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Thirst modulates a perception

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Abstract. Does thirst make you more likely to think you see water? Tales of thirsty desert travelers and oasis mirages are consistent with our intuitions that appetitive state can influence what we see in the world. Yet there has been surprisingly little scrutiny of this appetitive modulation of perception. We tested whether dehydrated subjects would be biased towards perceptions of transparency, a common property of water. We found that thirsty subjects have a greater tendency to perceive transparency in ambiguous stimuli, revealing an ecologically appropriate modulation of the visual system by a basic appetitive motive.

1 Introduction

The probabilistic framework for vision hypothesizes that the brain generates a percept that is its 'best bet' as to what is the source of the proximal stimulus (Helmholtz 1867/1962; Gregory 1997), and has received renewed interest in the last decade, with significant applications in a number of areas within visual perception (Knill and Kersten 1991; Nakayama and Shimojo 1992; Freeman 1994; Kitazaki and Shimojo 1996; Knill and Richards 1996; Brainard and Freeman 1997; Anderson 1999). In experiments within this framework the proximal stimulus is varied, thereby varying the probability distribution over the set of possible sources, and consequently changing the predicted percept. What a 'best bet' is, though, depends on more than what is probable and what is not; it also depends on the ecologically determined costs and benefits involved, or the *utilities.* If the probabilistic framework for perception is legitimate, it should be possible to devise an experiment where the probability distribution of the possible sources of a stimulus is kept constant, but where the utilities are experimentally modified and perceptions change in a predictable fashion. The most obvious way to carry this out is to have an experiment where the stimulus set is kept constant (and thus so is the probability distribution over the set of possible sources), but where the internal state of the subject is modified in such a way that the utilities are altered. This is the task we set ourselves, and we were specifically interested in utilities being altered by naturally occurring appetitive states.

Some interesting research exists on this score, but none is ideally suited for our aims. By communicating what we feel is missing from the existing research, we can distinguish more clearly the intent of our study. In one kind of study, subjects at various degrees of food abstinence were presented ambiguous stimuli, and it was found that food-restricted subjects had a greater propensity to make food-related interpretations (Sanford 1936a, 1936b; Levine et al 1942; McClelland and Atkinson 1948; Epstein 1961). The main difficulty with these kinds of studies as evidence for utility affecting perception is that it is not clear that the experiments are about perception at all. Rather, they are about the associations subjects make, and they appear to be of a more cognitive sort. For example, a picture of a smiling, seated baby with an outstretched finger was interpreted, by various subjects, as "pointing at one of his toys", "sticking his thumb in the pie", or "playing in the tub" (Sanford 1936a). Since no toy, tub, or pie was in the picture presented, it seems that it is, at a minimum, a stretch to say that these subjects *perceived* the baby to be pointing at one of his toys, or to be sticking his thumb in the pie. At any rate, we would like to show that modifying the utilities can alter something that is more obviously, or straightforwardly, perceptual. In another kind of study, subjects viewed ambiguous stimuli, stated what they perceived, and were explicitly rewarded for certain responses and punished for others (Proshansky and Murphy 1942; Schafer and Murphy 1943; Haggard and Rose 1944). These studies seem to be more clearly about perception than the earlier ones, but leave us a bit worried that subjects may just be saying what they must in order to get the reward. Also, anyone who has stared at bistable figures, such as the Necker cube, for very long will notice that he/she can, to a limited extent, control which of the two percepts is active; one can obviously do this when rewards are offered and penalties levied. A third inadequacy of this kind of study for our purposes is that we are interested in modifying the utility by modifying ecological appetitive states, not by explicit punishment and reward. There is a third kind of study where evidence was provided that poor children overestimate the size of coins more than do rich children (Bruner and Goodman 1947). While it is plausible that poor and rich children's utilities differ, it is plausible that their experiences are sufficiently different that they also differ, for any given proximal stimulus, in their probability distributions over the set of possible sources of the stimulus. This is not suited for our purposes because we are interested in modifying only the utilities, not the probabilities. Finally, there are studies on the effects of utility on perceptual categorization (eg Bohil and Maddox 2001), but these kinds of studies emphasize *categorization*, not perception, and the utility is not via natural, appetitive states.

