Speed, L. J., Papies, E. and Majid, A. (2023) Mental simulation across sensory modalities predicts attractiveness of food concepts. *Journal of Experimental Psychology: Applied*, 29(3), pp. 557-571. (doi: [10.1037/xap0000461](https://doi.org/10.1037/xap0000461))

There may be differences between this version and the published version. You are advised to consult the published version if you wish to cite from it.

http://eprints.gla.ac.uk/304877/

Deposited on 16 August 2023

Mental simulation across sensory modalities predicts attractiveness of food concepts

Laura J. Speed[1]

Esther K. Papies[2]

Asifa Majid[3]

[1]Centre for Language Studies, Radboud University, Nijmegen, Netherlands

[2]School of Psychology, University of Glasgow, Glasgow, UK.

[3]Department of Experimental Psychology, University of Oxford, Oxford, UK.

Corresponding author:

Laura Speed

Radboud University

Nijmegen

Netherlands

laura.speed@ru.nl

Acknowledgements

Competing interests statement.

The authors have no competing interests to state.

Abstract

Concepts are grounded in mental simulation of sensory information, but the exact role it plays in everyday cognition is unknown. Here we investigate its role in an important conceptual domain relevant for everyday behavior—food. We conducted two pre-registered studies to test whether multimodal mental simulation is linked to attractiveness of food concepts. In Study 1, using the Lancaster Sensorimotor norms for a variety of concepts, we found unhealthy food concepts are more strongly associated with gustation, olfaction, and interoception, than healthy food concepts. Importantly, these associations mediated the relationship between food healthiness and food attractiveness. In Study 2, we collected new sensory ratings with food words only, and found unhealthy food concepts were more strongly associated with all perceptual modalities than healthy food concepts. Again, these associations mediated the relationship between healthiness and attractiveness. The mediating role of sensory associations to food attractiveness was also affected by context. Specifically, when participants thought about food in an eating context cued by verbal instruction, mediation by perceptual strength was weaker. Overall, we find multimodal sensory experience underlies people's belief that unhealthy food is more attractive than healthy food. This suggests mental simulation has an important role in goal-directed behavior.

Keywords: sensory language; food; conceptual representation; sensorimotor norms; mental simulation

Public significant statement: Unhealthy food words are more strongly associated with sensory experience than healthy food woods. This stronger sensory association explains why unhealthy food is considered more attractive than healthy food. This has implications for

improving eating behavior as it suggests sensory associations could be used strategically to

make healthy food more attractive.

1. Introduction

Concepts are grounded in sensorimotor systems (Barsalou, 1999; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). A concept like *moon*, for example, may be represented through activations in the brain's visual system, whereas a concept like *velvet* may instead be represented more dominantly as tactile activation. Activation of the brain's sensory systems via language is known as mental simulation. Mental simulation can be considered a form of mental imagery that occurs during language comprehension. Some have argued mental simulation is less consciously activated than mental imagery (Barsalou, 1999), while others have debated whether mental imagery can also occur involuntarily (e.g., Pearson, Naselaris, Holmes, & Kosslyn, 2015). Evidence from behavioral studies support recruitment of sensorimotor systems during language comprehension (e.g., Kaschak, Zwaan, Aveyard, & Yaxley, 2006; Meteyard, Bahrami, & Vigliocco, 2007; Zwaan & Taylor, 2006) and imaging (e.g., Hauk, Johnsrude, & Pulvermüller, 2004; Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995), yet there is little understanding of the precise role mental simulation plays in everyday cognition and how mental simulation during language comprehension may affect real-world behavior. In this study, we explore whether mental simulation is related to the attractiveness of food.

Food is a domain where mental simulation of sensory information is relevant. Eating is a multisensory activity, beginning with the visual appearance of the food, moving to food aroma through the nose and mouth, to the mouthfeel, and overall taste (Auvray & Spence, 2008; Shepherd, 2006; Spence, 2015). Imagining flavor is also more vivid than imagining odor (a component of flavor) alone (Andrade, May, Deeprose, Baugh, & Ganis, 2014), suggesting there is elaborate sensory activation when thinking about eating food. This sensory experience can be reactivated with food cues, such as viewing pictorial images of food (Chen, Papies, & Barsalou, 2016; Simmons, Martin, & Barsalou, 2005; Spence, Okajima, Cheok,

Petit, & Michel, 2016; van der Laan, de Ridder, Viergever, & Smeets, 2011). Overall, research suggests the experience of food leaves a strong sensory stamp in memory which can be reactivated later via mental simulation.

