Research Report

Subliminal Smells Can Guide Social Preferences

Wen Li,[1,2] Isabel Moallem,[1] Ken A. Paller,[1,2] and Jay A. Gottfried[1,2,3]

[1]Cognitive Neurology and Alzheimer's Disease Center, [2]Department of Psychology, and [3]Department of Neurology, Northwestern University

ABSTRACT—*It is widely accepted that unconscious processes can modulate judgments and behavior, but do such influences affect one's daily interactions with other people? Given that olfactory information has relatively direct access to cortical and subcortical emotional circuits, we tested whether the affective content of subliminal odors alters social preferences. Participants rated the likeability of neutral faces after smelling pleasant, neutral, or unpleasant odors delivered below detection thresholds. Odor affect significantly shifted likeability ratings only for those participants lacking conscious awareness of the smells, as verified by chance-level trial-by-trial performance on an odor-detection task. Across participants, the magnitude of this priming effect decreased as sensitivity for odor detection increased. In contrast, heart rate responses tracked odor valence independently of odor awareness. These results indicate that social preferences are subject to influences from odors that escape awareness, whereas the availability of conscious odor information may disrupt such effects.*

The power of smell to influence social preference has been recognized since antiquity: When the women of Lemnos refused to pay tribute to the goddess Aphrodite, they were cursed with such a horrid stench that their husbands took new wives. Widespread use of perfumes centers on the assumption that pleasant fragrances enhance attractiveness. Supraliminal odors (i.e., odors above the threshold of detection) can regulate mood, cognition, and perhaps even mate selection (Herz & Schooler, 2002; Jacob, McClintock, Zelano, & Ober, 2002). Weak ambient scents, which participants do not explicitly notice, can also influence implicit odor memory (Degel & Köster, 1999; Köster, Degel, & Piper, 2002). However, it is unclear whether odors must be consciously perceptible in order to affect human behavior, and in particular social preferences.

It has long been known that subliminal affective information in visual stimuli can modify social judgments (Fazio, 2001). Studies on affective priming indicate that emotionally charged pictures or words presented subliminally alter subsequent preference judgments in valence-specific directions (e.g., Li, Zinbarg, Boehm, & Paller, in press). Two prominent theories, affective primacy (Zajonc, 1984) and feeling-as-information (Schwarz & Clore, 1996), have been proposed to explain these effects. By either account, an affective stimulus (i.e., prime) evokes an emotional response that is carried over to the processing of a subsequent stimulus (i.e., target), modifying affective evaluation of the latter stimulus. Given the tendency of smells to induce potent emotional responses (Schiffman, 1974), and given the intimate anatomical connection of the olfactory system with limbic brain regions involved in affective processing (Carmichael, Clugnet, & Price, 1994; Gottfried, 2006), it stands to reason that subliminal odors may be particularly capable of influencing social affective evaluations.

Nevertheless, recent attempts to demonstrate unconscious effects of odors on social preferences have been unsuccessful. These studies, however, did not test the full range of odor valence, and the inclusion of only a pleasant odor (Bensafi et al., 2002) or an affectively ambiguous pheromone-like steroid (Lundstrom & Olsson, 2005) might not allow for clear demonstration of unconscious affective effects of odors. Additionally, the studies relied on subjective self-reports (Bensafi et al., 2002) and predetermined odor thresholds (Lundstrom & Olsson, 2005) to exclude odors that were consciously perceived, and these methods may not be sufficiently rigorous to curtail sensory awareness (Hannula, Simons, & Cohen, 2005). Conscious odor perception might have occurred on individual trials or in some of the participants, triggering strategic control mechanisms, such as cognitive "discounting" (Kelley, 1973), and thereby diminishing any observable effects. For example, Murphy and Zajonc

Address correspondence to Wen Li, Northwestern University Feinberg School of Medicine, Cognitive Neurology and Alzheimer's Disease Center, 320 E. Superior St., Searle 11-453, Chicago, IL 60611, e-mail: wenli@northwestern.edu.