In sum, we wanted an experiment where we could modify the utilities, but not the probabilities, and modulate perception in a predictable manner; but also (a) where the perception is 'basic' enough to be straightforwardly perceptual, (b) where we avoid worries about the subjects just saying what we want them to, or perceiving what they are rewarded to perceive, and (c) where the utility is due to ecological, appetitive states. In attempting to devise an experiment satisfying these constraints, we first recognized that thirst is a naturally occurring appetitive state, is easy to induce in human subjects, and would thus be experimentally convenient. What perceptual change would be expected of thirsty subjects? One obvious answer is that we might expect thirsty subjects to be biased towards perceiving water: it is better for one who is thirsty to mistakenly see water in a place where there is none than to mistakenly not see water in a place where there, in fact, is water. The reason for this is as follows. If the thirsty person sees water, then there are two possibilities: (i) water is actually there, in which case things are very good (utility $= 10$) because he will survive; (ii) water is not there, in which case things are moderately bad (utility $= -1$) as he will spend some time before realizing the mistake. If, on the other hand, the thirsty person does not see water, the possibilities are these: (iii) water is actually there, in which case this is very bad (utility $= -10$) because he may have missed out on the only water in the area; (iv) water is not there, in which case this is moderately good since he keeps searching (utility $= 1$). There is not much to gain and a lot to lose by not seeing water, whereas there is a lot of possible gain and little cost for seeing water—it is therefore rational for the thirsty traveler to be biased toward water interpretations. If thirsty observers more probably see water, we expect them to be *biased towards perceptions representing scenes having properties typically indicating the presence of water*; this is what we take 'being biased toward water perceptions' to mean. Transparency is one property that is almost invariably associated with water; ie water is typically transparent. We therefore expect thirsty subjects to favor perceptions of transparency in stimuli that are ambiguous as to whether there is a transparent, and thus fluid-like, surface—whether or not there is a water interpretation. However, when a stimulus is not ambiguously transparent—ie either it is overwhelmingly probable that the scene has a transparent surface, or overwhelmingly improbable—then we expect all subjects to behave similarly. Perception of transparency is straightforwardly perceptual, satisfying one of our demands. Also, subjects do not know how they are 'supposed' to respond, as there is no obvious association between thirst state and transparency.

2 Method

In the experiment, seventy-four subjects were divided equally into a thirsty group [they ate one lunch bag of salty chips immediately before the experiment (1.25 oz or 35 g, 190 kcal, 350 mg sodium)] and a non-thirsty group (they drank water until not thirsty immediately before the experiment), and tested on one of two stimulus sets: set 1 (forty subjects) and set 2 (thirty-four subjects). Set 1 consisted of 72 stimuli (of the form shown in figure 1) with a circular pattern in which there were 18 'definitely' transparent, 36 'ambiguously' transparent, and 18 'definitely not' transparent stimuli (for example, see figure 2). Set 2 consisted of 64 stimuli (of the form shown in figure 3) with a rectangular pattern in which there were 20 'definitely' transparent, 24 'ambiguously' transparent, and 20 'definitely not' transparent stimuli (for example, see figure 4).

