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Sniffing the distance: Scents can make objects appear closer

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ABSTRACT

Judging distances between oneself and objects in the environment is vital. Such distance judgments are based mostly on visual cues. But can smelling an object also affect how close the object appears? Building on sensory distance theory, we suggest that scents can make objects seem physically closer. We investigate this effect across four studies (total $N = 479$) using a range of scents, objects, and distances. Leading to predictable estimation biases, the effect emerges regardless of scent salience and holds across different scent delivery modes: directly from an object (Study 1), surrogate via vial (Study 2 and 3), and ambient (Study 4). The biasing influence of scent persists even when the accuracy of estimates is incentivized (Study 2) and is stronger when cognitive resources are unconstrained (Study 4). While the effect emerges even when scents emanate from targets that are typically unscented (e.g., notepad; Study 1), it is attenuated when the scent is not associated with the target (Study 3). These findings highlight a novel role of scent in spatial cognition and hold implications for distance perception and distancing behaviors.

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1. Introduction

Distance judgments are *relevant* in our daily lives. Such judgments affect neural and behavioral responses involved in approaching, freezing, and fleeing (Löw et al., 2015; Mobbs et al., 2007; Yu et al., 2014) and are thus crucial for attaining rewards and avoiding threats. Mental representations of one's environment include estimated distances in spaces and between objects, rendering distance judgments vital for navigating our surroundings (Loomis et al., 1996). From an evolutionary perspective, judging distances between oneself and targets in the environment accurately and quickly is linked to adaptive behavior. Accurate distance judgments can help maintain desired distances to other people and objects. For example, in settings with contagion risks (such as during a pandemic), judging distances accurately can contribute to reduced pathogen transmission and thus, lower the likelihood of catching and spreading the contagious element (Fazio et al., 2021).

Distances are perceived primarily via vision; thus, visual cues are the most salient signals when deciding how close the target in the immediate environment is (Kunnapas, 1968). However, visual input is not the only sensory input we are exposed to in the physical world. Given that perception is multisensory (Krishna, 2012), the presence of other sensory cues plausibly also affects distance estimates (Klatzky, 1998). In this research, we take the novel approach of investigating whether and how object scents can affect distance judgments. While no academic research has examined this topic, there has been some reference to this possibility in the marketplace. For example, though likely intended as a pun, the candle company *Scent and Sip* has introduced a distancing-inspired scented candle with the tagline "If you can smell this, you are too close" (Scent and Sip, 2020). *Burger King* even suggested that food smells can help regulate physical distances (Beer, 2020). Beyond these humorous marketplace examples, scent as a distance signal is also acknowledged in linguistic metaphors, such as "within sniffing distance," implying close physical proximity (Collins, n. d.). Finally, a scent is an additional sensory input, and it is plausible that people will draw on this input, like they do for other sensory cues, such

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as sounds (Kolarik et al., 2016) or haptic feedback (Lederman et al., 1985), when judging distances. But does the presence of an object's scent actually help or hinder the accuracy of distance judgments?

Building on sensory distance theory (Hall, 1966; Rodaway, 1994), we suggest and, through four experiments, demonstrate that an object's scent can bias rather than improve distance judgments. Specifically, we suggest that it can make the object seem physically closer. To our knowledge, this research is the first to provide evidence for the role of olfaction in visual distance perception in humans. Thus, beyond adding to the literature on spatial and sensory perceptions, it adds to the literature on judgment biases that may hold practical implications for individuals, businesses and policymakers interested in estimating or keeping distances.

1.1. Sensory cues and physical distance judgment

Intuitively, distance estimations seem to be related to visual perceptions (Gibson, 1979; Proffitt, 2006). Thus, distance judgment is typically based on visual cues such as a target's apparent size (Epstein et al., 1961), perception of its surface details (Gibson, 1979), the visual angle between the perceiver's eyes and the distant target (Sedgwick, 1986), and the angularity of distance (Raghubir, 2008; Raghubir & Krishna, 1996). However, distance perception is not merely visual and cues in other sensory modalities can also affect spatial perception and visual distance judgment (Klatzky, 1998). Specifically, auditory cues such as loudness and presence or absence of high-pitch sounds (Kolarik et al., 2016; Rabaglia et al., 2016), as well as haptic cues such as hand and arm movements (Lederman et al., 1985), can affect physical distance perception. Here, we propose that olfaction can also influence physical distance judgment. Specifically, we suggest that the presence of the scent of an associated object biases distance judgments such that the object is judged as being nearer. We elaborate on this next.

1.2. Olfactory cues and physical distance judgment

The effect of olfactory cues on people's ability to judge the distance to visible and physically present objects has not yet been investigated. To our knowledge, the only research that comes close to this topic is research that studied the effects of olfactory cues on feelings of proximity (Ruzeviciute et al., 2020). This research found that printed ads that were infused with the scent of the advertised product could induce a sense of physical proximity to these advertised products, in particular, if the products were absent. However, the effect of scent substantially diminished when the advertised product was physically present (Study 4), which is in line with the authors' key argument that an object's scent can instill the pseudo-presence of an object. This research thus informs us about olfaction's ability to generate feelings of proximity to physically absent objects. It does not, however, tell us whether scents can also affect people's cognitive distance judgments to physically present objects.

Yet, the role of scent in accurately estimating one's immediate environment has been documented in research on navigation and orientation. Though not directly linked to distance judgments specifically, studies have indicated that humans, like many other animals (e.g., Wikelski et al., 2015; Zhang et al., 2021), can use scents for navigation and orientation (Hamburger & Knauff, 2019; Jacobs et al., 2015; Porter et al., 2007). Notably, the presence of olfactory cues can enhance navigation accuracy (Jacobs et al., 2015). However, there is a crucial difference between navigation and distance judgment. Navigation to a given target or location usually pertains to situations in which the target cannot be seen. In these cases, olfactory cues can help to compensate for the lack of visual information and facilitate localization and navigation accuracy (Jacobs et al., 2015; Porter et al., 2007). In contrast, when judging the distance to a visible target, olfactory cues are not needed to determine whether or where the target is present. Therefore, we argue that scent can serve as an informative proximity signal when judging distances to visible scent-emitting targets.

