch system in controlling movement.

In one of the first discoveries of experimental psychology, Weber (1834/1978) found that the relationship between mass and heaviness is imperfect but systematic. Subsequent investigations highlighted this finding by uncovering the “size–weight illusion”—that two objects of the same mass can feel unequally heavy depending on how those objects are constructed (Charpentier 1891).

Recently, research has sought to explain both (i) the imperfect but systematic fit between mass and heaviness and (ii) the size–weight illusion by explicitly linking perceived heaviness to the fundamental role of the touch system in generating and controlling movements (eg Shockley et al 2001). Wielding an object requires applying muscular forces so as to overcome that object’s resistance to being moved. Such resistance is determined by the object’s mass and how that mass is distributed relative to the wrist. Other things being equal, as mass increases and the centre of mass (CM) of the object is located farther from the wrist, larger and more diverse muscular forces are required to move an object, and, subsequently, the heavier that object feels. Moreover, when two objects of the same mass feel unequally heavy, it is because the combination of mass and mass distribution make one object more difficult to move than the other (Shockley et al 2004).

Although changing grasp position on a given object will not change its mass (and will not change its weight, given that weight equals mass times the gravitational constant), it will change how the mass of that object is distributed relative to the wrist. Therefore, changing grasp position on an object ought to influence perceived heaviness and generate a phenomenon similar to the size–weight illusion—ie the same object will feel more or less heavy depending on where it is grasped. We investigated this hypothesis.

Three hollow wooden rods (60 cm long, 1.27 cm outer radius, 0.64 cm inner radius) were partially filled with a column of lead shot and then ‘capped’ by two dowels such that the lead was contained between the dowels and the CM of each object coincided with its geometric centre (ie 30 cm from either end of the rod). Two objects were test objects—one was one quarter filled and weighed 344 g and the other was three quarters filled and weighed 740 g. A third object was the standard. It was half filled and weighed 542 g.

Blindfolded participants (N = 12) sat at a right-handed student desk with their forearm on the desk and wrist just beyond the desk edge. On a given trial, a participant
grasped and wielded the standard followed by a test object. He or she then rated how heavy the test object felt relative to the standard (which had an assigned value of 100). The standard was always grasped at its CM. Test objects were grasped at one of five locations along their lengths (10 cm, 20 cm, and 30 cm from either end). Given that the CM of each object was 30 cm from either end, each test object was grasped at three different distances from its CM (0 cm, 10 cm, and 20 cm). There were no limits on time or number of alternations between test and standard. Participants were unaware of the number of objects or that test objects were grasped at different locations.

A 2 (mass: 740 g vs 344 g) × 3 (distance from CM: 0 cm vs 10 cm vs 20 cm) analysis of variance was conducted on perceived heaviness. A main effect of mass found that the 740 g object (\(M = 155.73\)) felt heavier than the 344 g object (\(M = 56.1\)) (\(F_{1,11} = 87.78, p < 0.001\)). A main effect of distance from CM showed that objects felt differently heavy at different grasp positions (\(F_{2,22} = 19.19, p < 0.001\)). Pairwise comparisons found that objects felt heavier when grasped 20 cm from the CM (\(M = 119.4\)) than when grasped 10 cm from the CM (\(M = 104.3\)) than when grasped 0 cm from the CM (\(M = 94.1\)) (all corrected ps < 0.025). The interaction between mass and distance from CM was not significant (\(F < 1\)) (see figure 1). The results show that perceived heaviness increased as mass increased and as objects were grasped farther from the CM.

Grasping an object in a particular location creates a hand–object system with a particular dynamical symmetry (the distribution of mass relative to where it is held; Turvey et al 1999) and particular control dynamics (the pattern of forces required to control the object). Grasping the same object at a different location (potentially) creates a hand–object system with an entirely different dynamical symmetry and entirely different control dynamics (Wagman and Carello 2003). The results of this experiment show that, under some circumstances, such changes are sufficient to change how heavy a given object feels. Thus, when the same object feels unequally heavy at two different grasp positions, it is because the mass distributions created in each case make the object more difficult to move at one grasp position than at the other. Similarly, participants choose to grasp a tool closer to its CM with increasing precision constraints on the tool use task (Wagman and Carello 2003).

In general, the findings of this experiment bolster the claim that phenomena described as heaviness illusions (such as the size–weight illusion) are less a reflection of erroneous perceptual processing and more a reflection of the fundamental role of the touch system in generating and controlling movements (Wagman et al 2007).
Acknowledgments. The research reported here was supported by an Illinois State University Faculty Research Award awarded to Jeffrey B Wagman.

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