By taking the ratio of Os concentration in the primitive mantle to the present in the silicate Earth (assuming that ~10% of the mass of the planet (5.1 × 10²³ kg), the martian mass addition requirement is ~2.0 × 10²¹ kg. This yields a ratio for terrestrial/martian additions of 10. For the Moon, assuming HSE abundances in the lunar mantle are ≤20 times lower than in the terrestrial mantle, we obtain a maximum Os concentration of 0.16 ppb. Assuming the mass of the lunar mantle is 6.9 × 10²³ kg and the same average chondritic concentration for the impactor, we obtain a lunar mass addition requirement of 1.7 × 10²³ kg. This yields a ratio for terrestrial/lunar additions of 1200.}


17. Late accretion of this magnitude would have had a modest effect on the isotopic composition of Earth. The amount of impactor(s) mass envisioned to add the HSEs to the mantle would also add ~10% of the total W presently resides in the silicate portion of the Earth, and that the late accretion impactor made up ~1% of the mass of the Earth. This W value of bulk-silicate Earth, defined as a part in 10,000 deviation of 182W/184W) from the terrestrial ratio, is 0. If the bulk impactor had an W value of ~2.0 (chondritic) at the time of impact, as seems likely, then the composition of the Earth would have been very similar to that of the early Earth. This would imply that the Fe¹⁴/Fe ratio (where Fe is total Fe) of the mantle before the impact was ~0.15, rather than the present estimate of ~0.1, which is well within the range of ferrous/ferric ratios possible for the early Earth, based on chondritic measurements.

38. The intrinsic collision probabilities (P) and impact velocities (V) of stony planetesimals striking one another near 1 AU were computed from the numerical runs described in (37). We estimate that at ~1 AU, P = 6.0 × 10⁻³⁷ km⁻² yr⁻¹ and V = 11 km/s.
the impulse to eat one marshmallow immediately in order to eat two a few minutes later if they can see the marshmallow while they wait (4). Although much evidence appears to support this common intuition (4–7), its accuracy is quite puzzling, because it seems to contradict decades of research examining the overlap between direct perception and mental imagery.

Perception and mental imagery differ in their source (the senses and memory, respectively), but there is great overlap within modalities. Both engage similar neural machinery and similarly affect emotions, response tendencies, and skilled motor behavior (8–11). The thought of a spider crawling across one’s leg can produce the same increases in perspiration and heart rate that would result from a spider’s actual presence (5). Even the mere simulation of a motor skill can result in an improvement in its subsequent performance (9, 12). Because perception and mental imagery tend to elicit similar responses, one would expect that thinking about the consumption of a stimulus should habituate one to it.

Habituation denotes the decreased physiological and behavioral responses induced by extended or repeated exposure to a stimulus (13–15). A 10th bite of chocolate, for example, is desired less than the first bite. People habituate to a wide range of stimuli, from the brightness of a light to their income (16, 17). Habituation to food occurs too quickly for it to result from digestive feedback, so it is commonly thought to occur as a result of top-down cognitive processes (such as beliefs, memories, or expectations) or pre-emptive sensory factors (such as texture or smell) (13, 18). Given the overlap in perception and mental representation, thinking about the consumption of a food should lead people to habituate to it.

Why then might people exhibit sensitization when thinking about a stimulus? We suggest that the sensitizing effect of imagery found in previous research may be due to the kind of imagery it has used: having participants vividly imagine a single exposure to a stimulus or associated cues. This form of imagery is more analogous to the initial exposure to a stimulus that whets the appetite and induces sensitization than to the repeated experience of a stimulus necessary to engender habituation (13). We suggest that mentally simulating an experience that is more analogous to repeated exposure (such as repeatedly imagining the consumption of units of a food) might engender habituation to the stimulus. We report five experiments testing whether repeated mental simulation of experiencing a stimulus, alone, can engender habituation. Specifically, we examined the effects of repeatedly imagining the consumption of a food on subsequent consumption of that food.

