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Cross-Modal Associations Between Odors and Colors

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Abstract

In the present study, we investigated the nature of any cross-modal associations between colors and odors. In Experiment 1, we show that participants consistently match certain odors to specific colors when asked to explicitly select from among different colors the one that best matched a given odor. In Experiment 2, we investigated the robustness of these cross-modal associations using a cross-modal variant of the implicit association test (IAT). Participants made speeded discrimination responses to a random sequence of odors (strawberry vs. spearmint) and color patches (pink vs. turquoise). On the basis of the results of Experiment 1, the assignment of these targets onto the two response keys was manipulated in order to generate compatible (e.g., responding to the pink color and to the strawberry odor with the same response key) and incompatible (e.g., responding to the pink color and to the spearmint odor with the same response key) blocks of trials. The results showed that participants responded more rapidly and accurately to odor–color pairings having a stronger association than to those having a weaker (or no) association. These results suggest that odor–color associations can be both systematic and robust. The paradigm developed here provides a novel cross-modal extension of the IAT to probe the nature of color–odor associations.

Key words: color, cross-modal associations, implicit association test, olfaction, vision

Introduction

Many of the odors that we come across in everyday life can be readily described by means of color names. For example, it is more likely that a person would use the word "yellow" to describe the odor of a lemon than the word "blue" if they were asked to describe their olfactory experiences using color terms. Similarly, if you were in a market and suddenly noticed the wonderful smell of ripe strawberries you would look for a fruit that was red rather than for a fruit that was orange. Even though in everyday life the existence of such cross-modal associations between vision and olfaction would appear obvious, to date, surprisingly little research has attempted to investigate this potentially important topic.

Recent research by Gottfried and Dolan (2003) has shown that the presentation of visual stimuli (i.e., complex pictures) can influence olfactory information processing. Gottfried and Dolan (2003) reported that people detected the presence of an odor more rapidly and accurately when a semantically congruent picture was presented at the same time (e.g., the picture of a double-decker bus when smelling the odor of diesel). Cross-modal interactions between olfactory and visual stimuli have been demonstrated at both the behavioral (e.g., Morrot *et al.*, 2001) and neural levels (Österbauer *et al.*, 2005) in a number of other studies, even when the visual input has consisted of nothing more complex than a simple color patch. Gilbert *et al.* (1996; see also Schifferstein and Tanudjaja, 2004) have also demonstrated the existence of stable associations between certain colors and particular odors (e.g., between the color yellow and the odor of bergamot). Interestingly, these associations were shown to be consistent over individuals (at least within the same culture) and to remain stable over time when retested as much as 2 years later. Taken together, results such as these therefore suggest that a reliable multisensory interaction between olfaction and vision can take place even when the visual information consists of only simple stimulus features.

To date, however, all previous studies of color–odor correspondences have required participants to make explicit matches between specific colors and particular odors (Gilbert *et al.*, 1996; Schifferstein and Tanudjaja, 2004). Given that the implicit association test (IAT; Greenwald *et al.*, 1998) has been shown to provide a sensitive measure of the strength of the association between concepts (though see Rothermund and Wentura, 2004) and to be flexible enough to be used in many different behavioral contexts, we thought that it might be possible to extend its use to a cross-modal setting. In particular, we thought that if stable associations between odors and colors do exist, the IAT may represent a reliable paradigm with which to study them.

Participants in IAT experiments typically have to make speeded discrimination responses to targets using two response keys. The grouping of the targets onto responses is normally varied between blocks of trials. The idea being that people should be able to respond more rapidly and/or accurately to targets that share the same response key when the targets have attributes in common than when they do not. So, for instance, it should be easier to make one response to flower names and positive words and another response to insect names and negative words, than to respond to negative words and flower names (or to positive words and insect names) using a particular response (Greenwald *et al.*, 1998). The IAT was primarily developed to study social attitudes and general preferences by presenting unimodal visual stimuli (typically written words; e.g., Greenwald *et al.*, 1998; Banse *et al.*, 2001; Dasgupta and Greenwald, 2001; Karpinski and Hilton, 2001). Recently, however, Vande Kamp (2002, 2003) successfully widened the use of the IAT to a bimodal audiovisual domain by means of stimuli consisting of pictures and environmental sounds. In his study, Vande Kamp was able to highlight people's preferences for certain simple auditory stimuli (e.g., birds vs. insects) and also for more complex categories (such as the voices of European-Americans vs. African-Americans).