We develop our hypothesis by building on work in the domain of sensory distance theory (Elder et al., 2017; Hall, 1966; Rodaway, 1994), which suggests that the maximum physical distance at which a cue can be perceived in a given sensory modality can affect distance judgments. Visual and auditory cues can travel relatively long distances, as they are transmitted respectively by light and sound waves (Köster, 2002; Rodaway, 1994). Thus, far-away objects can be seen or heard, and conversely, things seen or heard could be far away. Haptic and gustatory sensations require direct physical contact with the object, and hence merely feeling or tasting an object unambiguously indicates extreme proximity (Rodaway, 1994).

The maximal distance at which olfactory cues (i.e., scents) can be perceived is intermediate between the other modalities. Scents consist of molecules that emanate from a scent-dispersing object (Dyson, 1938), and factors such as the scent's intensity, the ambient temperature, and the prevailing wind conditions affect the range of scent dispersion (Dyson, 1938; Silberberg, 2011). However, since scent is typically encountered in the presence of its emitter, scents may signal physical proximity to an associated object. Proximity to a physical target by itself may also signal its accessibility and reachability, thereby biasing physical distance perceptions towards a lower magnitude. In fact, reachability of objects affects distance perception, with reachable objects judged as being closer (Osiurak et al., 2012; Witt & Proffitt, 2008).

Taken together, we suggest that people incorporate scents beyond visual cues when making distance judgments and that the presence of an object's scent will make them estimate the distance to the object as shorter (i.e., closer). Since this effect is contingent on scents being processed as informative, we predict that this effect occurs when a scent is associated with an object but not when it is not. That is, we predict that the effect is not simply due to people paying attention to olfactory input. Given that the influence of scent is largely automatic (De Luca & Botelho, 2021; Holland et al., 2005), we suggest that the biasing influence of scent on distance judgment will persist even upon unrestrained cognitive capacity or enhanced motivation for judgment accuracy.

1.3. Overview of the studies

We investigate the predicted effect of scent on distance judgment in four studies, across various objects and distances, and using different scents and scent delivery modes (see Table 1 for an overview). Study 1 aimed to provide an initial test of our hypothesis that perceiving an object's scent will decrease distance perception, using two targets that emitted scents: an object that is typically scented (i.e., soap) and an object that is not typically scented (i.e., notepad). Study 2 aimed to replicate the hypothesized effect in a field setting. Additionally, it tested whether the effect also occurs when task motivation is high. We accordingly offered a financial incentive for accurate distance estimates. Study 3 aimed to explore whether the biasing influence of scent is contingent on its attribution to the target object (orange). Finally, Study 4 aimed to test the generalizability of the hypothesized effect with a

Table 1
Summary of stimuli and methods.

Study	Scent	Delivery Method	Target	Actual Distance to Target (m)
1	Lavender	Object	Soap bar	1.49 or 1.94
	Mint	Object	Notepad	1.49 or 1.94
2	Popcorn	Vial	Popcorn	22.5
3	Orange	Vial	Orange	5.17
	Mint	Vial	Orange	5.17
4	Vanilla	Ambient	Candle	1.44

Notes: "Object" indicates that participants directly smelled the target object, "Vial" indicates that participants sniffed a vial containing scented liquid, and "Ambient" indicates that the scent was infused in the ambient air.

different scent delivery mode (ambient scent), and to explore the influence of cognitive load on the proposed effect as another way of probing into the automatic nature of the effect.

To determine the sample sizes for the studies, we initially drew on previous research investigating effects of scent on different spatial perceptions (Hamburger & Knauff, 2019; Jacobs et al., 2015; Ruzeviciute et al., 2020). However, because effect sizes in those prior studies varied substantially from medium (Jacobs et al., 2015; Ruzeviciute et al., 2020) to large (Hamburger & Knauff, 2019), we also conducted a pilot study in the lab (see Appendix A for details) to obtain an initial estimate of effect size more directly relevant to our research. The effect size of the pilot (Cohen's d = 0.59) coincided with Jacobs et al. (2015) and Ruzeviciute et al. (2020). We next conducted an exploratory power analysis using G*Power 3.1 (Faul et al., 2009). It showed that 74 participants (80% power) were needed to detect such an effect size in a two-cell design. Therefore, we targeted a sample of at least 37 participants per condition whenever we were able to exert control over the actual sample size. Variations in cell sizes are due to participant allocation and availability in the subject pools available to us.

To facilitate comparison of effects across distances and studies, we report a *distance index* that is a ratio of perceived distance to actual distance (see Table 2 for results across studies). A score of 1.00 indicates a perfectly accurate estimate, whereas scores less (more) than 1.00 indicate underestimates (overestimates). For data analyses across all studies, consistent with the approach used in past studies (e.g., Sparkman et al., 2021), we excluded all distance estimates that deviate 3 or more *SDs* from the mean (henceforth referred to as "outliers"). No covariates were included in the main analyses across studies.

2. Study 1

Study 1 tested our hypothesis that perceiving an object's scent decreases actual distance judgments (in cm). We tested the generalizability of the effect across objects that are typically scented (i.e., a soap bar) or not typically scented (i.e., a notepad). We predicted that the proposed effect would hold across object types as long as a scent is attributed to an object. Additionally, we assessed object appeal, since scents can increase product liking (Bone & Jantrania, 1992; Bosmans, 2006), and apparent object size as alternative explanations that can affect distance perception (Balcetis, 2016; Epstein et al., 1961). We also assessed feelings of proximity (Ruzeviciute et al., 2020), which may also be triggered by olfactory cues and could plausibly influence distance judgments.