(1993) found that a happy or angry face influenced the likeability of a visual target only when the face was displayed subliminally. These authors proposed that when faces were explicitly perceptible, participants tended to attribute their preferences regarding the targets to the preceding faces. Then, to discount this self-perceived bias, they shifted ratings in the opposite direction, which resulted in null or even reverse effects. Likewise, subliminal primes can bias recognition judgments, whereas supraliminal primes do not (Jacoby & Whitehouse, 1989). From these observations, it is evident that the level of conscious awareness needs to be well controlled when investigating effects of odors on social judgments.

The present study was designed to test the hypothesis that the hedonic content of undetectable odors alters social likeability judgments of human faces, whereas conscious odor information may undermine this effect. We developed an olfactory affective priming paradigm, taking special care to limit and monitor the level of conscious odor awareness. Pleasant, neutral, and unpleasant odorants were presented at concentrations below participant-specific detection thresholds. Heart rate responses provided a physiological index of olfactory affective processing, given that odor valence can influence autonomic responses (Alaoui-Ismaili, Vernet-Maury, Dittmar, Delhomme, & Chanel, 1997). We predicted that a subliminal pleasant odor would make faces appear more likeable, whereas a subliminal unpleasant odor would make faces appear less likeable. We also tested whether the efficacy of affective priming decreases with increased availability of conscious olfactory information, as indexed by detection sensitivity computed from the odor-detection response on each trial.

METHOD

Participants

Thirty-nine undergraduate students (age range: 17–27; 23 women, 16 men) consented to participate in the experiment, which was approved by the Northwestern University Institutional Review Board. Five participants who rated the citral odorant as unpleasant or neutral in a screening session were excluded, and another 3 participants were unable to complete the experiment, resulting in a final sample of 31 (18 women, 13 men) participants. Physiological recordings were acquired in 17 of these participants.

Stimulus Materials

Odor Stimuli

Citral ("lemon"), anisole ("ethereal"), and valeric acid ("sweat") were chosen as the pleasant, neutral, and unpleasant odorants, respectively (Winston, Gottfried, Kilner, & Dolan, 2005). These valence designations were first verified by participants' ratings of odor pleasantness for isointense suprathreshold concentrations of the odorants (citral, 1%; anisole, 0.8%; valeric acid, 0.04%; diluted in mineral oil); ratings were made on a scale from −10 (*extremely unpleasant*) to +10 (*extremely pleasant*). Mean valence ratings were 3.03 (*SEM* = 0.61) for citral, −1.23 (*SEM* = 0.33) for anisole, and −6.71 (*SEM* = 0.27) for valeric acid, $\chi^2(2, N = 31) = 52.32$, $p < .001$ (Friedman test for related samples).

Face Stimuli

Eighty photographs of faces with neutral expressions were selected from a standardized set (Endl et al., 1998). The emotional neutrality of these faces was confirmed in an independent group ($N = 20$) who gave them a mean rating of 3.41 (*SEM* = 0.09) on a categorical scale from 1 (*very negative*) to 6 (*very positive*). Four unique lists containing 20 faces each were created for counterbalancing. Reported effects were not influenced by list assignment ($ps > .1$, analysis of covariance).

Procedure

Threshold Determination

Prior to the main study, participant-specific thresholds were obtained independently for each odorant using a forced-choice ascending-staircase technique (with a series of dilutions each at one third of the previous concentration, prepared from the suprathreshold concentrations used for the odor pleasantness ratings; criterion = five consecutive hits; see Fig. 1; Cain, Gent, Goodspeed, & Leonard, 1988). Mean detection thresholds (mean dilution steps) were 11.47 (*SEM* = 0.66) for citral, 12.87 (*SEM* = 1.51) for anisole, and 14.5 (*SEM* = 1.37) for valeric acid. The mean dilutions used in the subsequent task were two dilution steps below the thresholds, equivalent to mean volume/volume concentrations of 3,600 parts per trillion (ppt) citral, 720 ppt anisole, and 7.5 ppt valeric acid.

