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Perceptual and Mental Mixtures in Odor and in Taste: Are There Similarities and Differences Between Experiments or Between Modalities? Reply to Schifferstein (1997)

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D. Algom and W. S. Cain (1991b) found relative invariance in the pattern of judgments of perceptual and mental mixtures of banana and grass odors. Invariance held both for judgments of total intensity and for those of an individual constituent. For 2 tastes, H. N. J. Schifferstein (1997) found a pattern with both similarities to and differences from D. Algom and W. S. Cain's. A key difference lay in finding more symmetry of masking in mental mixtures than in perceptual mixtures. H. N. J. Schifferstein concluded from this alone that any similarity between the perceptual and mental arose from knowledge of "mixture suppression." The authors of this article do not refute the possibility; however, they reject the premise that a statistically reliable difference between the perceptual and the imaginal rules out imagery. The authors review relevant considerations and find no a priori reason to assume that what held for attributes in taste will hold for odors. An approach to resolve the issue is also suggested.

Schifferstein used the work of Algom and Cain (1991b) on odor as a starting point to explore perceptual and mental mixtures for taste. The two senses differ psychophysically and psychologically, a matter that Schifferstein refers to in passing but seems not to want to stress (Cain, 1987). His agenda apparently requires common enough functioning between the modalities to maintain that what he found to hold for taste would also hold for smell had he studied it. This contention lends itself to debate. Below, we recap the motivation, methods, and findings of Algom and Cain (1991b), classify Schifferstein's (1997) experiments with Algom and Cain's taxonomy, and examine the joint outcomes from that perspective.

Memory Psychophysics

Research on odor memory (see Schab & Crowder, 1995a) has concerned principally odor quality, with virtually no attention to intensity, a bias reflected in almost exclusive use of responses of identification and recognition (e.g., Cain, 1982; Engen & Ross, 1973; Rabin & Cain, 1984; Lyman & McDaniel, 1986). The perceived or remembered intensity of odors, particularly in remembered mixtures, provides a view of a modality rarely studied regarding perceptual representation in memory. Crowder and Schab (1995) offered one reason for a dearth of experimentation on imaginal representation of odor: "The standard paradigms for studying visual imagery make little or no sense when translated to the olfactory domain" (p. 94).

Mental imagery, regardless of modality, represents a special kind of memory characterized by an unfortunately ill-defined fidelity to original experience. Imagery, as often conceptualized, entails evocation upon command, or top-down processing. Nevertheless, memory often seems to involve an imaginal code, viewed more neutrally as a *perceptual code* (Paivio, 1986; Schab & Crowder, 1995b). (A perceptual code may technically require no commitment regarding imagery, particularly when backed into as the "residual" memory code left after discounting a semantic code.) In cases of an imaginal code, the cue for retrieval, rather than a command, presumably evokes the image, a case of bottom-up processing. Various studies of odor recognition memory have invoked a role for such a code (see Cain & Potts, 1996; Herz & Eich, 1995).

If asked to evoke an odor image at will, perhaps half of people will claim to do so, although the estimate may depend on the form of the request (Lindauer, 1969; Schab & Cain, 1992). When Brower (1947) asked, "Imagine a pan of onions frying on a stove.... Can you smell the odor of the onions?" (p. 199), 39% of respondents said yes, versus 59% who said they could hear sizzling, and 97% who said they could see the onions. Crowder and Schab (1995) noted, "Those of us who have ever ordered a meal in a restaurant are confident that imagery plays a role in our choices" (p. 94). Seen in that way, few could disavow some odor imagery, but Crowder and Schab acknowledged readily that personal experience fails to constitute scientific evidence.

Algom and Cain (1991b) pursued questions of memory for intensity for both single odorants that evoked, respec-

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tively, banana smell and grass smell, and for their mixtures through techniques of memory psychophysics (Algom, 1992a, 1992b), or mnemophysics (Algom & Marks, 1989), the branch of psychophysics that treats relationships between stimuli and remembered sensory impressions. Mnemophysics invites applications to multidimensional stimuli, such as mixtures, and especially to rules of integration or analysis. Algom and Cain (1991b) extended their study to mental and semimental mixtures and thereby brought top-down and bottom-up representations into the same arena.