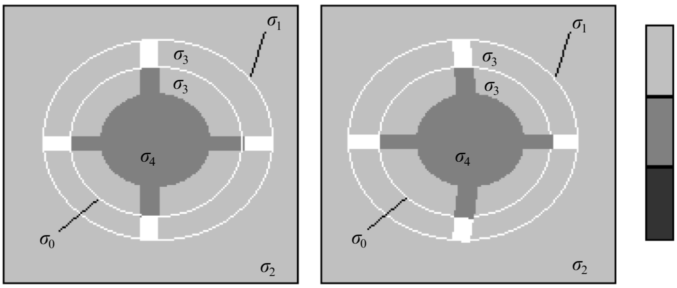
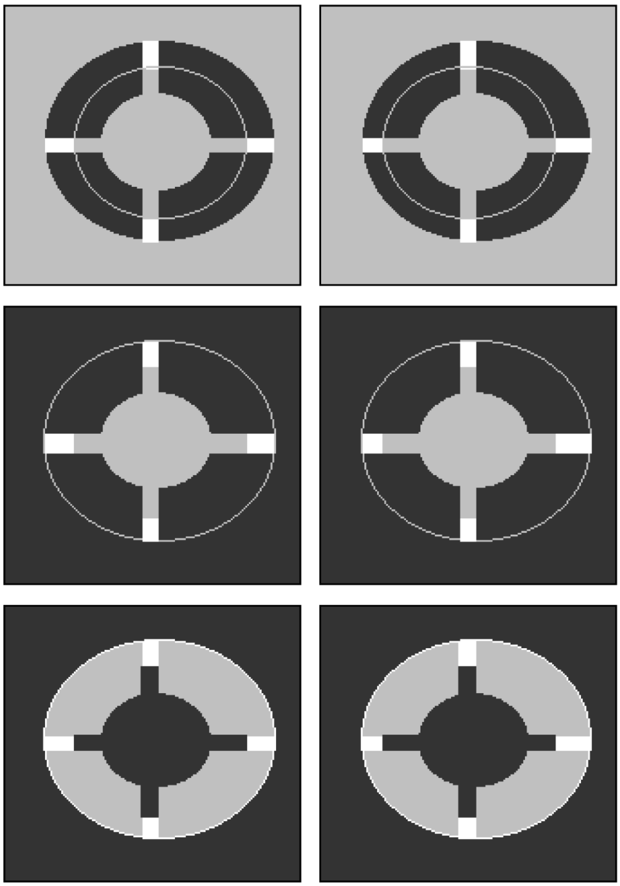


Figure 1. Description of stimulus set 1. The stimuli were presented in random order. The reader may see the images with divergent viewing. To do this, focus your eyes on a point behind the stimulus. You will see two copies of what is on the page—thus four squares—one pair of squares on the left and one pair on the right. The trick is to get the right square of the left pair to overlap the left square of the right pair. The overlapped squares will fuse into a single percept with three-dimensional qualities. A sample stimulus from set 1 is shown. This one is ambiguously transparent: one can sometimes perceive a very clear transparent surface embedded in the inner white circle. Generally, in these stimuli, if there is a transparent surface, it is perceived to be covering the portion of the image surrounded by the inner white circle. The σ_i variables indicate aspects of the stimulus which are varied to make the 72 images from this stimulus set. σ_0 indicates whether or not the white inner ring is included; it is present in this image, but, for example, is not present in figure 2b. σ_1 denotes whether or not the outer white ring is set to appear closer to the observer than the inner ring in such a way that the resulting percept is of a 'glass' seen from above; it is present in this image, but, for example, is not present in any stimulus from figure 2. The remaining three parameters refer to the relative luminance of three distinct regions of the stimulus; each parameter can take on any one of the three luminance levels shown to the right: σ_2 is for the area surrounding the outer white ring, σ_3 for the area inside the outer white ring but not including the radial arms or the innermost circle, and σ_4 for the area within the innermost circle and the portion of the radial arms within the inner white ring (whether or not the ring is actually present). σ_3 and σ_4 are constrained to have different luminances; there is therefore always a luminance discontinuity along the radial arms. There are therefore $3 \times 2 = 6$ possible combinations for σ_3 and σ_4, and thus a total number of possible stimuli of $2 \times 2 \times 3 \times 6 = 72$. There are two conditions here that are necessary and jointly sufficient for a definitely transparent stimulus: (a) $\sigma_3 < \sigma_4$ (where '$<$' means darker), and (b) the existence of the inner white ring. Both (a) and (b) are satisfied in 18 stimuli, and these are definitely transparent; neither (a) nor (b) are satisfied in 18 stimuli, and these are definitely not transparent; the remaining 36 stimuli satisfy one of (a) or (b) and are ambiguously transparent (as in this one).