Our first experiment (N = 51 participants) tested whether repeatedly imagining the consumption of a food would increase or decrease the amount of that food that people would subsequently consume. All participants imagined performing 33 repetitive actions, one at a time, to hold effort constant across conditions. Controls imagined inserting 33 quarters into a laundry machine. (This served as a control task because it involves motor actions similar to those involved in eating M&M chocolate candies.) Participants in a three-repetition condition imagined inserting 30 quarters into a laundry machine and then imagined eating 3 M&M’s. Participants in a 30-repetition condition imagined inserting 3 quaters into a laundry machine and then imagined eating 30 M&M’s. Then all participants ate ad libitum from a bowl containing 40 g of M&M’s as preparation for a “taste test” (19). The M&M’s were removed when participants indicated they were finished eating. The amount of food that each participant ate was surreptitiously measured on a digital scale after the experiment. In all experiments, condition assignment was random.

A between-subjects analysis of variance (ANOVA) showed that the amount of M&M’s eaten by participants was influenced by the imagination induction, F(2, 46) = 3.61, P < 0.05 (Table 1). Planned comparisons revealed that participants in the 30-repetition condition ate significantly fewer M&M’s than did participants in the three-repetition condition and participants in the control condition, F(1, 46) = 5.81, P < 0.05 and F(1, 46) = 4.50, P < 0.05, respectively (Table 1). The amount eaten by participants in the three-repetition and control conditions did not differ significantly, P < 1, so the imagination induction did not sensitize participants to the food. Rather, repeatedly imagining the consumption of a food habituated participants to the food.

To ensure that the results of the previous experiment were due to imagined consumption rather than to the control task, in experiment 2 (N = 51 participants), we orthogonally manipulated the experience that participants imagined (eating M&M’s or the control task) and the number of times that experience was imagined (3 or 30 repetitions). A 2(repetitions: 3, 30) × 2behavior imagined: eating, control) between-subjects ANOVA yielded a significant interaction, F(1, 47) = 4.65, P < 0.05. Planned comparisons revealed that participants who imagined eating 30 M&M’s subsequently consumed fewer M&M’s than did participants who imagined eating 3 M&M’s, F(1, 47) = 4.24, P < 0.05. Repetitions of the control task performed did not affect subsequent consumption of M&M’s, F(1, 47) = 1.05, P > 0.30. No main effects were found, F’s < 1 (Table 1).

Experiments 3 to 5 tested whether habituation or an alternative process causes repetitive imaginary consumption of a food to reduce subsequent consumption of that food. Experiment 3 (N = 68 participants) tested whether one must repeatedly simulate consumption of the food or whether repeated exposure to the stimulus (priming (20)) is sufficient to reduce subsequent food intake. Participants imagined eating 3 or 30 M&M’s (simulating consumption) or imagined placing 3 or 30 M&M’s into a bowl (priming) before consuming the candy ad libitum, as in the previous experiments.

A 2repetitions: 3, 30) × 2behavior imagined: eating M&M’s, moving M&M’s between-subjects ANOVA on the amount of food consumed yielded a significant interaction, F(1, 64) = 11.17, P < 0.05. Planned comparisons revealed that participants who imagined eating 30 M&M’s consumed significantly fewer M&M’s than did participants who imagined eating 3 M&M’s, F(1, 64) = 6.10, P < 0.05; whereas participants who imagined placing 30 M&M’s into a bowl (priming) before consuming the candy ad libitum, as in the previous experiments.

Table 1. Mean grams of the food consumed ad libitum after the imagery induction. Values are ±1 SD from the mean. Means within rows that do not share the same symbol ( or †) differ significantly (P < 0.05). Each M&M weighed approximately 0.8 g; each cheese cube weighed approximately 4.5 g.

<table>
<thead>
<tr>
<th>Imagery induction</th>
<th>Repetitions</th>
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<tr>
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<tr>
<td><strong>Experiment 1 (food consumed: M&amp;M’s)</strong></td>
<td></td>
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<tr>
<td>Eating M&amp;M’s</td>
<td>4.08* ± 0.33</td>
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<tr>
<td><strong>Experiment 2 (food consumed: M&amp;M’s)</strong></td>
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<tr>
<td>Manipulating quarters</td>
<td>4.31* ± 0.78</td>
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<tr>
<td>Eating M&amp;M’s</td>
<td>5.57* ± 0.90</td>
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<tr>
<td><strong>Experiment 3 (food consumed: M&amp;M’s)</strong></td>
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<tr>
<td>Moving M&amp;M’s</td>
<td>3.87* ± 0.60</td>
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<tr>
<td>Eating M&amp;M’s</td>
<td>7.59* ± 4.45</td>
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<tr>
<td><strong>Experiment 4 (food consumed: cheese)</strong></td>
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<tr>
<td>Eating M&amp;M’s</td>
<td>9.47* ± 0.98</td>
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<tr>
<td>Eating cheese cubes</td>
<td>11.25* ± 0.27</td>
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<tr>
<td><strong>After test (predicted consumption: cheese)</strong></td>
<td></td>
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<tr>
<td>Eating M&amp;M’s</td>
<td>12.53* ± 2.61</td>
</tr>
<tr>
<td>Eating cheese cubes</td>
<td>13.41† ± 1.81</td>
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</table>