2.1. Methods

2.1.1. Participants

In total, 153 students (76 female; $M = 22.01$ years; excluding one outlier [3 SDs from the distance estimation mean]) from a large European university completed the study that had a 2 (scent: present vs. absent [between-subjects factor]) x 2 (object: soap vs. notepad [within-subjects factor]) mixed design study.

Table 2
Main results: Distance estimation across studies.

	Scent		No Scent		Effect	
	M (SD)	*N*	*M (SD)*	*N*	*t*	Cohen's *d*
Study 1						
Soap bar	0.66 (0.18)	77	0.78 (0.18)	76	4.12	.67***
Notepad	0.65 (0.18)		0.78 (0.17)		4.73	.74***
Study 2	0.80 (0.27)	43	1.00 (0.56)	37	2.09	.47*
Study 3[a]	0.76 (0.12)	35	0.86 (0.18)	28	2.67	.68*
Study 4						
Low load	0.68 (0.21)	41	0.87 (0.37)	29	2.75	.67**
High load	0.71 (0.21)	38	0.75 (0.20)	44	0.86	.19

*$p < .05$, **$p < .01$, ***$p < .001$.
Notes: Distance estimates are based on a distance index that is calculated by dividing the perceived distance by the actual distance.
[a] Scent condition refers to the Associated-scent condition. There was a third Unassociated-scent condition: $M = .86$, $SD = .19$ ($N = 31$); Associated vs. Unassociated scent: $t = 2.43$, $d = .60$*.

2.1.2. Procedure

The research project was approved by the Ethics Committee of a large European university (Protocol number 70131–5). Participants took the study in individual testing cubicles equipped with a chair and a table. Upon starting the study, participants were exposed to two objects, a soap bar and a notepad, presented one at a time with the order counterbalanced. Both objects were placed in transparent boxes and either scented (soap = lavender, notepad = mint) or not. Under the guise of facilitating visual inspection of the objects, the experimenter opened the first box in front of the participant's face, thus either emitting a scent (i.e., manipulated between subjects) and enabling scent attribution (scent-present condition) or not (scent-absent condition). The box was then placed on a specific location on table (1.49 m [~4′11"] away from the participant; the location was inconspicuously marked on the table before study sessions; see Appendix B for stimuli). Subsequently, participants estimated the distance to the object and reported on the control measures (described below). This procedure was then repeated with the other object, which was placed at the other location on table (1.94 m [~6′4"] away from the participant).

2.1.3. Measures

Participants reported distance estimates by indicating perceived distance to both targets in centimeters ("How far away is this soap [notepad] placed from you?"). We assessed object appeal via two items (interitem correlation: Pearson $r = 0.66$, $p < .001$): liking ("How much do you like this soap [notepad]?"; 1 = not at all, 7 = very much) and desire ("How much would you like to have this soap [notepad] for yourself?"; 1 = not at all, 7 = very much). Additionally, participants reported on felt object proximity ("How far away does the soap [notepad] feel from you?"; 1 = very near, 7 = very far) and indicated apparent object size ("How large do you think this soap bar [notepad] is?"; length and width in centimeters). An object size index was estimated by dividing the perceived object area (length X width in centimeters) by the actual object area. As a check for the scent manipulation, participants were asked to indicate "How strongly does this soap [notepad] smell?" (1 = doesn't smell at all, 7 = smells very strongly). Finally, participants indicated their height (which can affect distance perceptions [Proffitt, 2006]) and whether they had any cold symptoms (which can affect scent perception [Åkerlund et al., 1995]). See Appendix C for the main measures and scales across all studies.

2.2. Results and discussion

First, we ran a 2 (scent: present, absent; between-participants) × 2 (object: soap, notepad; within-participants) mixed ANOVA on the manipulation check. As intended, participants in the scent condition ($M = 4.56$, $SD = 2.18$) perceived the objects as smelling more strongly than participants in the unscented control condition ($M = 2.19$, $SD = 1.57$; $F(1, 151) = 102.97$, $p < .001$, Cohen's $d = 1.25$). This effect of scent interacted with the object ($F(1, 151) = 8.83$, $p = .003$), but planned contrasts confirmed that the presence of a scent increased perceived scent for both the scent-typical object (soap; $t(151) = 11.10$, $p < .001$, $CI_{95\%}$ [0.26, 2.38], Cohen's $d = 1.79$) and the scent-atypical object (notepad; $t(151) = 5.82$, $p < .001$, $CI_{95\%}$ [0.32, 1.23], Cohen's $d = 0.94$). Thus, our manipulation of object scent was successful (see Table 3 for means and SDs).

Next, we investigated the main hypothesis via a 2 (scent) × 2 (object) mixed ANOVA on the distance index. As predicted, the main effect of scent was significant ($F(1, 151) = 23.44$, $p < .001$, Cohen's $d = 0.67$). Distances were more significantly underestimated when the object was scented ($M = 0.66$, $SD = 0.18$) than when it was unscented ($M = 0.78$,

Table 3
Means and mean differences of control variables across studies and conditions.