Odor Detection and Likeability Judgment Task

Participants were instructed to make the same moderate-sized sniff on each trial and were informed that an odor would be present on 75% of the trials. On each trial, participants first sniffed a bottle containing a pleasant, neutral, or unpleasant subthreshold odorant, or odorless mineral oil (i.e., room air), and indicated by key press whether the bottle contained an odor. Immediately after this response, a computer screen displayed a face for 1,200 ms and then a visual analog scale enabling participants to rate the face's likeability (anchors were *extremely unlikeable* and *extremely likeable*). Trials occurred in random order approximately once every 25 s. There were 20 trials per odor condition.

At the conclusion of the study, participants were asked to identify the odorless stimulus from among the four bottles, and only 4 participants identified it correctly. When these participants were subsequently asked to identify the valence of the odors in the other three bottles, they reported that they were unable to do so and were unwilling to venture a guess.

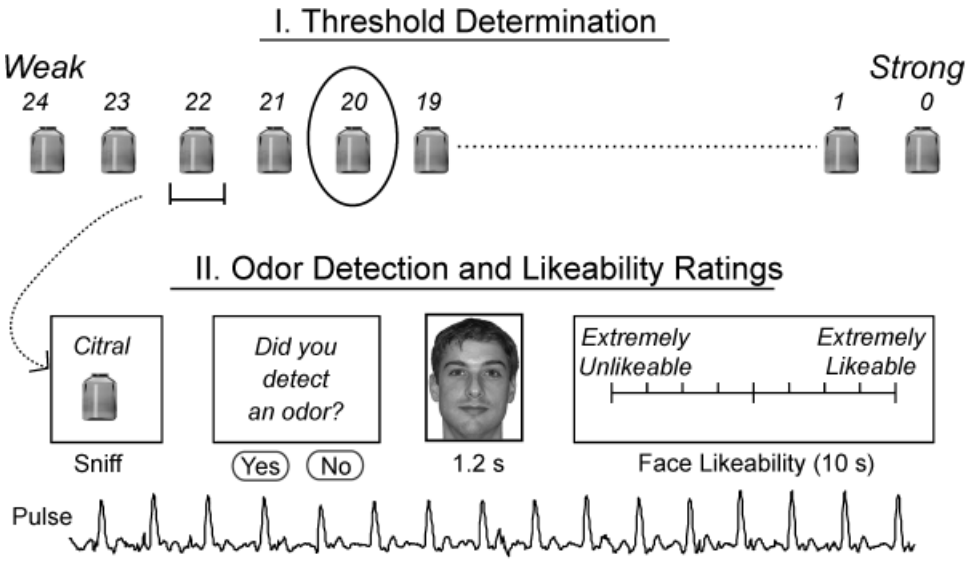

Fig. 1. The experimental paradigm. First, participant-specific odor-detection thresholds were determined using an ascending-staircase procedure. Then, participants completed an odor-detection and likeability judgment task. In this example, the detection threshold was at dilution 20, so dilution 22 was used in the main task. In that task, participants sniffed a bottle, indicated whether or not it contained an odor, viewed a face stimulus, and finally rated the likeability of the face. For a subset of the participants, heart rate was recorded.

Physiological Monitoring

Respiration and heart rate were measured in 20 participants, though recording failed in 3 because of technical problems. To record respiration, we used a pair of breathing belts connected by plastic tubing to a piezo-resistive differential pressure transducer (Li, Luxenberg, Parrish, & Gottfried, 2006), the output of which passed through a bridge amplifier. To record HR, we used a piezo-electric pulse transducer attached to the participant's left thumb.