One aim of the present study was to determine whether certain of the color–odor correspondences identified previously by Gilbert *et al.* (1996) under conditions of explicit report could be highlighted using a more controlled olfactory delivery system in terms of the duration of exposure, measure of the flow rate, and relative position of the odor source with respect to the participants, thus diminishing the possible sources of variability between them. More importantly, we then wanted to go on to investigate whether any such links would be strong enough to affect performance in the IAT as well (i.e., even when participants were not required to verbalize any specific color–odor associations). If this were to be the case, we would expect to find a facilitation of responses to olfactory and visual targets if the target stimuli were strongly connected (i.e., associated) and shared a common response key, as compared to when they were mapped onto different response keys. Such a result would provide the first empirical support for the claim that color–odor associations are strong enough to be highlighted indirectly.

Previous research has shown that the use of names to label odors can influence people's ratings of the pleasantness, familiarity, and intensity of those odor (Ayabe-Kanamura *et al.*, 1998; Distel and Hudson, 2001), as well as odor detection and hedonic valence judgments (when odors are ambiguous; see Herz and von Clef, 2001; de Araujo *et al.*, 2005). Recently, Herz (2003) demonstrated that verbally cued and verbally uncued olfactory perceptions seem to produce different experiences: the former being guided by verbal information and the latter being guided more by sensory experience. Thus, the effect exerted on the access to such cross-modal (i.e., odor–color) associations by the use of verbal labels to identify the target stimuli was also evaluated in Experiment 2 by providing verbal labels for the odors for a subset of participants but not for the others.

Experiment 1

Methods

Participants

Twenty-one university students (14 females and seven males) with a mean age of 22 years (range of 20–34 years) took part in this experiment. All the participants completed a questionnaire at the start of their experimental session. We only tested those participants who reported having a normal sense of smell with no history of olfactory dysfunction and normal or corrected-to-normal vision. The experiment lasted for approximately 30 min, and the participants were given a £5 UK Sterling gift voucher in return for their participation. The experimental procedure was approved by the Ethical Committee of the Department of Experimental Psychology, University of Oxford.

Apparatus and materials

Six odorants were used in Experiment 1: caramel (28664-35-9 CAS), cucumber, leather, lemon, spearmint, and strawberry (562692, 544427, 406803, 00870, and A118750, respectively, provided by Quest International, UK). All the odorants were diluted at a concentration of 10% in diethyl phthalate (529633, Quest International, UK), except for the caramel, which was diluted at 0.01%, as recommended by Quest International. A custom-built computer-controlled olfactometer was used to deliver the odorants. The olfactometer allowed for the delivery of odorized and odorless air at a flow rate of 8 l/min and was identical in design to that used by Rolls *et al.* (2003). The visual stimuli consisted of 10 color patches ($3.43 \times 2.63°$ in size) displayed on a computer monitor (30.7×23.4 cm in size) in a virtual ring (inner diameter 7.4 cm) centered on the middle of the screen. The colors and the corresponding RGB values were: red (231,0,0), yellow (248,248,0), blue (0,48,255), green (0,85,0), orange (255,85,12), pink (255,0,193), brown (98,48,0), turquoise (0,229,189), purple (99,13,253), and gray (56,56,56). The E-Prime software (Schneider *et al.*, 2002a,b) was used to control the presentation of both the olfactory and visual stimuli and to collect the participants' responses.