	Study 1			
	Soap		Notepad	
	Scent	Control	Scent	Control
	M (SD)	M (SD)	M (SD)	M (SD)
Appeal	4.36 (1.11)[a]	3.71 (1.32)[b]	4.69 (1.23)[a]	4.79 (1.19)[a]
Felt proximity	4.01 (1.57)[a]	4.19 (1.66)[a]	4.05 (1.40)[a]	4.15 (1.50)[a]
Size index	1.20 (0.57)[a]	1.30 (1.13)[a]	1.29 (1.39)[a]	1.63 (3.10)[a]
Scent intensity	2.50 (1.60)[a]	5.39 (1.62)[b]	1.88 (1.50)[a]	3.74 (2.35)[b]
	Study 2			
	Scent	Control	–	–
	M (SD)	*M (SD)*		
Scent liking	3.49 (1.76)	–		
	Study 3			
	Associated scent	Unassociated scent	Control	–
	M (SD)	*M (SD)*	*M (SD)*	
Scent liking	5.09 (1.63)[a]	4.81 (1.62)[a]	–	
	Study 4			
	Low load		High Load	
	Scent	Control	Scent	Control
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Pleasantness	5.09 (1.10)[a]	4.79 (0.93)[a]	5.17 (0.94)[a]	4.78 (1.15)[a]
Arousal	3.80 (1.17)[a]	3.95 (1.14)[a]	4.11 (1.26)[a]	3.73 (1.19)[a]
Difficulty remembering	1.80 (1.38)[a]		4.30 (1.99)[b]	

Notes: Different superscripts ([a] [b]) indicate significant differences at $p < .05$. Comparisons underlying superscript differences are per object in Study 1, per cognitive load condition in Study 4 and across associated and unassociated scent conditions in Study 3. Same superscripts ([a] [a]) indicate nonsignificant differences between comparisons.

$SD = 0.18$; see Table 2 for results across conditions). There was no main effect of object ($F(1, 151) = 0.14$, $p = .71$, Cohen's $d = 0.03$) nor an interaction with scent ($F(1, 151) = 0.32$, $p = .57$). Adding participants' cold symptoms as a covariate (0 = no, 1 = yes/had recently) did not emerge as a significant covariate ($F(1, 150) = 0.05$, $p = .82$) and did not change the pattern of the above-reported effects. The nonsignificant interaction highlights that the effect of scent on distance judgments held for both the soap (an object which is usually scented) and the notepad (which usually is not scented).

The effect of scent remains unaltered when analyses are conducted per individual object (soap: $M_{scent} = 0.66$, $M_{control} = 0.78$; $t(151) = 4.12$, $p < .001$, $CI_{95\%}$ [0.06, 0.18], Cohen's $d = 0.67$; notepad: $M_{scent} = 0.65$, $M_{control} = 0.78$; $t(151) = 4.73$, $p < .001$, $CI_{95\%}$ [0.08, 0.19], Cohen's $d = 0.74$; see Table 2).

Finally, we explored the influence of scent on the control variables. A 2 (scent) × 2 (object) mixed ANOVA showed that neither presence of scent ($F(1, 148) = 0.53$, $p = .47$, Cohen's $d = 0.10$) nor object type ($F(1, 148) = 0.00$, $p = .99$, Cohen's $d = 0.00$) or their interaction ($F(1, 148) = 0.06$, $p = .81$) affected felt object proximity (see Table 3 for means). Further bolstering the uniqueness of the observed phenomenon, no main effects of scent ($F(1, 151) = 0.73$, $p = .39$, Cohen's $d = 0.13$), object type ($F(1, 151) = 2.03$, $p = .16$, Cohen's $d = 0.12$) or their interaction ($F(1, 151) = 0.71$, $p = .40$) were observed for the perceived object size index (see Table 3 for means). These findings show that the effect is not a mere downstream effect resulting from a feeling of proximity (Ruzeviciute et al., 2020) or the result of a corresponding visual bias affecting perceived object size.

Effects of scent ($F(1, 151) = 3.51$, $p = .06$, Cohen's $d = 0.24$) and object type ($F(1, 151) = 29.15$, $p < .001$, Cohen's $d = 0.57$) on object appeal were qualified by the factors' interaction ($F(1, 151) = 8.42$, $p = .004$). Post-hoc analysis revealed that scent increased appeal of the soap ($M_{scent} = 4.36$, $M_{control} = 3.71$, $t(151) = 3.31$, $p = .001$, $CI_{95\%}$ [0.26, 1.04], Cohen's $d = 0.54$; see Table 3), but not the notepad ($t(151) = 0.52$, $p = .61$, $CI_{95\%}$ [−0.29, 0.49], Cohen's $d = 0.08$; see Table 3). These findings are in line with prior literature. Olfactory cues are more effective in enhancing appeal of products for which scent is a focal product attribute, as in the case of soap (Ruzeviciute et al., 2020). Nevertheless, soap appeal did not correlate with distance estimation ($r = -.03$, $p = .68$), suggesting that the observed effect of scent on distance judgment is not due to liking of or desire for the target.

3. Study 2

Study 1 showed that our proposed effect is not contingent on scent typicality or scent-induced object appeal when distances to objects are relatively short. Situated in a field setting, Study 2 provides further tests for the robustness of the phenomenon. First, it aimed to examine whether the effect generalizes to surrogate scents, such as scents administered via a vial rather than the object itself. Second, we also increased the actual distance, thus making the judgment task more difficult. A popcorn bowl was situated 22.5 m away from the place at which participants were asked to stand. Finally, we aimed to test whether the observed bias emerges when people are motivated to make accurate judgments. We thus provided a monetary incentive to encourage estimation accuracy. Given that the influence of scent is largely automatic (De Luca & Botelho, 2021), we predicted that distance estimates would be shorter with scent (vs. no scent) even upon incentive availability and the fact that the scent clearly did not directly emit from the object.

3.1. Methods

3.1.1. Participants

We recruited 80 participants (30 females; $M = 22.43$ years; excluding two outliers [3 SDs from the distance estimation mean]) on the campus of a large European university to participate in a two-cell between-subjects design study.