Data Analysis

We used the signal detection measure d' to assess odor detection. Given the uneven distribution of response probabilities (odor was present on 75% of trials and absent on 25% of trials), d' could have been critically distorted by individual response bias (β; Kroll, Yonelinas, Dobbins, & Frederick, 2002). We therefore adjusted d' for variability in β, obtaining standardized scores. Sixteen of the 31 participants had values of d' below 0 (their mean unadjusted raw d' was 0.04, $SD = 0.30$); they were assigned to the *unconscious* subgroup. In this group, d' scores for the three odorants did not differ ($p = .92$). Nevertheless, 1 participant showed above-chance detection ($d' > 0$) for anisole; data from this participant were excluded from relevant analyses, although this did not affect the patterns of results. The remaining 15 participants, for whom the value of d' was greater than 0 (their mean unadjusted d' was 1.06, $SD = 0.36$), were assigned to the *conscious* subgroup, so named because their detection performance indicated they might have consciously perceived the odors on some trials. One-sample t tests confirmed that the raw d' was significantly greater than 0 for the conscious group, $t(14) = 11.3$, $p < .001$, $p_{rep} > .99$, but did not differ from 0 for the unconscious group, $t(15) = 0.53$, $p = .61$, $p_{rep} = .42$. We also calculated participant-specific sniff volume, peak amplitude (both computed after subtracting a 500-ms presniff baseline), and latency (from the "sniff now" instruction to the peak amplitude). Calculations of instantaneous heart rate were based on the mean interbeat interval across five postsniff R-waves (the index of heartbeat, signifying early electric depolarization of the ventricle), after subtracting a presniff baseline (based on three presniff R-waves).

RESULTS

We first tested the effects of odor valence and odor awareness on face likeability ratings in a two-way repeated measures analysis of variance (ANOVA). There was no significant main effect of odor valence, $F(2, 58) = 1.61$, $p = .21$, or of odor-awareness group, $F(1, 29) = 0.02$, $p = .90$, $p_{rep} = .93$, but there was a significant interaction between valence and awareness, $F(2, 58) = 3.73$, $p = .03$, $\eta^2 = .11$ (see Fig. 2a). Follow-up contrasts indicated that in the unconscious group, faces were rated less likeable following the unpleasant odor than following the pleasant odor, $t(15) = -2.61$, $p = .02$, $p_{rep} = .93$, $f = .62$, or air, $t(15) = -1.92$, $p = .08$, $p_{rep} = .84$, $f = .46$. In the conscious group, however, effects of odor valence were absent ($ps > .1$, $p_{rep}s < .82$).

A similar ANOVA was conducted on heart rate changes. There were significant main effects of valence, $F(2, 30) = 4.68$, $p = .02$, $\eta^2 = .23$, and awareness group, $F(1, 15) = 6.61$, $p = .02$,