Understanding the role of mental simulation in the representation of food is important to address ongoing struggles in public health, such as unhealthy food choices. Obesity is a serious concern, in particular, the overconsumption of high-calorie, energy-dense foods. One explanation for the overconsumption of unhealthy food is that it is considered tastier, and therefore more attractive, than healthy food (Raghunathan, Naylor, & Hoyer, 2006). In particular, people prefer food they perceive to be unhealthy not "despite its unhealthiness", but "because of it" (Raghunathan et al., 2006, p. 170). Several studies have shown that people expect food to taste better, enjoy food more, and choose it more often when it is portrayed as unhealthy rather than healthy (e.g., described as containing more versus less fat, or described explicitly as "very healthy" versus "unhealthy"; Raghunathan et al., 2006). Moreover, belief in this so-called "unhealthy = tasty intuition" is associated with reduced consumption of vegetables and a higher BMI (Briers, Huh, Chan, & Mukhopadhyay, 2020). The degree of this association differs between consumers and between product categories (Haasova & Florack, 2019). Nonetheless, better understanding of the mental representation of food, and how such associations with food attractiveness and healthiness are grounded in the cognitive system can potentially help design interventions to change unhealthy eating habits, for example, by making attractive features of healthy food more salient.

Beyond taste, sensory information in other modalities may also be important in the attractiveness of unhealthy and healthy food. Initial evidence suggests people differentially associate healthy and unhealthy food concepts with the senses. Papies (2013) asked participants to generate features for unhealthy attractive foods (e.g., *chips, cookies*) and healthy, neutral foods (e.g., *cucumber*, *apple*) and found people listed features related to the

sensory experience of eating food (e.g., *crunchy*, *sticky*) more for unhealthy foods than healthy foods. This suggests mental simulation of sensory information more strongly underlies unhealthy food concepts than healthy food concepts. A similar finding has been observed for drinks: participants list more sensory experiences for sugary drinks compared to water and alcohol (Keesman et al., 2018), and listing such consumption simulation features predicts desire and ingestion (Papies, Claassen, Rusz, & Best, 2021). Although these experiments demonstrate the tremendous variability of participants' representation of food and drinks, with hundreds of unique features listed per item, the role of individual sensory modalities was not explored.

If unhealthy foods are mentally represented more strongly by mental simulation— specifically simulations of eating experience—then this could explain why unhealthy food is more attractive. Specifically, the grounded cognition theory of desire suggests mental simulation of consumption behavior (such as eating) leads to desire (Papies, Barsalou, & Rusz, 2020; Papies, Best, Gelibter, & Barsalou, 2017). The theory outlines how appetitive cues (e.g., seeing food, looking at images of food, or reading food words) can activate mental simulation of consuming food. This mental simulation is thought to contain rich sensory information extracted from previous eating experiences. Re-enacting pleasurable sensory content activates reward signals in the brain which can trigger desire for the associated food (Papies, 2013), making the food appear more attractive. This proposal has similarities with the elaborated intrusion theory of desire which places conscious mental imagery as a key element in both associative and elaborated mental representations preceding states of desire (Kavanagh, Andrade, & May, 2005). Supporting the two theories, participants salivate more when they mentally simulate consuming food vividly compared to when they simply look at the same foods (Keesman, Aarts, Vermeent, Häfner, & Papies, 2016). Food cravings also increase after imagining eating food compared to imagining being on holiday (Harvey,

Kemps, & Tiggemann, 2005), and increase more for vice products (considered high in hedonic reward, e.g., a packet of crisps) than virtue products (considered high on a utilitarian dimension, e.g., a green smoothie) (Muñoz-Vilches, van Trijp, & Piqueras-Fiszman, 2019, 2020).