Mental Synthesis and Mental Analysis

In Algom and Cain's (1991b) study, *perceptual mixtures* entailed physical (vapor-phase) mixing of stimuli, presentation of the mixtures, and asking participants to judge the percepts. *Remembered mixtures* entailed physical mixing, presentation of the mixtures perceptually, but asking participants later to recall the percepts and judge them. *Mental mixtures* entailed presentation of the components separately to perception, but asking the participants later to recall them, mix them mentally, and judge the mixtures. *Semimental mixtures* resembled mental mixtures in that they entailed presentation of no physical mixtures. Judgments were based on exposure to separate, unmixed stimuli. In a semimental mixture, however, one component of a binary mixture was physically presented. Therefore, participants mixed a remembered component represented symbolically at testing with a perceived component, then judged the intensity of the mixture.

In these conditions, participants judged overall intensity. Algom and Cain (1991b) also tapped the complement, *mental analysis:* How accurately can people predict the intensity of an odorant in a mixture? The investigators asked participants to judge the intensity of a target when physically mixed or when mentally mixed, with variation in the intensity of the masker and target.

Algom and Cain (1991b): Transrepresentational Invariance

The results of Algom and Cain (1991b) proved simple. The pattern of integration characteristic of perception appeared as well in memory-based and mental estimates of intensity; a similar interactive pattern held for physical mixtures, remembered mixtures, and mental mixtures. Factorial plots revealed categorically the same bilinearly interacting pattern for the various types of mixtures (conditions). The interaction Banana × Grass proved significant in each case, whereas the interaction Banana × Grass × Condition (physical, remembered, mental, and semimental) did not. For all, addition of a low level of one component to that of the other augmented sensation appreciably, whereas addition of a low level to a high level left sensory magnitude essentially unchanged.

Algom and Cain (1991b) summarized their data by a model of vector addition often applied to perception of odor mixtures (e.g., Berglund, Berglund, & Lindvall, 1976). The angle c between the vectors that represented how the two components added to produce the intensity of a mixture formed the parameter of interest. Its value has commonly exceeded 90° ($\cos c < 0$) and has typically lain between 100° and 130° (e.g., Cain, 1975; see Cain, Schiet, Olsson, & de Wijk, 1995, for an overview). Such values express the phenomenon of suppression between components—c would equal 0° or $\cos c$ would equal 1.0 without suppression. Algom and Cain (1991b) discovered considerable suppression even for mentally constructed mixtures. Values of c equaled 114°, 93°, and 111°, for physical, mental, and semimental mixtures, respectively. Hence, by this description also, mental mixtures displayed approximate invariance in mode of integration.

Mental analysis displayed constancy across perceptual and mental mixtures, too. Participants who had never smelled the target as a component in a mixture predicted attenuation of its intensity in the mental mixture. Just as in perception, the intensity of the target depended lawfully on concentration of the masker as well as on its own concentration. Algom and Cain (1991b) concluded that people possess a valuable reservoir of knowledge about olfactory experience, a conclusion that should in itself evoke no controversy. They noted the following:

> Surely, as is clear *prima facie* from everyday experience, perceptual mixing and mental mixing operate in wholly different systems. What the present results imply is that the two share some common or functionally similar algorithms for at least certain kinds of olfactory responses. (p. 1113)