Procedure

The participants sat on a comfortable chair, 50 cm from the computer monitor. They were instructed to rest their head on a chinrest to which a nosepiece was attached. The top of the two output tubes of the nosepiece were positioned approximately 3 cm directly below the participant's nostrils.

On each trial, a 100-ms pure tone [500 Hz, 50 dB(A)] was presented from two loudspeaker cones (one positioned on either side of the screen) to cue the participant to inhale so that he/she would be sure to perceive the odor. Each odorant was presented for 4 s prior to the presentation of the color patches. All 10 colors were displayed on the screen until the participant responded. The relative spatial position of each of the color patches was randomly varied on a trial-by-trial basis to ensure that their position on the screen remained unpredictable. The participants were instructed to select the color that they felt most closely matched the odor presented on that trial by pointing to it using the computer mouse and clicking the left-mouse button to confirm their choice. If participants gave a response outside of any of the colored squares, then a message appeared on the screen informing them that he/she had to press one of the color squares in order to proceed to the next trial. After participants had responded, odorless air was delivered for 15 s to extract any residual odor between trials. This protocol also helped to ensure that participants did not habituate to the olfactory stimuli. The experiment consisted of 10 blocks of experimental trials in which each of the six odors was randomly presented once, giving rise to a total of 60 trials per participant. Each block was followed by a short break, and participants rested for 2 min after they had completed 30 trials.

Results

We used a nonparametric χ^2 statistic to test whether the observed color associations for each of the odors deviated from an equal distribution (i.e., were nonrandom). Table 1 shows the results for each of the odors computed from the overall data. Given that we were interested in possible associations between particular odors and specific colors, we conducted *post hoc* χ^2 comparisons (Bonferroni corrected, $\alpha = 0.004$) between the participants' responses to the colors for each of the odors. That is, for each odor condition, the frequencies with which the participants chose each color were compared. Each of the tested odors was significantly associated with at least one color. Surprisingly, while certain of the odors were consistently matched to colors in agreement with their postulated natural associations (e.g., the cucumber odor was matched to the green color), others were associated to colors in a less intuitive manner (e.g., the leather odor to the green, gray, and brown colors). An interesting example is provided by the strawberry odor which was recognized by a number of participants as being similar to the strawberry flavor found in many everyday foodstuffs such as strawberry milkshakes and strawberry-flavored bubble gum. This association is compatible with the frequent choice of the pink color as the best match for this odor, rather than, say, the color red which one might intuitively expect people to match with real strawberries (or perhaps even with the word "strawberry" if presented visually on the screen).

Table 1 Color matches reported by participants in Experiment 1

Odor	χ^2	*P*	Associated colors
Caramel	120.38	<0.0001	Brown (28%), yellow (18%)
Cucumber	270.38	<0.0001	Green (35%)
Leather	278.28	<0.0001	Green (31%), gray (28%), brown (22%)
Lemon	191.52	<0.0001	Yellow (31%), orange (23%)
Spearmint	587.23	<0.0001	Turquoise (59%)
Strawberry	420.85	<0.0001	Pink (42%), red (32%)

Results of χ^2 analysis for each of the odors used in Experiment 1 are reported in the left-hand columns. A significant *P* value implies that participants' color responses to a particular odor were not equally distributed between the 10 available color options (i.e., they responded to certain of the colors on significantly more than 10% of the trials). The right-hand column shows the results for the *post hoc* comparisons (Bonferroni corrected, $\alpha = 0.0037$) used to test for particular odor–color associations, together with the percentage of choices for each color.

Discussion

In Experiment 1, we investigated whether people would consistently match olfactory stimuli with particular colors using a computer-controlled odor delivery system. The results showed that participants chose the odor–color combinations in a nonrandom manner: all the odors presented in the experiment were systematically matched to at least one color, supporting the existence of consistent cross-modal associations between particular odors and colors. The turquoise color was the only color to have been chosen significantly more frequently than chance across the whole experiment (whereas the blue and purple colors were the colors that were chosen least often).