3.1.2. Procedure

Participants were told that this study aimed to gauge students' opinions about the availability of popcorn on campus. This cover story served to avoid potential demand effects that might be associated with knowing the purpose of the study. Participants were asked several questions about popcorn (see Appendix C) and were then asked to look at a popcorn bowl placed on a table 22.5 m (~73′10″) away (see Appendix B for the study setting). We told all participants that the popcorn could be potentially available on campus. Critically, as part of the cover story, participants in the scent condition sniffed a vial containing the scent of popcorn and then rated their liking of this scent. They were informed that this scent is the actual scent of the popcorn in the bowl. Participants in the no-scent group did not smell or evaluate any scent. All participants then estimated distance to the popcorn bowl. To incentivize accuracy, we informed participants that the most accurate estimate would win a €10 voucher. At the end of the study, participants provided their email addresses (which were used to contact the voucher winner and then deleted) and were debriefed.

3.1.3. Measures

Participants estimated the distance by indicating the distance to the popcorn bowl in meters ("How far from you is the popcorn bowl in front?"). Participants in the scent condition also rated liking of scent on a 7-point scale ("How much do you like this scent?"; 1 = not at all, 7 = very much). We used this variable to assess scent liking as a potential confounding factor.

3.2. Results and discussion

As predicted, and despite financial incentivization of accuracy, an independent samples *t*-test revealed that exposure to the popcorn scent significantly reduced distance estimates ($M_{scent} = 0.80$, $M_{control} = 1.00$, $t(78) = 2.09$, $p = .04$, $CI_{95\%}$ [0.01, 0.39], Cohen's $d = 0.47$; see Table 2). The presence of a scent reduced the accuracy of distance judgments. Liking of the scent ($M = 3.49$; see Table 3) was unrelated to distance estimates ($r = 0.05$, $p = .73$). These results show that enhancing participant motivation for judging distances accurately does not eliminate the biasing influence of scent, suggesting that the effect occurs non-consciously.

4. Study 3

The studies so far showed that the effect of scent on distance judgment emerges whenever participants assume that the scent originates from the object, even when the object is not usually scented (Study 1) or when it is presented indirectly via a vial. These findings are in line with our theorizing, but they are not able to rule out an important alternative possibility. It could be that smelling scents per se, regardless of their source, can bias distance judgments. For example, scents trigger affective reactions (Herz & Engen, 1996), which in turn affect perceived proximity (Cole & Balcetis, 2013). In Study 3, we address such a possibility and test whether the presence of *any* scent or only associated scents can influence distance perception. Since scents convey identities of specific targets (Yeshurun & Sobel, 2010), which is key to their informativeness (Ruzeviciute et al., 2020), we predict that only an associated but not an unassociated scent will decrease distance perceptions. As in prior studies, we also generalize insights to another target object, an orange fruit.

4.1. Methods

4.1.1. Participants

We recruited 105 students. Ninety-four participants (52 female; $M = 22.97$ years; excluding nine participants who misunderstood the task[1] and two outliers [3 SDs from the distance estimation mean]) were retained for final analyses.

4.1.2. Procedure

We placed an orange fruit 5.17 m (~16′12") away from the participant's location and asked them to estimate the distance to the orange (see Appendix B for the study setting). We used an orange because oranges have a clearly distinguishable and familiar scent (González et al., 2006). Depending on the condition, participants first sniffed either a vial containing orange scent (*associated-scent*), a vial containing mint scent (*unassociated-scent*) or were not asked to sniff any vial (*control*). We reinforced an association between the object and the scent by informing participants that the scent in the vial is a scent of an orange or fresh chewing gum, in the associated and unassociated conditions, respectively. In both scent conditions, participants rated liking of the scent before estimating the distance to the orange on the table. Participants in the control condition did not smell or rate any scent.

4.1.3. Measures

Participants reported distance estimates (in meters and centimeters) to the orange fruit in front of them ("How far away is this orange placed from you?"). Scent liking (only in the scent conditions) was gauged using the same measure as in Study 2 ("How much do you like this scent?"; 1 = not at all, 7 = very much).

4.2. Results and discussion

An ANOVA revealed that distance estimates differed significantly across conditions ($F(2, 91) = 3.90$, $p = .02$). Participants in the *associated-scent* condition underestimated the distance significantly more ($M = 0.76$) than participants in both the *unassociated-scent* condition ($M = 0.86$; $t(64) = 2.43$, $p = .02$, $CI_{95\%}$ = [0.02, 0.17], Cohen's $d = 0.60$) and the *control* condition ($M = 0.86$; $t(61) = 2.67$, $p = .01$, $CI_{95\%}$ = [0.03, 0.17], Cohen's $d = 0.68$; see Table 2). There was no difference between the *unassociated-scent* and *control* conditions ($t(57) = 0.14$, $p = .89$, $CI_{95\%}$ = [0.05, 0.10], Cohen's $d = 0.04$). Olfactory cues, thus only biased visual distance estimates to the object when the scent was likely to emanate from the object. Notably, liking of the scent did not differ between the *associated* (orange scent, $M = 5.09$) and *unassociated* conditions (mint scent, $M = 4.81$; $t(64) = 0.70$, $p = .49$, $CI_{95\%}$ = [−1.08, 0.53], Cohen's $d = 0.17$; see Table 3), and scent liking was unrelated to distance estimates ($r = -0.11$, $p = .36$).

The result of this study shows that a scent that is not associated with the target does not bias distance estimates. This study thus rules out potential alternative accounts that relate to the potentially biasing influence of scent per se or the mere act of sniffing. Rather, we find support for our proposition that attribution of scent to an object is needed for the effect of scent on distance judgment to emerge.

5. Study 4

Study 4 aimed to deepen our theoretical understanding of the effect and reaffirm our prior insights in three ways. First, we tested whether the influence of scent might be affected when cognitive constraints are induced. Precisely estimating distances is a cognitive task. Cognitive tasks can be hampered by cognitive load (Credé et al., 2020; Glasauer et al., 2007; Klatzky et al., 2006), which we manipulated in this study. Given that the effect had already emerged even when people were incentivized to provide accurate distance judgments (probed in Study 2), manipulating cognitive load provides another test for the presumed non-deliberate nature of the effect (Raghubir, 2008).