Classification of Schifferstein's (1997) Experiments

Schifferstein took issue with some of Algom and Cain's conclusions. His experiments on taste, he stated, "demonstrate that the interaction patterns underlying the perception and imagination of mixture intensities are not the same" (p. 18). Schifferstein tested two conditions to probe synthesis—perceptual and mental mixtures (his PERC and IMAGE conditions). He included a condition, SUM, in which participants were instructed "to judge the sum of the intensities of the left and right samples of each pair" (p. 8). This condition taps mental calculation and has neither a physical parallel nor a counterpart in Algom and Cain's (1991b) study. Schifferstein included the condition to show that the responses of his participants displayed linearity and to cover the case where participants might express so little ability to imagine combinations of tastes that they merely computed a sum from judgments of individual constituents. (In a historically interesting and more exotic exercise, Francis Galton [1894] concluded that a person could use smells [or tastes] to perform mental arithmetic: Two whiffs of peppermint equaled one of camphor; three whiffs of peppermint equaled one of carbolic acid, etc.: "I convinced myself of the possibility of doing sums in simple addition with simple speed and accuracy solely by means of imaginary scents" [p. 62].) By Algom and Cain's (1991a, 1991b) terminology, Schifferstein's (1997) two other experiments probed mental analysis.

Schifferstein (1997): Synthesis

Schifferstein found that a family of functions for the perceived intensity of mental mixtures (IMAGE) of sucrose-citric acid looked much like that for the physical mixtures (PERC) (Schifferstein's Figure 1, left and middle panels, respectively). Both families displayed convergent, approximately bilinear interactions, but differed in particulars. Participants' judgments anticipated suppression between tastes but underestimated it in the mental mixtures. Because of the differences, Schifferstein questioned whether mental mixtures could exhibit their similarity by any match of mechanism to actual perception. He suggested that Algom and Cain would probably have found similar disparity between mental and perceived mixtures had their data possessed the statistical power to find it. After the first experiment of its kind in the chemical senses, should Algom and Cain have highlighted the differences between perceived and mental mixtures more than obvious similarities? The similarities seemed far more striking.

Both Schifferstein's study of taste and Algom and Cain's of odor therefore indicated that for overall intensity the construction of mixtures in perception and cognition largely comply with the same rule of integration. Admittedly, the magnitude of responses and their variation could differ across conditions, but vagaries of numerical responding inevitably produce occasional crossovers of functions in one plot, overshooting in another. Such phenomena occur in replications of the same experimental condition.

How much correspondence could we expect even if mental manipulations of olfactory or gustatory representations followed rules analogous to those in other modalities? Paivio (1986) noted,

> The operations that can be performed on images do not precisely parallel the operations that can be performed on perceptual objects. What the evidence suggests, however, is that mental and perceptual representations contain similar structural information and that it can be used and manipulated in similar ways. (p. 177)

So far, so good, although Schifferstein did then find a notable incompatibility between mental and perceptual representations.

Schifferstein (1997): Analysis

The incompatibility in Schifferstein's study concerned how sucrose masked sourness, but citric acid failed to mask sweetness. The effect of sucrose on sourness might lead one to conclude that, once again, perceptual and mental mixing produce only nominally distinguishable outcomes. (The interaction Sucrose × Citric Acid × Condition achieved statistical significance, but the visual picture suggests quite decent similarity.) The particular asymmetry of masking that Schifferstein observed, which replicated his earlier findings (Schifferstein & Frijters, 1990), does afford an interesting comparison between perceived and mental mixtures. (Although their data showed asymmetry of masking, Schifferstein & Frijters [1990] showed a significant effect of citric acid on perceived sweetness and a significant interaction of Sucrose × Citric Acid, two outcomes that failed to achieve significance in Schifferstein's [1997] PERC condition. The family of functions for sweetness in Schifferstein & Frijters [1990] lie between those for Schifferstein's IMAGE and PERC conditions.) In their judgments of sweetness and sourness of mental mixtures, participants anticipated more symmetry than actually occurred: Sour would mask sweet almost as much as sweet masks sour. Schifferstein argued that the absence of asymmetry meant an absence of common mechanism between mental and perceived mixtures. We take no issue with that strict conclusion.