(a) (b) (c)

Figure 2. Three example stimuli from stimulus set 1. (a) An example stimulus that has very high probability that it is due to a scene with a transparent surface. (b) An example stimulus for which the probability that there is a transparent surface is neither very high nor very low. (c) An example stimulus with very low probability that it is caused by a scene with a transparent surface.

All stimuli were stereograms because this presentation technique enhances the perception of transparency and provides a relatively unique visual display to engage subjects' attention. Stimuli were viewed at a computer terminal with the aid of a prism-based stereoscope, which was positioned approximately 1 ft (30 cm) in front of the computer screen; disparities were constant for each stimulus set. To check that subjects could properly view in stereo, they were asked to describe the three-dimensional relationships on a test stimulus; all subjects passed this test. Readers may visualize the images that subjects saw using divergent viewing of figures 2 and 4. Subjects used the computer mouse to press a 'transparent' button if they perceived a transparent surface in the image, and pressed a 'not transparent' button if they did not perceive a transparent surface.

After the experiment, subjects were asked to report their degree of thirst on a 1 – 5 scale from 'not at all thirsty' to 'very thirsty'. Thirst-rating for thirsty subjects was 3.17 (SEM 0.17), and for non-thirsty subjects was 1.71 (SEM 0.15). For the purposes of this experiment, we were not concerned with whether the increased thirst resulted from a fluid balance shift (eg cellular dehydration from the salt load of the snack)

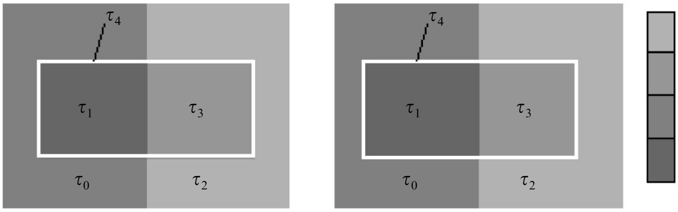


Figure 3. Description of stimulus set 2. The stimuli were presented in random order. A sample stimulus from set 2 is shown. This one is definitely transparent: it is very difficult not to perceive a horizontal, tinted, transparent rectangle floating in front of the background. Generally, in set 2, if there is a transparent surface, it is perceived to be a horizontal, rectangular surface floating out in front. The τ_i variables indicate aspects of the stimulus which are varied to make the 64 images from this stimulus set. τ_0, τ_1, τ_2, and τ_3 denote the relative luminance of the four regions depicted. For the definitely transparent stimuli the four regions may be any of these luminances subject to the constraints that (i) $\tau_1 < \tau_0$, (ii) $\tau_3 < \tau_2$, (iii) $\tau_0 < \tau_2$ if and only if $\tau_1 < \tau_3$, and (iv) $\tau_0 \neq \tau_2$, $\tau_1 \neq \tau_3$, $\tau_0 \neq \tau_1$, $\tau_2 \neq \tau_3$. (i) and (ii) ensure that the transparent surface reduces the luminance due to the background surface, (iii) ensures that the luminance order of both surfaces is the same, and (iv) guarantees that each of the four regions is distinguishable. (See also Metelli 1974 and Masin 1997.) Only ten variations satisfy these constraints: namely $\langle \tau_0 \tau_1 \tau_2 \tau_3 \rangle$ equal to $\langle 1021 \rangle$, $\langle 1031 \rangle$, $\langle 1032 \rangle$, $\langle 2031 \rangle$, $\langle 2032 \rangle$, $\langle 2110 \rangle$, $\langle 3110 \rangle$, $\langle 3210 \rangle$, $\langle 3120 \rangle$, and $\langle 3220 \rangle$, where 0 through 3 denote the four luminance levels (3 being the highest luminance). τ_4 refers to the status of the frame of the floating, horizontal rectangle. For each of the 10 definitely transparent stimuli there are two variations—with (eg the stimulus in this figure) and without a white rim (eg figure 4a)—making 20 definitely transparent cases. 20 definitely not transparent stimuli were created by swapping the luminance of τ_1 and τ_3; when this results in either $\tau_0 = \tau_1$ or $\tau_2 = \tau_3$, a black frame is placed around the floating rectangle to distinguish it from the background (eg figure 4c). Finally, ambiguously transparent stimuli were made by having all combinations of luminances subject to the constraints that $\tau_0 \neq \tau_2$, $\tau_0 = \tau_1$, and $\tau_2 = \tau_3$; ie the luminances on any given side are uniform, but are different from the luminance on the opposite side (eg figure 4b). There are 12 cases satisfying this, but we also allow the rectangular frame to be either black or white, making for 24 ambiguously transparent cases. In total, there are thus $20 + 20 + 24 = 64$ stimuli in set 2.