Multisensory mental simulation may increase food attractiveness even more than mental simulation of taste alone (Elder & Krishna, 2010). Indeed, visual and olfactory mental imagery unrelated to food has been shown to reduce food cravings, implicating a causal role of visual and olfactory mental imagery in food cravings (Kemps & Tiggemann, 2007). One limitation to previous studies examining a broader range of sensory modalities is they typically only test one or a few food items in a single study. This limits the generalizability of findings and means the reliability of outcomes is unknown. Moreover, it remains unclear which specific sensory modalities are involved in food attractiveness.

Beyond explicit mental imagery or mental simulation instructions, there is evidence food descriptions highlighting sensory properties can increase the attractiveness of healthy and sustainable food (Papies, Johannes, Daneva, Semyte, & Kauhanen, 2020; Turnwald et al., 2019; Turnwald & Crum, 2019; Turnwald, Jurafsky, Conner, & Crum, 2017). Across several studies, taste-focused or "indulgent" language in cafeteria food labels (e.g., *Sizzlin' Szechuan Green Beans with Toasted Garlic*) led to increased selection and consumption of vegetables compared to health-focused language (e.g., *Nutritional Green Beans*; Turnwald et al., 2019; Turnwald, Boles, & Crum, 2017; Turnwald & Crum, 2019, see also Papies, Johannes, et al., 2020). This suggests such descriptions activate mental simulations of sensory information which increase the attractiveness of vegetables and subsequently increase selection and consumption. Although the food descriptions used in the studies were carefully designed in order to evoke positive taste and reward expectations, it is unclear exactly what semantic aspects of the descriptions led to increased attractiveness. Descriptions could be successful

because they activate representations of taste, other sensory modalities, or something else such as emotion associations or general positive affect. For example, it has been shown that the relationship between explicitly imagining eating a cereal bar and desire for the cereal bar is mediated by the valence of the imagined eating experience (Muñoz-Vilches et al., 2020).

1.1. The current study

In order to specifically test the role of mental simulation evoked by descriptions, the present study assessed the contribution of sensory associations to a range of healthy and unhealthy food concepts presented as individual words, and tested the role of mental simulation across sensory modalities in food attractiveness. To do this, we examined ratings of sensory strength across perceptual modalities using sensorimotor ratings of food words (also known as modality ratings; Lynott & Connell, 2009; Lancaster Sensorimotor Norms: Lynott, Connell, Brysbaert, Brand, & Carney, 2020). Sensorimotor ratings reflect participants' sensory associations with word meanings across the perceptual modalities of vision, audition, gustation, olfaction, haptics, and interoception, and are therefore thought to reflect mental simulation. By rating experience on a 5-point scale, a fine-grained measure of a concept's multimodal representation can be obtained. Sensorimotor ratings can tell us about the role of sensory modalities in word meaning (Strik Lievers & Winter, 2018; Winter, 2016, 2019; Winter, Perlman, & Majid, 2018), predict behavioral responses to words (Connell & Lynott, 2014; Lynott & Connell, 2009; Lynott et al., 2020; Speed & Brysbaert, 2020; Speed & Majid, 2017; Vergallito, Petilli, & Marelli, 2020) and explain language use (Winter, 2016, 2019; Winter, et al., 2018), and are therefore a valid methodological tool with which to explore mental simulation.

We first used the existing sensory modality ratings of English words from Lynott et al. (2020) for healthy and unhealthy food concepts to assess whether the mental representation of food differs depending on its healthiness. In order to assess whether mental simulation plays a

role in the desire for food, we collected ratings for the attractiveness and healthiness of a range food concepts. We then tested whether the relationship between healthiness and attractiveness is mediated by mental simulation, as predicted by the grounded cognition theory of desire (Papies et al., 2017). Specifically, we hypothesized: (H1a)[1] unhealthy foods would be associated more strongly with gustation, olfaction, and interoception, than healthy foods. We also assessed two composite measures of perceptual strength: modality exclusivity and Minkowski3. Modality exclusivity refers to how multimodal a word meaning is, and Minkowski3 is a composite measure of perceptual strength in which the influence of weaker modalities are attenuated. We investigate these two measures because elsewhere they have been shown to sufficiently capture the role of sensory information in word processing in a single variable (Lynott et al., 2020). We predicted that (H2a) unhealthy food words would be more multimodal than healthy food words and (H3a) have higher Minkowski3 scores. Following the "unhealthy = tasty intuition" (Raghunathan et al., 2006) we hypothesized (H4a) unhealthy foods would be perceived as more attractive than healthy foods. In addition, we predicted (H5–7) simulation across sensory modalities would be associated with increased attractiveness of food (Papies, 2013). Crucially, we hypothesized (H8) unhealthy foods are more attractive because they are more associated with gustatory, olfactory, and interoceptive simulation. In other words, we predicted the relationship between food healthiness and attractiveness is mediated by sensory simulation. Overall, then, we aimed to establish whether mental simulation plays a role in food attractiveness.