Our results are consistent with those reported by Gilbert *et al.* (1996) in their seminal study of people's ability to explicitly match colors to odors. Gilbert *et al.* (1996) demonstrated the existence of stable associations between specific colors and odors, both between individuals and over time. The major difference in the present experiment was that we were able to demonstrate such links using an experimental setup that allowed for the more controlled presentation of olfactory stimuli. Our results replicate those reported previously using explicit tasks and extend the use of such a task to a population of English participants (vs. the North American participants tested by Gilbert *et al.*, 1996; and the Dutch participants tested by Schifferstein and Tanudjaja, 2004). This is potentially important given that different color–odor associations may be found in different cultural areas (cf. Ayabe-Kanamura *et al.*, 1998). Having demonstrated (and replicated) the existence of robust cross-modal associations between odors and colors using an explicit odor–color matching task in Experiment 1, we next went on to investigate whether we could also highlight the existence of specific odor–color associations more indirectly (i.e., without having to ask the participants overtly about them). Such a result would provide evidence regarding just how strong such cross-modal associations can be. In Experiment 2, we also explored whether labeling the odors would influence the results significantly (cf. Herz, 2003).

Experiment 2

Methods

Participants

Thirty-four new untrained participants (19 females and 15 males) from the University of Oxford, with a mean age of 26 years (ranging from 19 to 34 years), took part in the experiment. All reported having a normal sense of smell and normal (or corrected-to-normal) vision by completing the same questionnaire as used in Experiment 1. All the participants were naive to the purpose of the study.

Apparatus and materials

These were exactly the same as those used in Experiment 1, with the following exceptions. We used the strawberry (A118750) and spearmint (00870, Quest International, Ashford, England) odorants as these odors had been most consistently matched to the colors pink/red and turquoise/green, respectively, in Experiment 1 (see Table 1). The visual stimuli consisted of two color patches (6.44° wide × 4.66° high), one pink and the other turquoise (RGB values 255,0,193 and 0,229,189, respectively), presented at the center of the computer screen.

Procedure

The participants sat on a chair 70 cm from the computer screen, with their head resting on a chinrest. They were instructed to look at the center of the screen and to identify each of the olfactory and visual targets by pressing the "z" or "m" keys on the keyboard, as informed at the start of each block of trials. Just before the onset of each target, a semantic cue (the word "color" or "odor" printed in bold Courier New size 18) was presented for 100 ms from the center of the screen, followed 400 ms later by either a visual target (presented for 100 ms) or an odor target (delivered until a response was made, or the trial was terminated 3000 ms after stimulus onset). The participants were instructed to breathe in slowly through their nose whenever they saw the word odor and to try to respond to every stimulus as rapidly as possible while avoiding making errors. The semantic cues predicted the target modality correctly on every trial (i.e., the cues were 100% valid).

Before the beginning of each block of experimental trials, the participants read a set of instructions presented on the computer monitor by means of which they were informed about the particular assignment of the target stimuli to the response keys. Half of the participants were presented with the verbal labels referring to the target stimuli (e.g., "Press the 'm' key to respond to the strawberry odour and to the pink colour, and the 'z' key to respond to the spearmint odour and to the turquoise colour ···"), while the other half of the participants were familiarized with the target stimuli without being given any verbal cues concerning the identity of the stimuli (e.g., "Now breath in through your nose. When you smell this odour press the 'z' key ···"). One pair of stimuli (e.g., the strawberry odor and the pink color) were assigned to one response key and the other pair of stimuli (e.g., the spearmint odor and the turquoise color) to the other response key. This assignment was manipulated across successive blocks of trials, giving rise to two possible pairings of the visual and olfactory stimuli to each response key (compatible and incompatible; see Table 2). Compatible trials occurred when the odor and color mapped onto the same response key were considered to be more easily associated on the basis of the results of Experiment 1 (e.g., the color pink and the strawberry odor). Likewise, incompatible trials occurred when the odor and the color sharing the same response key were less easily associated (e.g., the color pink and the spearmint odor). Both the assignment of the stimuli to the response keys and the order of presentation of the various conditions were counterbalanced across participants with compatible and incompatible response mappings alternating over successive blocks of trials.