The asymmetry of masking seen between sucrose and citric acid has apparently one companion finding in olfaction. Laing and Willcox (1987) found that propionic acid failed to suppress the intensity of either (+)-limonene or pinene, although each suppressed the intensity of the acid. (The pungency of propionic acid adds potential complications to the interpretation of these results.) Otherwise, the literature on binary odor mixtures indicates that any odor can mask any other to a degree predictable almost entirely by relative perceived intensity (Cain, Schiet et al., 1995). The difference between the taste system, with its four-channel simplicity, and the olfactory system, with a complexity more similar to visual pattern perception, could be decisive in a comparison of Schifferstein's outcome with Algom and Cain's. Olfaction, unlike taste, provides unambiguous means to identify objects in the world (see Cain, 1987). Olfaction perceives objects, whereas taste perceives attributes. Olfaction has its first synapse in the olfactory bulb of the brain, where a neural substrate for imagery has already received attention:

> Even though we cannot know whether rabbits introspect, I have elected here to call [an EEG contour plot in the olfactory bulb] a "mental image" partly because I believe that neural and mental images are two sides of the same coin, and partly because I want to attract the attention of cognitive psychologists, who believe that such "images" or "representations" must exist. (Freeman, 1983, p. 1121)

We welcome Schifferstein's observations on taste but feel that we might preclude interesting possibilities for understanding if we merely accept his conclusion, "Participants implicitly or explicitly knew the phenomenon of mixture suppression, and knew that the degree of suppression increased with an increase in the intensity of the suppressor" (p. 287).

Algom and Cain (1991b) ventured no mechanism but left various avenues open. Similarities between perceived and mental mixtures of odors still arouse curiosity amplified, if anything, by similar parallelism found later in mixtures of an odorant (orange) and tastant (sucrose; Algom, Marks, & Cain, 1993). In that case, neither the perceived nor the mental heteromodal mixture displayed a significant interaction of Sucrose × Orange. Algom et al. (1993) noted,

> Consider now the present heteromodal mixtures, in which the perceptual rule of odor–taste combination is not interactive, but additive .... The additive structure also appeared in the mental-mixture condition, despite the fact that the subjects believed they were mixing mentally two tastes..... Physical taste mixtures are generally interactive, not additive. (p. 158)

Some investigators have maintained that the presence or absence of perceptual interactions between the two modalities depends on the particular stimuli (Frank & Byram, 1988). Here, as with the asymmetry between sucrose and citric acid, we might make a differential prediction (see Murphy & Cain, 1980; Murphy, Cain, & Bartoshuk, 1977).

Perceptual and Memorial Representation in Olfaction

In the olfactory modality that gets so little direct instruction in everyday life (Cain, Stevens et al., 1995), either a considerable amount of veridical learning has indeed occurred or some hitherto unexplored processing has been tapped. Veridicality reveals itself in how close the data from Algom and Cain's studies of mental and semimental mixtures came in quantitative terms to those of the many studies of perceived mixtures, not just Algom and Cain's (see Laing, Cain, McBride, & Ache, 1989). Is this veridicality trivial, an example of learning, even if imperfect, that goes on incidentally and that can give little or no insight into how people process odors? We believe that the exploration of perceptual representation in olfaction should continue and hope that Algom and Cain's work will figure in conclusions about its nature. Depending upon the validity of the boundaries between taste and smell in this domain, so perhaps will Schifferstein's.

The study of cognitive processing in the lower senses usually contains lessons for study of the higher senses, even if rarely heeded. One might conjure up a voice, a musical instrument, a scene during almost any set of external circumstances. One can, for example, make the voice angry or sweet, change the key of an instrument even while an imaginary song plays, and have a scene grow brighter or dimmer. For smell, one might imagine the smell of a pizzeria with an odor of beer as a server goes by with a pitcher, but the images may seem less vivid or "real" than those evoked through vision or audition of the sight of the server or the sound of other patrons. If imaginal odors seem less vivid than imaginal sights, perhaps this mirrors ecological reality. Smells generally do seem less distinct, as even Aristotle noted (Cain, 1978a). This seems to manifest itself in part in the ease with which one can induce olfactory "false alarms" (Cain, 1978b; Engen, 1982). Let a person suggest that he or she smells pizza in the office and almost certainly someone or even everyone might agree. When Slosson (1899) poured simple water over cotton and gave the suggestion that the water was an odorant, he found that

> About three-fourths of the audience claimed to perceive the smell.... More would probably have succumbed to the suggestion, but at the end of a minute I was obliged to stop the experiment, for some in the front seats were being unpleasantly affected and about to leave the room. (p. 407)