Second, Study 4 directly addressed the potential competing explanation of affect. Study 3 provides some evidence against this possibility by highlighting that the effect only emerges for an associated scent. To provide conclusive insights on the possible mediating role of affect, we directly measured it in Study 4.

Third, Study 4 generalizes results to the prevalent practice of scent infusion via ambient air (e.g., Lefebvre & Biswas, 2019). This procedure allows us to gauge whether our findings would generalize to common settings in which people pay no particular attention to scents. Given that people are able to process scents automatically, we anticipate that the observed bias will remain even when people are not alerted to the presence of the scent. Finally, we also generalize our insights to another target object, a candle.

5.1. Methods

5.1.1. Participants

One hundred fifty-two students (66 female; $M = 21.78$ years; excluding one participant who failed the cognitive load task[2] and three outliers [distance estimates that deviate more than 3 SDs from the mean]) completed the study.

5.1.2. Procedure

Participants were randomly induced with high or low cognitive load

[1] Participants who estimated distance to the vial rather than the target, as observed by the research assistant, were excluded. The average distance indicated by these participants was $M = 37.78$ cm, whereas the target object was more than 5 m away.

[2] Participant who recalled fewer than 4 of the 9 letters (Chun & Kruglanski, 2006).

by rehearsing a nine- (**zgnlwczqr**) or two-letter (gb) combination, respectively, until the end of the experiment session (Chun & Kruglanski, 2006; see Appendix C for the instructions). Next, they were escorted to individual testing cubicles and were seated in a chair. In each cubicle, a pillar candle stood on a Table 1.44 m (~4′9″) away from the back of the participant's chair. We infused half of the cubicles with a scent by applying 10 drops of candle-congruent vanilla scent (based on a pretest, $N = 25$) on paper strips that were hidden behind the table. The cubicles in the control condition were unscented. Subsequently, participants were asked to provide distance estimates to the candle and answer a few control questions.

5.1.3. Measures

Participants estimated how far away the candle was in centimeters ("How far away is this candle placed from you?"). Participants also reported their affective state, by rating how pleasant (unhappy/happy, unsatisfied/unsatisfied; interitem correlation: Pearson $r = .49$, $p < .001$) and aroused (calm/excited, unaroused/aroused; interitem correlation: Pearson $r = .32$, $p < .001$; all on 7-point scales) they feel. Finally, as a check for our cognitive load manipulation, we asked participants to reproduce the combination of letters they had been requested to remember and to indicate how difficult it was to remember the letters (1 = very difficult, 7 = very easy, reversed-coded).

5.2. Results

A 2 (scent: present, absent) × 2 (cognitive load: low, high) between-participants ANOVA on perceived difficulty of remembering the letters showed that the manipulation of cognitive load was successful (F (1, 148) = 80.14, $p < .001$, Cohen's $d = 1.44$). Participants reported greater difficulty in remembering the letters in the high load condition (M = 4.30) than in the low-load condition ($M = 1.80$; see Table 3). Scent did not affect the reported cognitive load levels (F (1, 148) = 0.84, $p = .36$, Cohen's $d = 0.04$), nor did scent interact with cognitive load (F (1, 148) = 1.41, $p = .24$).

Next, a 2 (scent) × 2 (cognitive load) ANOVA on distance estimates corroborated our prior findings: The candles were judged to be nearer when a congruent scent was present in the ambience ($M_{\text{scent}} = 0.70$, $M_{\text{control}} = 0.80$; F (1, 148) = 8.08, $p = .01$, Cohen's $d = 0.41$). There was no main effect of cognitive load (F (1, 148) = 1.23, $p = .27$, Cohen's d = 0.11) but a marginal interaction (F (1, 148) = 3.48, $p = .06$). When cognitive load was low, as in our preceding studies, ambient scent significantly reduced distance estimates ($M_{\text{scent}} = 0.68$, $M_{\text{control}} = 0.87$; t (68) = 2.75, $p = .01$, $CI_{95\%}$ = [0.05, 0.33], Cohen's $d = 0.67$). However, when cognitive load was high, scent did not further reduce distance estimates ($M_{\text{scent}} = 0.71$, $M_{\text{control}} = 0.75$; t (80) = 0.86, $p = .39$, $CI_{95\%}$ = [−0.13, 0.05], Cohen's $d = 0.19$). In line with prior research (Glasauer et al., 2007), when there was no scent present, cognitive load reduced distance estimates directionally ($M_{\text{low load}} = 0.87$, $M_{\text{high load}} = 0.75$; t (71) = 1.81, $p = .08$, $CI_{95\%}$ = [−0.01, 0.25], Cohen's $d = 0.43$). When the scent was present, however, cognitive load had no effect on distance estimates ($M_{\text{low load}} = 0.68$, $M_{\text{high load}} = 0.71$; t (77) = 0.64, $p = .52$, $CI_{95\%}$ = [−0.13, 0.06], Cohen's $d = 0.14$). Scent thus does not appear to decrease distance estimates further when other cognitive constraints are present. It seems that the biasing effect of scent is particularly pronounced when people have the cognitive capacities to counteract other potential biases that also appeared to decrease distance judgments (see Table 2).