or from the peripheral or conditioned effect of eating something that tasted salty or produced a dry mouth; we were only concerned that a subjective state of thirst was present. Is it possible that there may be some other consequence of eating salty chips that is the source of the effects on perception? Although there are a number of consequences of eating salty chips, most them appear to be part of the subjective state of thirst. For example, one consequence is the greater degree of dry mouth, but the feeling of having a dry mouth is part of what subjects may mean when they say they are thirsty. Another consequence is the greater degree to which they have a salty taste in their mouth, but this, again, is one of the feelings that is part of the subjective state of cellular thirst. As a last example of a consequence of eating salty chips, subjects could report having a lesser degree of hunger. Hunger was not controlled in subjects, but since the bag of chips is only 1.25 ounces (35 g), the differences in hunger state between subjects in the thirsty and non-thirsty condition should be minimal. At any rate, the feeling of having recently eaten is also highly associated with the subjective state of thirst, since most food is dehydrating; thus this feeling of recently having eaten food may also be part of the feeling of being thirsty. The basic point here is just that subjects recognized they were in a different 'thirst' state as a result of having eaten the chips.

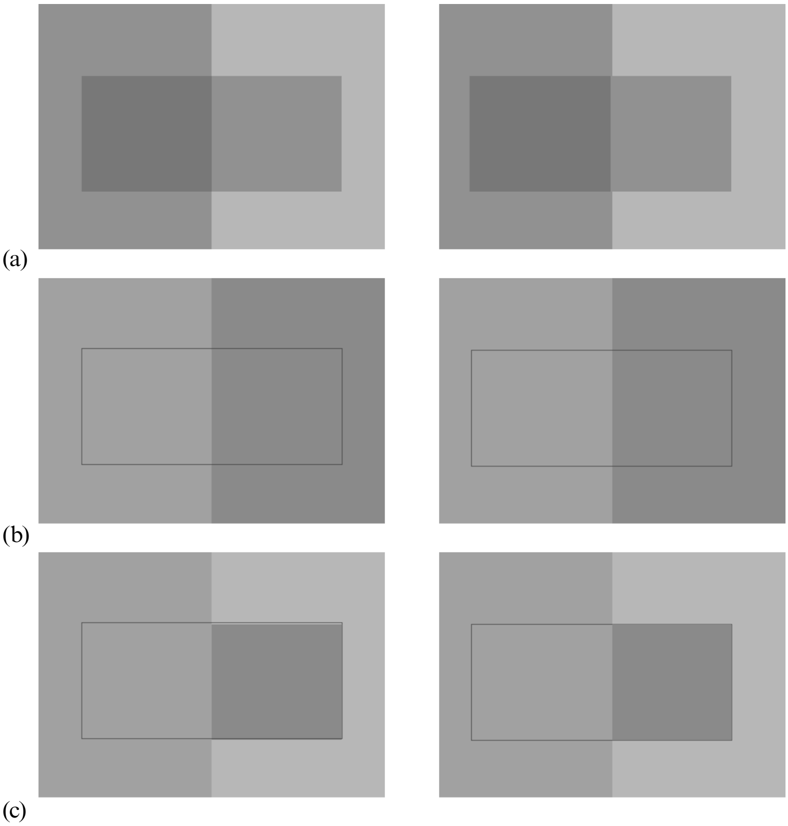


Figure 4. Three sample stimuli from stimulus set 2. The legend is similar to that of figure 2.