This study builds on previous work in several important ways. First of all, we assessed sensory associations and attractiveness for a large number of food concepts. Previous studies

---

[1] Hypothesis numbers refer to hypotheses outlined in the pre-registration (https://osf.io/e7wt8/). Here we present hypotheses with healthiness as a categorical variable, however we also hypothesized a negative effect of healthiness as a continuous variable.

are often limited to only a few foods or a single experimental trial per participant (Elder &
Krishna, 2010; Harvey et al., 2005; Keesman et al., 2016; Kemps & Tiggemann, 2007;
Muñoz-Vilches et al., 2019; Raghunathan et al., 2006), which precludes conclusions about
generalizability across foods. Second, we looked at the individual effects of each sensory
modality rather than focusing only on taste or the more abstract concept of food. Finally,
when participants were asked to rate food attractiveness, we did not give explicit instructions
to mentally simulate or imagine. This means we can assess the sensory contributions to food
concepts in a more naturalistic, unconscious, manner, in line with a critical distinction made
between mental simulation (unconscious) and mental imagery (conscious; Barsalou,1999; but
see ongoing discussions about the relation between mental simulation and mental imagery
e.g., Ibañez et al., 2022).

2. Study 1

2.1. Methods

We used existing sensory norms from Lynott et al. (2020) that contained sensory ratings for a
large number of words, as well as collecting new ratings of healthiness, attractiveness, and
familiarity from a new set of participants. This study was approved by the University of York
Psychology Departmental Ethics Committee.

2.1.1. Transparency and Openness

This study was preregistered with the Open Science Framework (OSF; https://osf.io/e7wt8/).

2.1.1.1. Data

All data are available at https://osf.io/z9eyg/.

2.1.1.2. Analytic methods

The analytic codes to produce the analyses are available as SPSS syntax (SPS) or RMarkdown files at https://osf.io/z9eyg/.

2.1.2. Participants

Eighty-four English speaking participants were recruited to take part in an online questionnaire through Prolific Academic. For the first set of analyses (H1–3) we used existing data from Lynott et al. (2020). For the analyses of attractiveness (H4–8), according to a power analysis with G*Power, 54 participants were required to detect a medium effect size for a regression with one predictor (healthiness or perceptual strength). One participant was removed for indicating English was not their native language. The remaining 83 participants (52 females, $M_{age} = 35.6$, range $= 18 – 66$) were all native speakers of English and were born in the UK.

2.1.3. Material

We selected food words from the Lancaster Sensorimotor Norms (Lynott et al., 2020), which provide ratings for over 40,000 English words for each sensory modality. Each word is rated in terms of how much is it associated (i.e., perceptual strength) with the following sensory modalities on a scale from 0 (not experienced at all with that sense) to 5 (experienced greatly with that sense): gustation, vision, olfaction, haptics, interoception (sensations inside the body, e.g., heartbeat, stomach ache), and audition.

Four hundred and thirty-four food nouns were selected from the norms. The food nouns selected are available as part of the available data (see link in Author Note). To reduce the duration of the study and potential fatigue effects, words were randomly divided into two lists to be rated by participants using a Qualtrics survey (Qualtric, Provo, UT, USA). The following variables were retrieved from the Lynott et al. (2020) norms to be used for the operationalization of perceptual strength: mean perceptual strength in each modality

(gustation, vision, olfaction, haptics, interoception, audition), modality exclusivity, and Minkowski3 distance.