The experimental session consisted of four blocks of 24 randomized trials each (96 trials in total) and lasted for approximately 30 min in total. In order to minimize any possible carryover effect from the presentation of the odors, the interstimulus interval was set at 7000 ms. Clean medical air was continuously delivered through the olfactometer except when the olfactants were being presented.

Results

The mean reaction time (RT) data for each participant on trials where he/she correctly discriminated the identity of the targets were filtered and responses falling 2.5 standard deviations or more from the participant's mean for each condition were considered as outliers and discarded from any further analysis (i.e., less than 2% of trials overall). The data from one participant were discarded from any subsequent analyses because all the data in one specific condition were missing. The remaining data were submitted to two repeated-measures analyses of variance (ANOVAs; one for the accuracy data and the other for the RT data), with the within-participants factors of response mapping

Table 2 Sample stimulus-to-response assignments in Experiment 2

Response key		
Condition	z	m
Compatible	Spearmint + turquoise	Strawberry + pink
Incompatible	Spearmint + pink	Strawberry + turquoise

(compatible vs. incompatible) and target modality (olfactory vs. visual) and the between-participants factor of whether or not the target stimuli were labeled verbally (labeled vs. unlabeled). The analysis of the accuracy data revealed no significant main effect of the presence versus absence of verbal labels, $F(1,31) = 1.25$, NS. The accuracy of participants' responses varied significantly as a function of the compatibility of the two stimuli mapped onto the same response key, resulting in a main effect of response mapping, $F(1,31) = 17.74$, $P < 0.001$. The participants responded more accurately in the compatible response mapping blocks (M = 96%) than in the incompatible response mapping blocks (M = 90%) and when responding to visual targets (M = 95%) than when responding to olfactory targets (M = 91%). This latter difference led to a significant main effect of target modality, $F(1,31) = 6.02$, $P < 0.05$ (see Figure 1a). None of the terms involving the verbal label factor approached significance.

The analysis of the RT data revealed no main effect of verbal labels, $F < 1$. Just as for the analysis of the accuracy data, there were main effects of both response mapping, $F(1,31) = 35.63$, $P < 0.001$, and target modality, $F(1,31) = 440.70$, $P < 0.001$. Participants responded more rapidly in the compatible response mapping blocks (M = 1129 ms) than in the incompatible response mapping blocks (M = 1307 ms) and to visual target stimuli (M = 728 ms) than to olfactory target stimuli (M = 1307 ms; see Figure 1b). In contrast to the analysis of the accuracy data, however, there was a significant interaction between the presence versus the absence of verbal labels and response mapping, $F(1,31) = 4.98$, $P < 0.05$. A subsequent t-test comparison on the IAT effect (i.e., the difference between the mean RT in the incompatible and compatible blocks of trials) revealed that the group of participants for whom the target stimuli were labeled showed a significantly larger IAT effect (M = 244 ms) than those who were familiarized with the targets without any specific verbal labels to identify the stimuli being provided [M = 111 ms; $t(31) = 2.23$, $P < 0.05$]. This result supports the idea that the magnitude of the IAT effect can be modulated by the use of semantic labels and, in particular, suggests that the use of verbal labels may influence a person's access to specific odor–color associations. The interaction between verbal label and target modality just failed to reach significance, $F(1,31) = 3.35$, $P = 0.08$. The interaction between verbal label, target modality, and response mapping was not significant, $F < 1$.