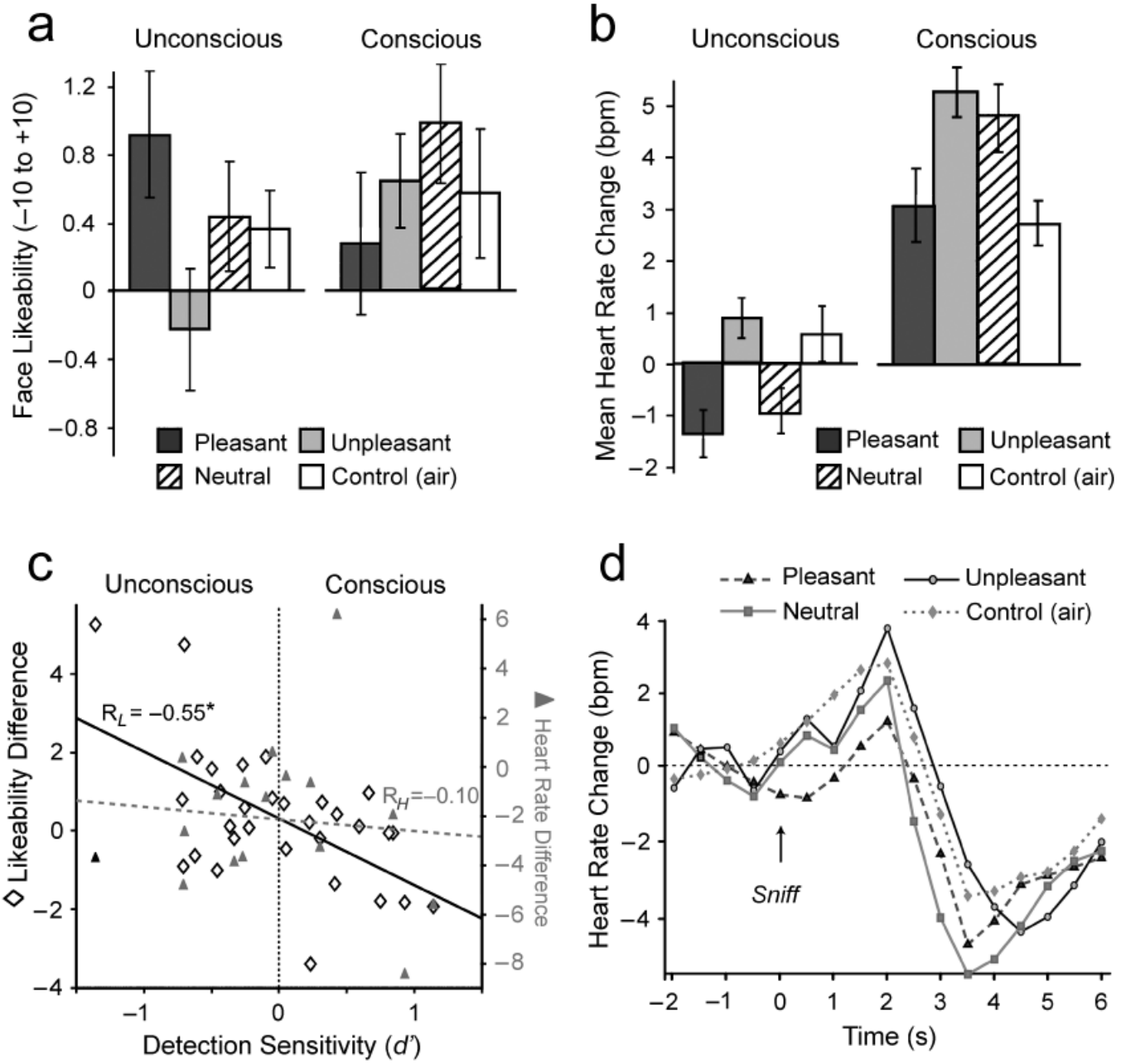

Fig. 2. Experimental results. The bar graphs present (a) face likeability ratings and (b) heart rate change as a function of odor awareness (unconscious vs. conscious) and odor valence. Error bars indicate standard errors of the means, adjusted for individual differences. Heart rate change was measured as average heart rate (beats per minute, or bpm) across five postsniff R-waves (approximately 4 s after the sniff) after subtracting the baseline rate. The graph in (c) shows the correlations between d' (corrected for β and standardized) and likeability shifts (difference scores: pleasant – unpleasant) and between d' and heart rate change (difference scores: pleasant – unpleasant). The asterisk indicates a significant correlation, $^*p = .001$. The graph in (d) presents the time course of odor effects on heart rate (bpm), after subtracting the baseline rate, in the unconscious subgroup (waveforms were developed using linear interpolation, with two heart rate estimates per second based on the instantaneous heart rate measurements).

$p_{rep} = .93$, $\eta^2 = .30$, but the valence-by-group interaction was not significant, $F(2, 30) = 0.62$, $p = .54$, indicating that the influence of valence on heart rate response was independent of the level of conscious awareness. Follow-up contrasts demonstrated that heart rate was faster following the unpleasant odor than following the pleasant odor, $t(16) = 2.79$, $p = .01$, $p_{rep} = .95$, $f = .68$, or the neutral odor, $t(16) = 1.99$, $p = .065$, $p_{rep} = .86$, $f = .36$ (see Fig. 2b). Figure 2d illustrates heart rate change as a function of time following odor presentation for the unconscious group alone, $t(9)$s > 2.92, ps $< .05$, p_{rep}s $> .89$. These heart rate effects conformed to previous results using supraliminal odors (Alaoui-Ismaili et al., 1997). Odor affect thus influenced behavior and physiology at concentrations so low that the odorants were not consciously perceived.

To determine whether conscious odor information systematically suppressed the behavioral effect of unconscious odor processing, we performed a participant-wise correlation analysis between d' scores and the effect of odor valence on face likeability judgments (i.e., difference scores between odor conditions). Considered as a continuous variable, the amount of odor information available (indexed by d') correlated negatively with likeability shifts (pleasant vs. unpleasant: $r = -.55$, $p = .001$, $p_{rep} = .99$; neutral vs. unpleasant: $r = -.35$, $p = .05$, $p_{rep} = .87$; see Fig. 2c), but not with odor-evoked changes in heart rate. These patterns coincided with the ANOVA results reported earlier in this section.