Modality exclusivity describes the multimodality of a word, i.e., to what extent the word is associated with multiple senses. It is calculated by dividing the range of sensory ratings by the sum of sensory ratings, with a value of 0 indicating an entirely multimodal concept and 1 indicating a completely unimodal concept. For example, the word *everything* has a modality exclusivity score of 0.21 (i.e., fairly multimodal), and the word *rainbow* has a modality exclusivity score of 1 (i.e., experienced only through vision). Minkowksi3 represents a composite of ratings across sensory modalities. It is a distance measure of the 6-dimensional vector of sensory ratings in which higher ratings contribute more to distance and the influence of weaker dimensions are attenuated. That is, high-value dimensions (i.e., sensory modalities with high ratings) will make a stronger contribution to this measure than low-value dimensions.

2.1.4. Procedure

Participants were presented with each of 217 words one at a time in a random order. They were asked to rate each word for healthiness, attractiveness, and familiarity in three separate blocks. Familiarity was always rated in the third block, since it was not a critical dependent variable and would be used instead to screen out unsuitable items. The order of healthiness and attractiveness rating was counterbalanced across participants. Participants made their ratings on a scale from 0 (very unhealthy, very unattractive, very unfamiliar) to 100 (very healthy, very attractive, very familiar) by clicking on a scale.

2.2. Results

Following our preregistered data exclusion criteria, thirty-six words were removed from analysis for having a mean familiarity rating of less than 50. Individual trials were removed if

a participant rated a word's familiarity less than 50 (9.4% of trials). No participants had low mean familiarity ratings or unusual patterns of response across all items. We also looked at the items rated highest and lowest on healthiness (*broccoli* and *cotton candy*) and attractiveness (*chocolate* and *tripe*) and checked that participants' ratings were in line with these. One participant rated *tripe* as 72 on attractiveness (i.e., unlike the mean rating), however their other responses were not deemed unusual so we did not remove their data.

For further analyses, ratings of healthiness, attractiveness, and familiarity were averaged over participants for each word, as is typical in analyses of psycholinguistic norms (e.g., Brysbaert, Warriner, & Kuperman, 2014; Lynott & Connell, 2009). We categorized food as healthy or unhealthy to conform with the distinction in the literature between unhealthy food being tastier than healthy food. Words with a mean healthiness rating less than 50 were categorized as "unhealthy", and words with a mean healthiness rating greater than 50 were categorized as "healthy". The healthy category was coded as 1 and the unhealthy category as -1. We chose to split the data this way to correspond with the rating scale participants used where 50 would be the boundary between a healthy and unhealthy category. A median split would assume our food items contained the healthiest and unhealthiest foods, which may not be the case. This led to 219 words categories as "healthy" ($M = 73.04$, $SD = 11.84$) and 179 as "unhealthy" ($M = 29.56$, $SD = 11.85$).

2.2.1. Data Analysis

We first compared perceptual strength between healthy and unhealthy foods across sensory modalities to establish whether previous reports of unhealthy foods being tastier is supported by the sensory norms across a range of food concepts. We used a mixed ANOVA in SPSS to test for main effects of healthiness as a between-item variable (healthy vs. unhealthy) and perceptual modality as a within-item variable (gustation, vision, olfaction, haptics,

interoception, audition)[2], and the interaction between the two variables on perceptual strength ratings. Then, in order to assess whether differences in sensory associations between healthy and unhealthy food mediate food attractiveness, we first established whether unhealthy foods are indeed perceived as more attractive that healthy foods using an independent t-test. Next we ascertained whether perceptual strength predicts food attractiveness, as hypothesized by the grounded cognition theory of desire (Papies et al., 2017), using simple linear regressions. Finally, we conducted a mediation analysis to test whether the relationship between healthiness and attractiveness is mediated by perceptual strength.

2.2.2. H1–3: Are healthy and unhealthy foods differentially associated with the perceptual modalities?

There was a significant effect of perceptual modality, $F(5, 1980) = 3425$, $p < .001$, $\eta_p^2 = .896$, but not healthiness, $F(1, 396) = 2.62$, $p = .11$ Crucially, there was a significant interaction between perceptual modality and healthiness, $F(5, 1980) = 4.93$, $p = .001$. To decompose this interaction, we tested the effect of healthiness for each perceptual modality separately using independent t-tests.