A subsequent ANOVA was also performed on the response data from just those participants for whom the odors

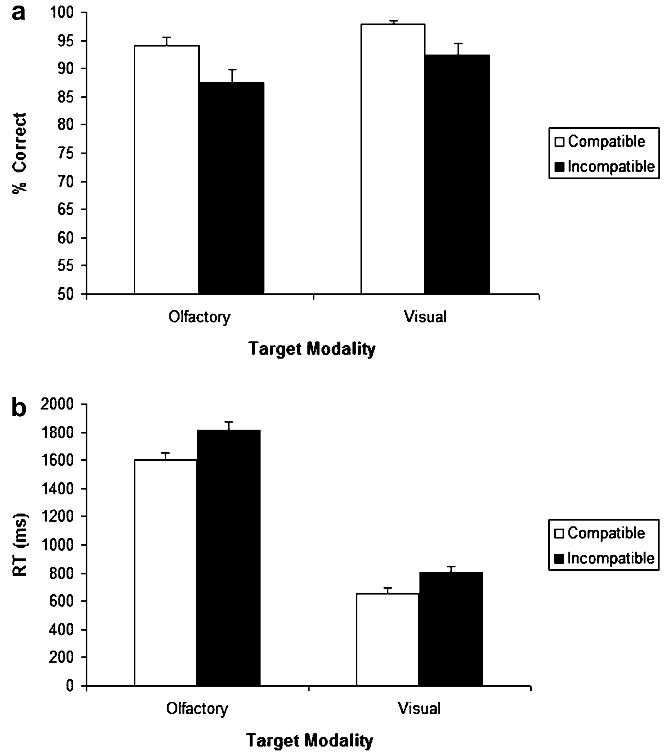

Figure 1 Mean percentage of correct responses to the olfactory and visual targets as a function of the compatibility of the stimulus-response mapping in Experiment 2: compatible (open bars) and incompatible (filled bars): **(a)** Percentages of correct responses. **(b)** Mean reaction times. Error bars represent the standard errors of the means.

were not verbally labeled in order to directly verify the magnitude of any compatibility effects in this condition. The accuracy data analysis revealed a significant main effect of response mapping, $F(1,16) = 4.86$, $P < 0.05$, compatible with the results described above (compatible blocks, M = 96%; incompatible blocks, M = 92%). The main effect of target modality, $F(1,16) = 2.06$, NS, and the interaction between the two factors, $F < 1$, did not reach statistical significance. With regards to the analysis of the RT data, there were main effects of both response mapping, $F(1,16) = 12.96$, $P < 0.01$, and target modality, $F(1,16) = 284.67$, $P < 0.001$, due to the fact that, as expected, participants responded more rapidly on compatibly mapped trials (M = 1183 ms) than on incompatibly mapped trials (M = 1294 ms) and to colors (M = 791 ms) than to odors (M = 1686 ms) overall. The interaction between the factors was not significant, $F(1,16) = 1.72$, NS. These results thus showed in more detail the presence of a cross-modal compatibility effect (and its magnitude) in a task where there was no use of any verbal labels to describe the odors.

Discussion

The primary aim of Experiment 2 was to determine whether the IAT could be used to demonstrate the existence of associations between specific colors and odors, given that the IAT has only been studied using unimodal visual stimuli (and in one case, bimodal audiovisual stimuli; Vande Kamp, 2002, 2003) in previous research. Our results provide support for the existence of a privileged cross-modal association between specific olfactory stimuli and colors. Moreover, our results show that such cross-modal associations can be strong enough to influence performance in tasks that do not rely on explicit cross-modal matching. In Experiment 2, the participants were not required to explicitly express any association between the odors and colors but instead simply to discriminate each unimodally presented visual and olfactory target stimulus. Nevertheless, the participants still responded significantly more rapidly and accurately when they used a particular response key to respond to compatible olfactory-color target mappings than when responding using an incompatible mapping. The fact that performance was better overall in the compatible blocks of trials than in the incompatible blocks supports there being a robust association between these colors and odors, which can influence speeded responses as well as unspeeded intentional cross-modal matches. Our results therefore provide the first empirical evidence that the IAT can be used to study cross-modal associations involving olfactory stimuli.

