

The Size-Weight Illusion is not anti-Bayesian after all

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Summary: When we lift two objects of the same weight but different sizes, we expect the *larger* to be heavier, but the *smaller feels* heavier. This Size-Weight Illusion (SWI) cannot be explained by differential motor forces[1], and has been labeled “anti-Bayesian” because it opposes simple Bayesian predictions utilizing a “larger is heavier” prior. However, we report that this previously-considered Bayesian framework for the SWI neglects crucial information available to observers.

We present a competitive prior model, in which objects’ expected weight relationship is based not only on their size difference, but also on their inferred density relationship. Until now, studies of the SWI have assumed observers believe two similar-looking (same visual material) objects have equal density. However, our previous work demonstrates this assumption is flawed: smaller objects in the environment are denser than larger objects, and humans’ perceptual systems appear cognizant of this relationship[2]. Therefore, we postulate that when faced with two similar-looking objects, the nervous system examines competing hypotheses regarding their relative densities.

We measured observers’ (1) expectations under “equal density” and “smaller is denser” scenarios and (2) SWI magnitude. The model reproduces the basic illusion, and explains the finding reported in the literature that illusion magnitude grows with larger size differences. Moreover, the model predicts (1) the degree to which an individual believes smaller objects are denser correlates with his SWI magnitude; and (2) after training with “small-heavy” and “large-light” objects, illusion magnitude is attenuated and ultimately reversed[3]. Ours and others’ psychophysical experiments validated both predictions.

These findings demonstrate that the SWI is not anti-Bayesian as previously claimed, unifying the SWI with the sensorimotor literature and demonstrating that it, too, can be explained by competitive-prior Bayesian inference that can account for other illusions such as the ventriloquist and sound-induced flash illusions.

Model: The density relationship between two objects, A and B with volume relationship $V_A < V_B$ can be described as belonging to one of three categories: (R_1) $d_A = d_B$; (R_2) $d_A > d_B$; (R_3) $d_A < d_B$ with d being the density of each object. Then, the a priori probability of each of these relationships $p(R)$ will vary by observers’ visual assessment of the objects’ relative sizes and materials.

The posterior probability of each density relationship given incoming haptic information about weight, $p(R|x_h)$, where x_h represents the haptic sensory evidence of the ratio of the weight of A to the weight of B , $w = \frac{w_A}{w_B}$, is then assessed via Bayes’ rule:

$$p(R|x_h) = \frac{p(x_h|R)p(R)}{p(x_h)} \quad (1)$$

For $p(x_h|R)$ we obtain:

$$p(x_h|R) = \int p(x_h|w)p(w|R)dw \quad (2)$$

The likelihood $p(x_h|w)$ was modeled by a Gaussian function $\sim N(\mu_w = 1, \sigma_w)$, where μ_w is the true weight ratio $w = \frac{w_A}{w_B}$ (which is 1 in SWI experiments). Priors $p(w|R)$ were estimated through the behavioral experiments described below. Assuming a mean-squared-error cost function, the optimal estimate of the felt heaviness of the two objects’ weights, \hat{w} , is found through model averaging:

$$\hat{w} = p(R_1|x_h) * \hat{w}_1 + p(R_2|x_h) * \hat{w}_2 + p(R_3|x_h) * \hat{w}_3 \quad (3)$$

where \hat{w}_i refers to the optimal percept for R_i , found via:

$$\hat{w}_i = \int w p(w|x_h, R_i)dw = \int w \frac{p(x_h|w)p(w|R_i)}{p(x_h|R_i)}dw \quad (4)$$

Behavioral methods: We conducted a series of experiments to determine the *priors* $p(S|R_i)$ under each R as well as the magnitude of the SWI itself. Each experiment included 30 new observers. All experiments used stimuli consisting of 3 sets of 4 sizes of cubes (2", 3", 4", and 6" on a side; sets of 150g, 350g, and 550g) covered in balsa wood with small handles affixed to the top. Observers were asked to make judgments about the ratio of the weights or volumes for pairs of cubes. *Experiment 1:* Observers were asked to judge the cubes' relative volume without touching them, (*priors* in R_1). *Experiment 2:* Observers were told that the small cube was denser than the larger (but not by how much), and asked to guess their weight ratio, again without touching them (*priors* in R_2). Observers then returned on a second day to lift the same pairs of cubes and judge their weight ratio (*small/large*, thus a response > 1 indicates the smaller feels heavier, as is typical in the SWI) to validate Prediction 1: Individuals whose Day 1 answers indicated they expected larger density asymmetry as a function of size experienced stronger SWI magnitude on Day 2. *Experiment 3:* Observers performed the same procedure as *Experiment 2* Day 2, to collect a pure measure of SWI magnitude for model fitting purposes. Finally, Prediction 2 was validated by using training parameters from Flanagan and colleagues[3] to predict the result of training with their small-heavy and large-light object stimuli. The magnitude of the predicted illusion reversal from our model matches the magnitude of the illusion reversal reported in their study.