Critically, the absence of significant differences in sniff volume, latency, and peak amplitude across odor conditions and awareness groups (ps $> .4$) makes it unlikely that the reported effects were due to respiratory variations. Finally, to rule out the possibility that repetitive odor exposure might have converted nondetectors to detectors in the unconscious group toward the end of the experiment (Wysocki, Dorries, & Beauchamp, 1989), we computed participant-specific d' scores separately for the first and second halves of the experiment. Analyses indicated that odor detectability did not change significantly over the course of the study in either the unconscious or the conscious group (ps $> .1$, p_{rep}s $< .82$).

DISCUSSION

Using odors with distinct affective valence and stringent criteria to exclude odor awareness, we have provided evidence that subliminal odors can influence social likeability judgments and autonomic responses in a valence-consistent manner. The behavioral effects on social preference emerged only when odor information was minor enough to prevent top-down regulation, whereas valence-specific heart rate changes were independent of the level of odor awareness, perhaps reflecting a relative immunity to strategic discounting.

Our findings extend the current literature by showing cross-modal priming effects of subliminal odors on likeability judgments of faces. Critically, the fact that minute amounts of undetectable odorants (as low as 7 ppt) could elicit salient psychological and physiological changes highlights the acute sensitivity of human olfaction, which tends to be underappreciated (Shepherd, 2004). In particular, the reliable effects of the subliminal unpleasant odor imply that there may be a specialized high-affinity sensory channel for odors carrying threatening messages. It is tempting to speculate that a subcortical pathway linking the olfactory bulb directly to the limbic system, especially the amygdala and entorhinal cortex (Carmichael et al., 1994), could provide the means by which below-threshold odors exert their effects on human behavior. Such high-acuity olfactory evaluation is remarkable, but may be required to evoke ecologically relevant behavior, as olfactory input must overcome significant challenges due to the gradual odorant sorption through the nasal mucosa, changes in wind speed or direction, and respiratory cycling.

Recent studies using visual stimuli have led to an intriguing notion that top-down control mechanisms can be exerted on unconscious processing even though individuals have no conscious awareness of what is to be controlled (Dehaene & Naccache, 2006; also see Bargh & Ferguson, 2000). In the present study, even the participants who showed above-chance odor detection (i.e., $d' > 0$) did not evidence explicit knowledge of odor affect. Yet the lack of affective priming among these participants implies that inhibitory mechanisms (e.g., discounting) may emerge even without explicit perception of the odor stimuli, provided that sufficient odor information is available. The negative correlation between the amount of odor information available to the participants and the efficacy of affective priming extends a recent finding (Jolij & Lamme, 2005) that implicit visual processing was evident only with minimal visual input (16.7-ms stimulus presentation), and was absent at a slightly longer presentation duration (33.3 ms). Similarly, we suspect that when sensory input is insufficient to provoke conscious olfactory experience, subliminal processing will prevail, but that greater executive control will be engaged to counteract unconscious olfaction as the level of awareness increases. However, as Bargh (1989) pointed out, awareness of the prime and awareness of the link between the prime and the behavior may constitute different automatic processes. Therefore, we cannot exclude the possibility that the potential link between the odors and the face judgments was salient to all participants, and that if it had been less clear, the likeability results might have been similar for the conscious and unconscious groups.

In conclusion, the time-honored belief that scents play an important role in human social settings appears to withstand scientific scrutiny. Furthermore, our data suggest that it is in the absence of conscious awareness that odors best exert their effects. Human cognitive function is so intricate that bottom-up sensory input often induces top-down regulation, resulting in synthesized processes (Schneider & Chein, 2003). Given that at any moment people have conscious access to only a small fraction of the information impinging on their sense organs, top-down mechanisms that operate in the absence of conscious volition could be very adaptive at preventing people from being constantly led by irrelevant sensory input. Nevertheless, as shown here, when sensory input is infinitesimal, important information fragments can escape strategic regulation and influence social judgments. Consequently, we can only hope that the subtle smells we emit make a pleasant impression on other people.

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