3 Results

We found that the modest thirst resulting from the consumption of a single lunch bag of chips caused subjects to show a greater inclination to perceive transparency in ambiguously transparent stimuli (figure 5, middle column). Also, as expected, there was little or no overall difference between thirst conditions for the 'definitely transparent' and 'definitely not transparent' stimuli (figure 5, bottom left and bottom right panels); these results provide some confirmation of the legitimacy of our categorizations of stimuli into definitely, ambiguously, and definitely not transparent. An overall measure of thirsty subjects' greater tendency to see transparent surfaces was the average number of ambiguously transparent stimuli perceived to have a transparent surface, reported as percentages in the legend for each panel. The average for all thirsty subjects is 58% (SEM 3.8%) but for non-thirsty subjects is 47% (SEM 3.9%). An examination of the distribution of responses in the cases of stimulus set 1 and the set of all ambiguous stimuli shows that the frequency histograms are roughly normal, and there is a clear shift towards transparency for thirsty subjects ($t_{20} = 2.24$, $p < 0.05$ for set 1; $t_{37} = 2.09$, $p < 0.05$ for all stimuli). The distribution of responses for ambiguous stimuli in set 2 was not normal—it is, instead, multimodal—and a t-test is inappropriate, although it again shows a strong shift of responses by thirsty subjects to favor transparency (59% for thirsty subjects, 47% for non-thirsty subjects), providing a strong replication of the results from stimulus set 1.

The multimodality of the frequency distribution of stimulus set 2 suggests that subjects may, to a degree, be settling on certain 'perceptual rules' for determining which stimuli are transparent. In the simplest and most extreme possible case of this