What do people actually experience when they agree, "Yes, now that you mention it, there does seem to be a hint of pizza in the air?" If one asked a colleague to imagine a pizza on a desk, he or she would do so readily. If the person suggested that he or she truly saw a pizza on the desk, that person would seem to be hallucinating and a candidate for neurological consultation. If he or she did this regarding smell, his or her experience would appear to fall within normal boundaries. (Slosson [1899] noted, "No one in the audience seemed offended when it was explained that the real object of the experiment was the production of a hallucination" [p. 407].) Henning (1916), known to generations of psychology students for his odor prism and taste tetrahedron, held that people could not often evoke images for any of the "lower senses" voluntarily, but that imagery evoked in those senses took the form of hallucinations indistinguishable from actual stimulation. If unable to relate personally to this position regarding taste or smell, think about touch. If one directs attention to one's head for just a minute, an itch will usually appear. Did a stimulus induce it? Few would worry about it, but would scratch and turn attention elsewhere. We raise this matter to illustrate how the various senses need to be studied as they "come." We doubt Henning's conclusion, for it does appear that mental representations of odors at least play some mediating role in odor memory without any hint of confusion with reality.

If imaginal representations play a role in odor perception, it undoubtedly reflects itself in a descriptive analysis of products, an activity that goes on many times a day in companies that develop comestible and personal products (Meilgaard, Civille, & Carr, 1987; Stone & Sidel, 1985). A product with chemosensory appeal, be it a bar of soap, a cup of coffee, a deodorizer, a margarine, typically has several attributes that one might abstract from the whole. In the analysis of the products, panelists use words such as lemony, skunky, floral, but typically have an exemplar available to "define" the word. As a panelist scans a product, he or she typically can do so for just one attribute at a time. Hence, as one seeks to appreciate the bouquet of a California Chardonnay, one may "look for" the oakiness on the first sniff, the butteriness on the second, the fruitiness on the third. Upon each sniff the perception seems reorganized into figure and ground, depending on the image sought. People can not only reorganize existing perceptions, but can project ideals. They can rate how much lemon flavor will make a shrimp salad most savory. They can even "design" an ideal product from exemplars of ingredients. The questions asked in such contexts go beyond asking, "Can you smell the onions frying?" They presuppose that at least screened panelists can work with odor (and taste and texture and thermal) representations, can combine them, and can analyze them. One could readily formulate a research plan on how veridically people can do these tasks and how outcome varies from homomodal to heteromodal "products." In this domain, however, the "structural engineering" (product design) has moved ahead of the "structural physics" (the basic understanding of the representations).

Concluding Comment

Schifferstein's families of functions show impressive orderliness, which in turn suggests impressive prior knowledge of the perceptual rules of mixtures, if that explains the outcome. Algom and Cain raised the same issues as Schifferstein regarding imagery versus learning. We note, however, that although the capacity for imagery may exist without learning, content presumably cannot. (People can imagine situations that cannot in reality occur, but generally are aware through learning, and within reasonable tolerances, when imagination takes them beyond the bounds of reality.) To argue that learning may underlie judgments of imaginal mixtures offers no criticism, but perhaps Schifferstein means to argue that participants need not even taste or smell unmixed components to give the data that both he and Algom and Cain obtained. If participants gave the same estimates of odor intensity with and without actually perceiving the unmixed constituents of a mixture, we would find it too uncanny not to take pause. If, for example, participants would assign a value of 8 to a mixture of component A at a hypothetical intensity of 5 with component B at a hypothetical intensity of 5 and if participants who gave ratings to the directly perceived components gave the same outcome, we would know that participants who smelled the components had gained nothing by the experience and could therefore have used prior knowledge just as readily as perception. Such a study would be straightforward to perform. We would predict a difference between the estimates of intensity for mixtures of perceived versus those of imaginal components. Irrespective of the outcome, however, we hope that this exchange of views stimulates productive thought on imagery and related issues in a domain where such topics receive but spare attention.

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