Although participants felt more pleasant when a scent was present ($M_{\text{scent}} = 5.13$, $M_{\text{control}} = 4.79$; F (1, 148) = 3.89, $p = .05$, Cohen's d = 0.33), this affective experience did not relate to distance estimates, r = 0.06, $p = .44$. Cognitive load neither affected pleasantness ratings (F (1, 148) = 0.05, $p = .82$, Cohen's $d = 0.001$) nor interacted with scent (F (1, 148) = 0.08, $p = .78$). No effects of scent (F (1, 148) = 0.36, $p = .55$, Cohen's $d = 0.11$), cognitive load (F (1, 148) = 0.04, $p = .84$, Cohen's d = 0.03) or their interaction (F (1, 148) = 1.77, $p = .19$) were observed for arousal (see Table 3 for pleasantness and arousal means across conditions).

6. Discussion

Prior research has shown that people estimate distances based on visual, auditory and haptic cues (Gibson, 1979; Kolarik et al., 2016; Lederman et al., 1985; Proffitt, 2006; Raghubir & Krishna, 1996). Across four studies, we show for the first time that object scents can also affect visual distance judgments. The presence of an object's scent biased participants by making them underestimate the actual distance to the object. This bias emerged across a range of distances (i.e., from 1.44 to 22.5 m) and objects, including objects that are not typically scented (Study 1). It also emerged across different scent presentation methods, including situations in which people are fully aware that the scent cannot directly come from the object, such as when sniffing from a vial (Studies 2 and 3), and situations in which they are not alerted to the presence of the scent, such as when the scent is ambient (Study 4).

This suggests that the effect may be rather automatic so that it cannot be overcome via conscious attempts at debiasing. In particular, two studies that focused on cognitive capacity and task motivation (see Raghubir, 2008) lend support to such an automatic nature of the effect. In Study 2, the effect emerged when distance estimation accuracy was incentivized. In Study 4, high, compared to low cognitive capacity (manipulated via cognitive load) even helped rather than hindered the effect. The effect thus clearly emerged in situations in which people had the capacity and the motivation to come up with accurate distance estimates.

Moreover, this bias was unrelated to affect (Study 4), which is frequently linked to olfaction (Herz & Engen, 1996; Roschk & Hosseinpour, 2020), and it did not emerge because of differences in liking of the scents (Studies 2 and 3), perceived object appeal (Study 1), the apparent size of the scented target (Study 1) or felt object proximity (Study 1). However, in line with our theorizing, the bias did not emerge when the scent was not associated with the object (Study 3). The effect is thus not a general reaction to the presence of scents in the environment but arises when scents are attributed to the object and, thus, are potentially informative.

Overall, the findings of our research suggest a novel effect of olfaction on spatial judgments that operates in a non-deliberate yet object-specific manner. Theoretically, this insight contributes to the literature on spatial cognition (e.g., Klatzky, 1998; Loomis et al., 1996) and adds to the evidence on sensory influences, such as haptic or auditory cues (Kolarik et al., 2016; Lederman et al., 1985) on distance judgment. It also enriches the literature on multisensory perception (Doucé et al., 2014; Krishna, 2012; Park & Hadi, 2020), particularly the emerging body of research that investigates olfactory effects on spatial perception (Hamburger & Knauff, 2019; Madzharov et al., 2015; Porter et al., 2007), extending the prior work on scent-guided navigation in humans (Hamburger & Knauff, 2019; Jacobs et al., 2015; Porter et al., 2007). While prior research shows that scents can enhance navigation accuracy in settings when targets are not visible (Jacobs et al., 2015), we demonstrate that in the context of distance judgment to visible targets, scents reduce accuracy towards the lower magnitude. The addition of an olfactory cue appears capable of reducing the accuracy of a judgment that can more reliably be made via drawing on vision only.

We also add to recent research on scent and experience of distance (Ruzeviciute et al., 2020). Notably, our results highlight that it makes sense to distinguish between visual distance perception and felt proximity in the realm of sensory influences. While scents appear to trigger feelings of proximity for absent objects (Ruzeviciute et al., 2020), they appear to bias visual distance judgments for present objects. Notably, Study 1 suggests that these effects may even be unrelated.

Our research highlights several important but unexplored avenues for future research. Although we tested the effect across a range of objects, we cannot be sure that it would generalize to all sorts of objects.

For example, we did not test the effect on particularly disgusting or desirable objects. It is possible that strong object appeal may overrule or interact with the effect of scents.

Relatedly, future research could investigate the role of scent characteristics in driving the effect. In the current studies, we used neutral or positive scents. Highly aversive or appetitive scents that trigger avoidance or approach motivation may attenuate, strengthen or reverse this effect (cf., Balcetis, 2016). Scent intensity is another characteristic that warrants future research attention. While the results across studies were robust despite different scent delivery modes that assured less (i.e., in the ambiance or on the product) vs. more intense (e.g., in the vial) scent presence, the actual intensity of scent might accentuate or moderate the proposed effect. This is because scents tend to be more intense around scent-emitting objects due to higher molecular concentration (Silberberg, 2011). Notably, environmental factors, such as airflow, could disperse these molecules, and thus affect intensity of scent (Baker et al., 2018). Therefore, future research could also investigate whether the effect of scent on distance perception holds under turbulent (vs. still) airflow conditions.

In line with the focus of this research, our examination pertained to scents and distances judged to inanimate objects. It is unclear whether our observed effect would generalize to an interpersonal context when the target emitting the scent is a human herself (e.g., wearing fragrance). Pleasant scents can increase human attractiveness (Seubert et al., 2014), and human attractiveness can trigger approach tendencies (Balcetis, 2016), which could potentially overrule the bias we detected for objects.

Individual's ability to judge distances might also influence the strengths of the effect. People who are preoccupied with distance estimation daily, for example, professional drivers or athletes, can judge distances more accurately than the general public (Durgin et al., 2012; Peruch et al., 1989). Therefore, such individuals might be less susceptible to this bias.