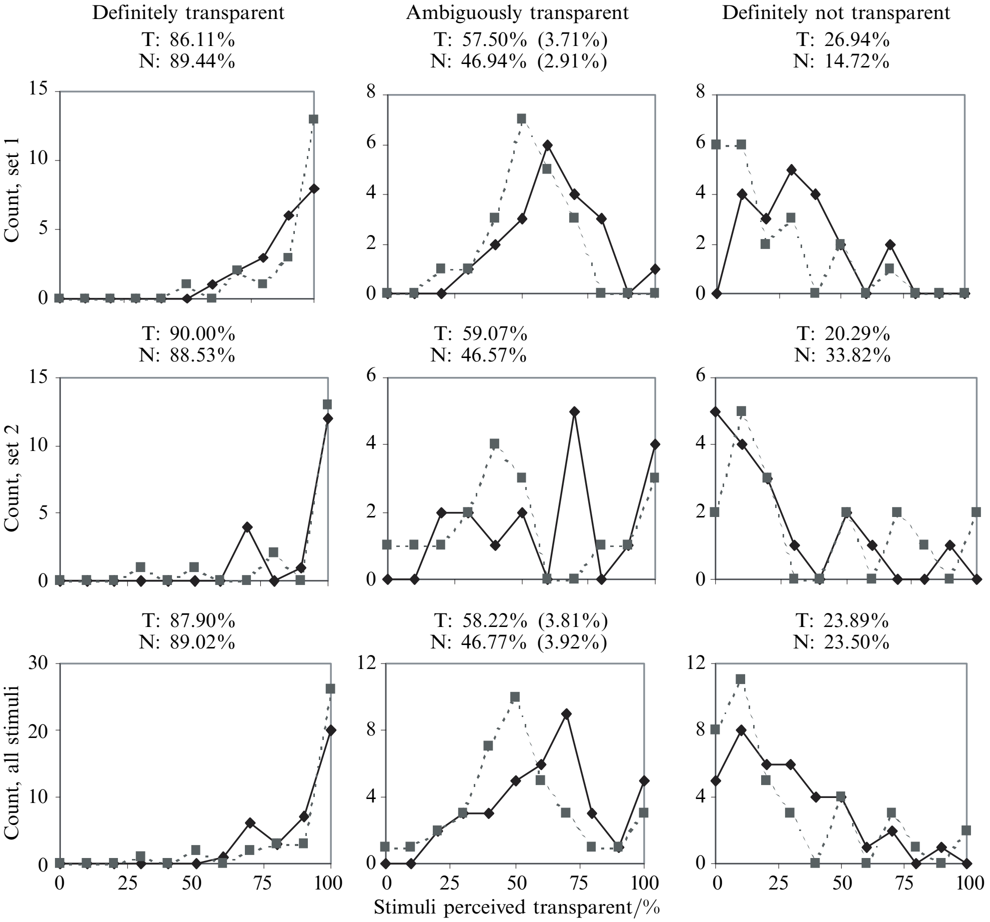


Figure 5. Frequency histograms for the percentage of stimuli perceived to have a transparent surface. That is, for each x, the plot shows the number of subjects who perceived x% of the stimuli to have a transparent surface. The first column shows histograms for definitely transparent stimuli, the second column for ambiguously transparent stimuli, and the third column for definitely not transparent stimuli. The first row is for stimulus set 1, the second row for stimulus set 2, and the last row for all the stimuli combined. Observe that the histograms are qualitatively different for thirsty (◆) and non-thirsty (■) subjects only in the ambiguously transparent cases, and in these cases thirsty subjects have a tendency to perceive a greater percentage of the stimuli as having a transparent surface. The means are shown in each plot (T = thirsty, N = non-thirsty); standard errors are shown in parentheses in those cases where the distributions are approximately Gaussian.

sort, each subject would make a single ‘perceptual decision’ that either all or none of the ambiguous stimuli are transparent. In such a circumstance, it would be appropriate to compare the number of thirsty versus non-thirsty subjects that made a pro-transparency decision and then to ask whether the difference is significant. Our subjects are not behaving in this kind of most-extreme binary fashion toward all the ambiguous stimuli in set 2, but there are a number of different ambiguous stimuli, and they may have a more complex set of rules. Because the multimodality may be due to some amount of ‘perceptual decision-making’ of this sort, we thought it justified to compare the number of thirsty versus non-thirsty subjects that are pro-transparency, where a subject is pro-transparency if he perceives at least half of the stimuli as having a transparent surface; otherwise a subject is anti-transparency. For stimulus set 1 and the set of all stimuli combined—where, as discussed earlier, a t-test was appropriate and where statistical significance was determined—this pro-transparency test coheres with the earlier statistical test: for stimulus set 1, nine of twenty non-thirsty subjects were pro-transparency compared to fifteen of twenty thirsty subjects; and for the set of all stimuli combined, fourteen of thirty-seven non-thirsty subjects were pro-transparency compared to twenty-five of thirty-seven thirsty subjects. In each case the frequency of pro-transparency among thirsty subjects is significantly greater than for non-thirsty subjects (respectively, $p \approx 0.005$ and $p \approx 0.0002$, under a binomial distribution, assuming the null hypothesis is given by the frequency of pro-transparency among non-thirsty subjects). For stimulus set 2, five of seventeen non-thirsty subjects were pro-transparency compared to ten of seventeen thirsty subjects, which is again significantly different ($p \approx 0.008$ under a binomial distribution, again assuming the null hypothesis is given by the frequency of pro-transparency among non-thirsty subjects). In sum, stimulus set 2 appears to replicate the findings of stimulus set 1: in each case, thirsty subjects have a greater propensity to perceive transparency than non-thirsty subjects. Unlike stimulus set 1, however, stimulus set 2 led to a multimodal frequency distribution; we do not believe this weakens the power of the replication, since we had no expectation that the shapes of the distributions would be identical.

4 Conclusion

The modulation of perception by a person's state reflects a common intuitive understanding of one way that underlying appetitive processes may influence behavior. Such modulation may be more pervasive than we recognize, producing directional and evocative effects on behavior accounting for much of what is meant by the terms 'motivation', 'desire', and 'appetite'. This view is consistent with an understanding of perception within a decision-theoretic framework by which perceptions arise as a result of stimulus probabilities *biased by current utilities*. We have reported here that a simple alteration of a basic biological state can influence low-level perceptual responses to a visual scene. Such biases would no doubt contribute to subsequent behavioral responses in real world settings, thus appropriately orienting behavior to an individual's state.

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