The second issue addressed by Experiment 2 was whether the presence versus absence of verbal labels to identify the target stimuli would have led to a difference in the access to the cross-modal color–odor associations. The results show that these associations can be accessed even when no verbal context (i.e., identifying names) was given to the participants, supporting the reliability of the extension of the use of the IAT in cross-modal nonverbal studies.

General discussion

The results of the two experiments reported in the present study further our understanding of the cross-modal associations that exist between olfactory and visual stimuli and, in particular, the link between odors and colors. In Experiment 1, we demonstrated the systematic nature of the perceived correspondence between specific odors and certain colors. In Experiment 2, we chose the two odor–color combinations that had given rise to the most consistent cross-modal matches in Experiment 1; using these stimuli, we devised a modified cross-modal version of the IAT to assess the strength of these associations (using an indirect measure of performance). Our results support the existence of specific cross-modal associations between odors and colors that are stable enough to be highlighted under conditions where these associations were not directly relevant to the participants' task. In particular, the participants in our study were explicitly instructed to associate pairs of stimuli onto the response keys, but this was required for every possible combination of target stimuli. If the link between specific odors and colors were to have been unrelated to some preexisting association, one would not have expected to find any specific difference in the pattern of participant's performance on ''compatible'' versus ''incompatible'' blocks of trials.

It is possible that the effects reported in the present study may reflect interactions between olfactory and visual information taking place at a cognitive level. Indeed, in Experiment 1, the participants were explicitly asked to choose the color that (in their opinion) best matched the odor that they were presented with. Therefore, it may be that the olfactory stimulation could have mediated access to any semantic knowledge related to the odor (such as its color). This could also have been the case in Experiment 2 and may account for the associations that we were able to highlight behaviorally. In particular, the odors themselves may have activated the semantic information related to them (such as perhaps the color that in nature is more often combined or associated with them). This account is also consistent with the fact that the majority (24 out of 34) of the participants who took part in Experiment 2 appeared (on postexperimental questioning) to have been aware of the existence of some form of congruence/incongruence between the olfactory and visual target stimuli that were used.

The difficulty people often experience in naming even very familiar odors has usually been interpreted in terms of a lack of activation of the semantic information related to the olfactory stimuli. This phenomenon (known as the ''tip-of-the-nose'' phenomenon) has often been cited as providing evidence against the semantic access account of olfactory perception (e.g., Gilbert *et al.*, 1996; Lawless and Engen, 1977). Dalton (2002) has suggested a possible solution to this problem, namely, that odors may be dually encoded within the cognitive system by means of both verbal and visual representations. According to Dalton (2002), olfactory information activates semantic knowledge to differing degrees depending upon a number of factors such as, for example, the person's familiarity with the particular odors that are used (see also Davis, 1975, 1977). Therefore, the presentation of highly familiar odors, such as those used in Experiment 2, may have provided ready access to a multisensory network involving both olfactory and visual information, which might in turn have generated differences in performance, that would presumably reflect the degree of compatibility of the particular odor–color pairing. This is compatible with the fact that almost all the participants in the no-labels group of Experiment 2 who perceived the existence of associations between the target stimuli (13 out of 16) could easily name the odors on the postexperimental questioning as ''mint'' or ''tooth-paste'' and as ''strawberry'' or ''bubble gum,'' confirming their familiarity to the odors and probably reflecting an easy accessibility to a number of information related to them.