It would also be interesting to explore whether our documented effect holds when scent is imagined. Olfactory imagery, like imagery induced by other imagined sensory cues (e.g., haptic cues, Peck & Shu, 2009), can activate the same brain regions (González et al., 2006) and elicit similar behavioral responses (Krishna et al., 2014) as an actual sensory cue (e.g., scents). Therefore, such a generalization is plausible, though the automatic nature of the observed effect suggests that the effect might be weaker in settings in which no actual scent is present.

Beyond exploring boundaries and extensions of our proposed effect, it would be important to investigate its cognitive correlates and downstream consequences on other spatial behaviors, such as navigation. If olfactory cues can bias distance perception, it seems plausible that it affects the broader mental representation of a person's surroundings. Relatedly, it may also well be that it affects locomotion. For example, if upon the presence of scent, attributed visible targets are represented as closer, speed or movement patterns might be adjusted accordingly. Similarly, scent induced distance perception might yield a difference in reaction times related to the target supposedly emitting the scent. Such potential downstream effects of scent might hold powerful implications for how people navigate their immediate surroundings. In sum, there is scope for significant additional research in this topic domain.

Our findings also hold practical implications that may be of public and commercial interest. Physical proximity to targets in the environment can influence purchase intentions (Esmark & Noble, 2018), product choice (Xu et al., 2012) and perceptions (Jia et al., 2017; Thomas & Tsai, 2012). Our results suggest that beyond enhancing mood or providing olfactory sampling opportunities (Roschk & Hosseinpour, 2020), ambient or point-of-sale scenting solutions could make products appear closer. In turn, this could affect people's anticipated ability to reach a product. While most of our studies operated with distances that are beyond a person's peripersonal space, at relatively close proximity, product-congruent scents could nudge people to reach out for products from farther away. Given that scents exert their influence on distance perception only if they are associated with the target object (Study 3), localized scent diffusion appears to be critical to induce such potential effects.

Notably, distance estimation has become very important in the recent pandemic. Because proximity to other people could entail health-related consequences (Fazio et al., 2021), different distance approximation cues have been suggested and implemented. These cues were predominantly visual, such as actual distance markets or creative distance estimation analogies via body parts or animal size comparisons (Wissgott, 2020). Since distances to scented targets are underestimated, our findings suggest that olfactory cues in a service environment (e.g., placing clearly identifiable fragrant objects nearby service employees or customers waiting in line), could be a helpful tool in regulating social distances too.

Finally, our results may be considered in conjunction with emerging technologies. Recent developments in sensory technology, such as multisensory masks or olfactory virtual reality (VR) devices (Schott, 2022), might soon extend the practical relevance of this research to the VR retailing and metaverse.

7. Conclusion

This research highlights a novel role of scents in distance perception by humans. Across four studies, using different distances, scents and objects, we show that scents of specific targets can make them appear physically closer. Our findings suggest that this effect emerges in a non-deliberate yet object-specific manner, as only target-associated scents can exert this biasing influence. Overall, our research shows that olfaction can influence spatial cognition and can yield a robust cognitive bias that goes beyond the many established olfactory effects, such as enhanced affective reactions, target appeal, or felt proximity. We hope that this research inspires future research as well as practice.

Author statement

R. Ruzeviciute and B. Kamleitner developed the study concept. All authors contributed to the design of the studies. Data were collected, analyzed and interpreted by R. Ruzeviciute under the supervision of B. Kamleitner and Z. Estes. R. Ruzeviciute, B. Kamleitner and Z. Estes wrote the manuscript and D. Biswas provided critical revisions. All the authors approved the final version of the manuscript for submission.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2023.102104.

Appendix A

8. Pilot study

8.1. Method: participants, procedure and measures

Given that olfactory effects on distance perception have not been investigated before, we conducted a pilot study to test for preliminary evidence of an effect and an estimate of its size. Fifty-five participants (33 females; $M = 24.95$ years) from a large US university participated for course credit.

The target object was a soap bar. In fact, we purchased two identical soap bars that were originally scent-free. One of the bars was maintained in its original scent-free state, serving as a "no-scent" control stimulus. We created a scented stimulus by adding four drops of lavender essential oil to the other soap bar. Thus, the two versions of the stimulus were visually identical and differed only in the presence (or absence) of lavender scent. Participants were randomly assigned (in groups) to either the scent or no-scent condition.

The experiment was conducted in groups of eight participants or fewer. Upon arriving at the lab, each participant was seated at one of eight locations around a large table, with each chair remaining in a fixed location (i.e., participants were prevented from moving the chairs). The experimenter handed out a questionnaire and then presented a soap bar, which was either scented or not. The experimenter carried the soap around the room, stopping at each participant ostensibly to allow for a detailed visual inspection and finally placing it on a pre-specified mark on the table. This procedure ensured that all participants were subtly exposed to the soap's scent (or lack thereof). Participants were then asked to estimate the distance to the soap in inches. Finally, participants were asked for their height (which can affect distance perceptions) and whether they had any cold symptoms (which can affect scent perception).

8.2. Results and Discussion

The reported analyses exclude one participant whose distance estimate was more than 3 *SDs* from the group mean. There was no significant difference among conditions in participants' height ($p = .97$) or presence of cold symptoms ($p = .26$). Since the different seats around the table were not equidistant to the soap (from 1.79 m to 2.64 m [~5′10.5 to 8′8]), participants' distance estimates were put into relation to the respective actual distance (i.e., ratio of perceived to actual distance). This standardized *distance index* was also used in the main experiments reported in the paper. As predicted, distance estimates were significantly shorter when the soap bar was scented ($M = 0.53$, $SD = 0.30$) than when it was unscented ($M = 0.69$, $SD = 0.22$), $t(52) = 2.12$, $p = .04$, Cohen's $d = 0.59$. When included as covariates in an ANCOVA, neither participant height nor cold symptoms (0 = no, 1 = yes) were significant (p's $>$. 90), and the effect of scent on distance estimates remained significant ($p = .04$).

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