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which the repetitive imaginary consumption of a food reduces subsequent food intake. Rather, repetitive priming appeared to sensitize participants to the food (27).

Habituation is stimulus-specific. Habituation to a food leads to diminished consumption of that food without much affecting the consumption of other foods (15, 18). To further test whether the effect of imaginary consumption engendered habituation or merely primed a feeling of “fullness,” participants in experiment 4 (N = 41 participants) imagined eating the food they subsequently consumed (cheddar cheese) or imagined eating a different food (M&M’s) before consuming cheddar cheese.

Participants imagined eating 3 or 30 cheddar cheese cubes or M&M’s and then ate ad libitum from a bowl containing 40 g of cheddar cheese cubes. A 2(repetitions: 3, 30) × 2(food imagined: cheddar cheese, M&M’s) between-subjects ANOVA on the amount of cheese that participants consumed yielded a significant interaction, F(1, 37) = 4.99, P < 0.05. Planned comparisons revealed that participants who imagined eating 30 cheese cubes consumed less cheese than did participants who imagined eating 3 cheese cubes, F(1, 37) = 5.14, P < 0.05. In contrast, participants who imagined eating 3 M&M’s or 30 M&M’s did not differ significantly in the amount of cheese they consumed, F < 1. No main effects were found, F’s (1, 37) < 1.19, P’s > 0.28 (Table 1). The stimulus-specific effect of imagined consumption provides further evidence that habituation is the process by which repetitive imaginary consumption of a food leads to a reduction in its subsequent intake.

To ensure that the results of experiments 1 to 4 were not due to experimental demand, we described the design of experiment 4 to a new sample of participants (N = 80), who predicted average cheese consumption in each of its four conditions. Predictors correctly anticipated that the imagined consumption of M&M’s did not influence the actual subsequent consumption of cheese, t(79) = 0.66, P = 0.51, but incorrectly predicted that participants who imagined eating 30 cubes of cheese would consume more cheese than would participants who imagined eating 3 cubes of cheese, t(79) = 3.09, P < 0.01; within-subjects ANOVA yielded a significant interaction, F(1, 79) = 9.23, P < 0.01 (Table 1).

Two psychological processes with distinct neural substrates appear to regulate food selection and intake. One process entails the hedonic responses to the food (liking or palatability) and may diminish intake through sensory-specific satiety (18). The other entails the motivation and appetitive drive to obtain it (wanting) and diminishes intake through habituation (15, 22, 23). In experiment 5 (N = 81 participants), we used a standard procedure to test changes in liking and wanting (23–25) to identify the process by which imagined consumption reduces food intake. Participants rated their liking for the imagined food before and after an imagination induction and played a reinforcement game, a measure of habituation (15, 15, 23–25). (Note that this method tested whether repeatedly imagining the consumption of a food leads one to feel disgusted by the food, which could also diminish consumption.)

First, all participants rated how much they liked cheddar cheese on a seven-point scale with endpoints: dislike extremely (1) and like extremely (7). Then, they imagined 33 repetitive tasks. Participants in a three-repetition condition imagined performing 30 repetitions of the control task (as in experiment 1) and then imagined eating 3 cheddar cheese cubes. Participants in a 30-repetition condition imagined performing three repetitions of the control task and then imagined eating 30 cheddar cheese cubes.