An interesting question for future research will be to try and determine how such cross-modal associations are generated. One possibility is in terms of some kind of associative learning process (e.g., Blake, 2004) which has recently been used to account for interactions taking place between gustation and olfaction (e.g., Stevenson *et al.*, 1998; Stevenson and Boakes, 2004). The human brain appears to be sensitive to the repeated presentation of specific combinations of odors and tastes and to be able to rapidly create stable correspondences between these co-occurring unisensory inputs. Cross-modal associations between specific odors and particular colors may rely upon a similar mechanism: that is, an object will often be perceived visually first, and the information regarding its color would be encoded together with any other visual properties associated with the stimulus; next, the same object would be experienced through the other sensory modalities, such as, for instance, through touch and smell (e.g., Sakai *et al.*, 2005). The systematic combination of olfactory and color properties of an object through associative learning could therefore account for the existence of stable cross-modal associations. However, it must be said that the evidence available to date concerning people's ability to effectively learn arbitrarily combinations of odors and visual stimuli (e.g., words, colors, etc.) is not particularly encouraging (e.g., see Davis, 1975, 1977; Schab, 1991; Bowers and Doran, 1994). Further research is thus needed in order to try and verify the relative importance of a number of factors in this specific form of olfactory associative learning, such as odor familiarity, odor identification (i.e., naming), and stimulus order presentation.

It would also be interesting in future research to investigate possible cultural differences in color–odor associations since the availability and the frequency of the use of particular stimuli (e.g., fruits or spices) changes between different geographical zones and/or populations (cf. Ayabe-Kanamura *et al.*, 1998; Stevenson and Boakes, 2004). For instance, it might come as little surprise to find differences between Europeans and North Americans in terms of the colors that they would perceive as best matching the odor of cinnamon. For while in Europe, the smell of cinnamon is frequently associated with the naturally occurring spice of the same name (i.e., a brown color); in North America, it is often associated with red sweets (candy). These differences may be very relevant in the field of sensory marketing because they may have an influence on a consumer's choice of a particular product (e.g., a perfume). Indeed, Schifferstein and Tanudjaja (2004) recently observed that people find it easier to reliably match a fragrance with colors differing in brightness rather than those differing in hue. Their results would appear to be perceptual in nature; nevertheless, it is still possible that cultural effects could be highlighted on these perceptual correspondences (cf. Dalton *et al.*, 2000). By using a different task, differences between individuals might be expected depending upon the particular culture in which the participant grew up (see Ayabe-Kanamura *et al.*, 1998).

Another intriguing question for future research is related to the role played by multisensory perceptual integration in modulating cross-modal interactions between olfactory and visual stimuli such as those reported here (e.g., Allen and Schwartz, 1940; Calvert *et al.*, 2004). Previous research has highlighted a number of examples of odor–color interactions taking place at relatively early (or low) levels of information processing. For example, the existence of correspondences between the intensity of odors and the brightness of colors highlighted by Kemp and Gilbert (1997) and perceived correspondences between colors, odors, and even sounds that were often reported in earlier studies (e.g., Ryan, 1940; though see also Cohen, 1934; Börnstein, 1936). Therefore, at present, it seems rather uncertain what role cross-modal perceptual interactions (i.e., multisensory integration effects) play in the creation and maintenance of these cross-modal associations between colors and odors.

It is important to consider the results reported here within the wider debate regarding the various different interpretations that have been put forward to explain "what" is being measured in the IAT (e.g., see Klauer and Mierke, 2005; Rothermund and Wentura, 2004; Steffens, 2004; Back *et al.*, 2005; De Houwer *et al.*, 2005; Kinoshita and Peek-O'Leary, 2005; Rothermund *et al.*, 2005). Recently, De Houwer *et al.* (2005) put forward a hypothesis that appears capable of integrating the majority of different viewpoints on this topic. They suggested that the IAT may measure the similarity between stimuli in terms of some of their qualities, such as their meaning, their salience, or their perceptual features. Here, we suggest that the common element between the odors and the colors we used may have been semantic in nature, even though we do not exclude the possibility that perceptual similarities between the target stimuli might have played a role in the performance differences that we highlighted.

In conclusion, the olfactory and visual sensory systems appear to share robust and consistent associations. Particularly interesting in the present context is that these links can influence performance even when they are not overtly involved in the task at hand (Experiment 2). The results reported here therefore represent the first evidence of the effects of multisensory interactions between olfaction and vision using an indirect measure of association.

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