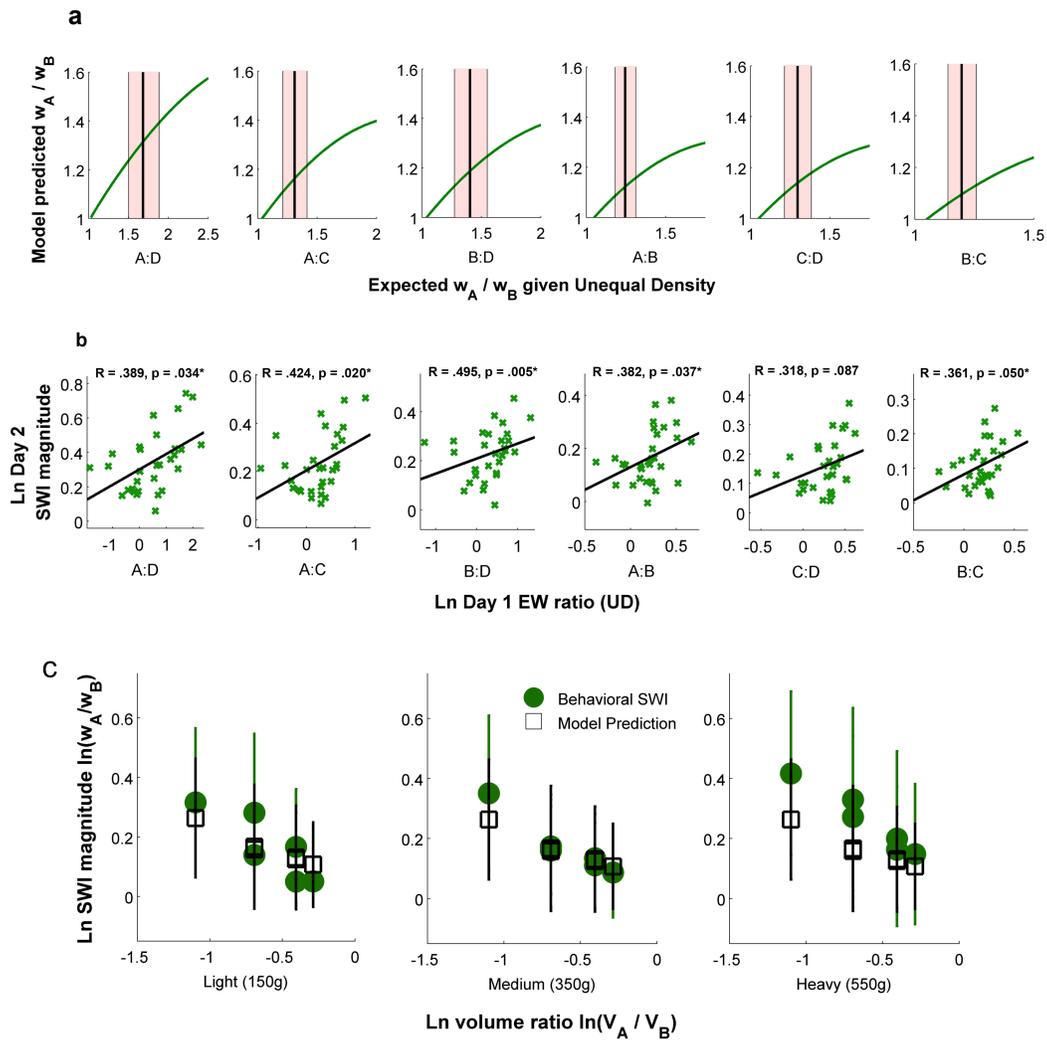


Figure 1. (a) Prediction 1 and (b) confirmation of Prediction 1. (c) Model fitting results show good fit to behavioral data.

References

- [1] Flanagan & Beltzner. *Nat Neuro* **3**, 737-741 (2000).
- [2] Peters, Balzer, & Shams. Biases in human density perception mirror the natural distribution of object density (submitted).
- [3] Flanagan, Bittner, & Johansson. *Curr Bio* **18**, 1742-1747 (2008).