Then, all participants played the reinforcement game: Participants were shown a picture of a cheddar cheese cube and a STOP sign; they could collect points by clicking on the cheddar cheese cube. The game began with a fixed-ratio reinforcement schedule of 4 (FR4), in which every fourth click earned a point. Every time participants earned five points, the reinforcement ratio was doubled, progressing through FR8, FR16, FR32, FR64, and FR128. Participants could end the game at any time by clicking the stop sign. For each three points earned in the game, participants received one cheddar cheese cube at the end of the experiment. At the end of the game, participants re-rated how much they liked cheddar cheese on a scale identical to the scale used in the beginning of the experiment.

We calculated the difference between liking ratings before and after the imagination task to create an index of change in liking, and log-transformed responses in the reinforcement game to create an index of wanting. A 2(repetitions: 3, 30) × 2(determinant: wanting, liking) mixed ANOVA with replications imagined as a between-subject factor and determinant as a within-subjects factor yielded a significant main effect for determinant, F(1, 66) = 637.10, P < 0.01, and a marginally significant main effect for repetition, F(1, 66) = 3.00, P < 0.1, which were qualified by a significant interaction, F(1, 66) = 4.82, P < 0.05. Planned comparisons revealed that participants who imagined eating 30 cheese cubes clicked fewer times for cheese cubes in the reinforcement game (Mlog response = 3.68 ± 1.40) than did participants who imagined eating 3 cheese cubes (Mlog response = 4.35 ± 1.02), F(1, 66) = 5.01, P < 0.05. No difference in the change of liking was observed between the two conditions (Mthree-repetitions = 0.00 ± 0.87, Mthirty-repetitions = 0.03 ± 0.51), F < 1.

Response elasticities [responses per unit price (26)] were then computed as [log(number of responses emitted during a specific reinforcement schedule)/log(number of reinforced responses during that reinforcement schedule)] and are displayed in Fig. 1. A 2(Repetitions: 3, 30) × 6(Reinforcement schedule: FR4-FR128) mixed ANOVA with replications as a between-subject factor and reinforcement schedules as a within-subject factor revealed that response elasticities declined linearly as reinforcement schedules progressed, F(5, 62) = 315.08, P < 0.001. As revealed in our previous analysis, participants who imagined eating 30 cheese cubes were less motivated to earn points toward cheese cubes than were participants who imagined eating 3 cheese cubes, F(1, 66) = 4.69, P < 0.05. There was a marginally significant repetitions × reinforcement schedule interaction, F(5, 62) = 2.31, P < 0.1. These results suggest that imagined consumption of a food decreased its subsequent consumption through habituation because it diminished the degree to which people wanted the food; imagined consumption did not appear to affect how much they liked it.

Together, the results show that repeatedly imagining the consumption of a food leads people to habituate to it. Participants who imagined con-
Sex Determination in the Social Amoeba Dictyostelium discoideum

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The genetics of sex determination remain mysterious in many organisms, including some that are otherwise well studied. Here we report the discovery and analysis of the mating-type locus of the model organism Dictyostelium discoideum. Three forms of a single genetic locus specify this species’ three mating types: type I, type II, and type III, and type II/type III. Although several genes are known to be involved during the sexual cycle (15), the determinant of mating type has proved elusive. Genetic analysis suggested that mating type is stable and is determined by a single locus with two or more alleles (10, 14, 16). We argued that it might be possible to identify this postulated locus by searching for genes that are present in any member of one mating type but absent or highly diverged in any member of another. For this purpose, we performed comparative genomic hybridizations using DNA microarrays composed of probes for around 8500 of the 10,500 predicted genes in the sequenced type I D. discoideum genome (17).

We analyzed 10 strains derived from independent wild isolates (table S1) using this micro-

**References and Notes**

5. P. Lang, Behav. Ther. 8, 862 (1977).
19. Materials and methods are available as supporting material on Science Online.

31. This work benefited from financial support from a grant to C.K.M. from the Berkman Faculty Development Fund at Carnegie Mellon University. We thank A. Kim, K. Khanna, M. Fei, L. Mosca, M. Christian, and Center for Behavioral Decision Research summer interns in 2008 and 2009 for help with the data collection. We thank C. Janiszewski, D. Kahneman, G. Loewenstein, B. Rolls, and L. Williams for helpful comments.

Supporting Online Material

www.sciencemag.org/cgi/content/full/330/6010/1530/DC1

SOM Text

References

27 July 2010; accepted 28 October 2010

10.1126/science.1195701