There was no effect of healthiness in the auditory, visual, or haptic modality. However, as predicted, there was an effect of healthiness in the gustatory, $t = 2.27$, $p = .02$, $d = .23$, olfactory, $t = 2.57$, $p = .01$, $d = .26$, and interoceptive modalities, $t = 3.35$, $p < .001$, $d = .33$. Across the three modalities, ratings were higher for unhealthy than healthy food (see

---

[2]ANOVA was used instead of linear mixed effects models because we did not have participant level data. Perceptual strength ratings are average ratings per word from the Lancaster Sensorimotor norms (Lynott et al., 2020). In addition, the perceptual ratings and attractiveness ratings are taken from different sets of participants. Therefore an item-level analysis was appropriate.

Figure 1). Overall, unhealthy foods were more strongly associated with gustation, olfaction, and interoception, compared to healthy foods.[3] Independent t-tests showed no difference between healthy and unhealthy food in modality exclusivity, $t = .06$, $p = .95$, $d = .004$, or Minkowski3, $t = 1.41$, $p = .16$, $d = .14$.
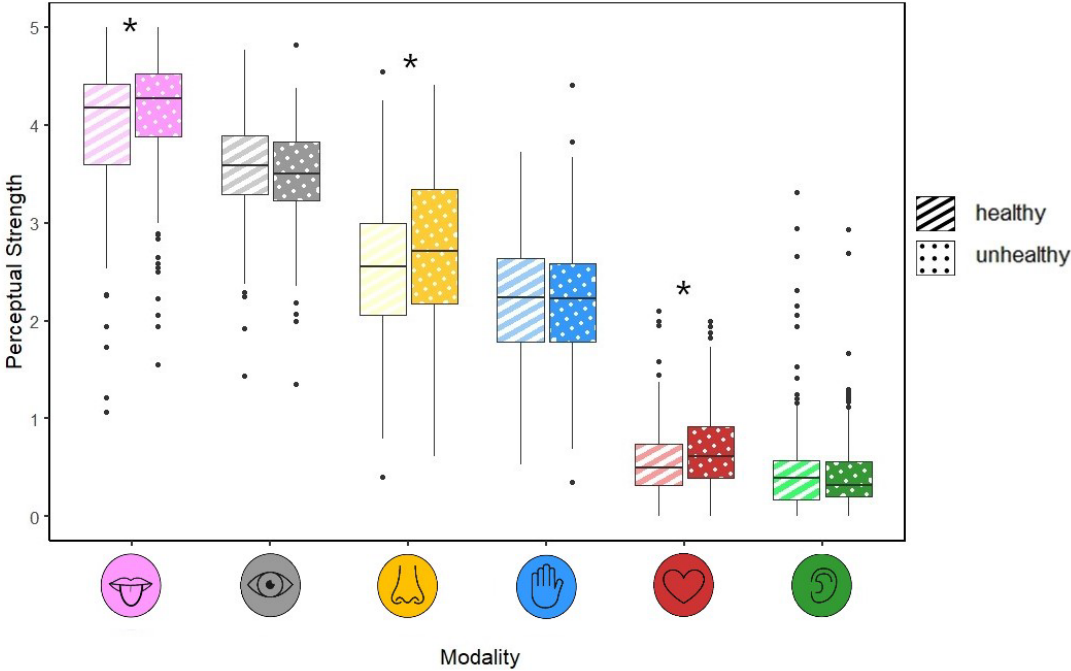

Figure 1. Mean perceptual strength rating across modalities for healthy and unhealthy food in Study 1: gustation, vision, olfaction, haptics, interoception, audition. Asterisks indicate a significant difference.[4]

2.2.3. H4: Are unhealthy foods more attractive than healthy foods?

---

[3] All results are the same when using healthiness as a continuous rather than categorical variable in simple regression models, except that in addition to a negative effect of healthiness on ratings of gustation, olfaction, and interoception, a positive effect of healthiness on ratings of vision was found.

[4] Sensory icons in all figures are taken from iStock.com/OndřejPros

An independent t-test found that, as predicted, unhealthy foods were rated as significantly more attractive than healthy foods, $t = 5.03$, $p < .001$, $d = .51$ (see Figure 2).
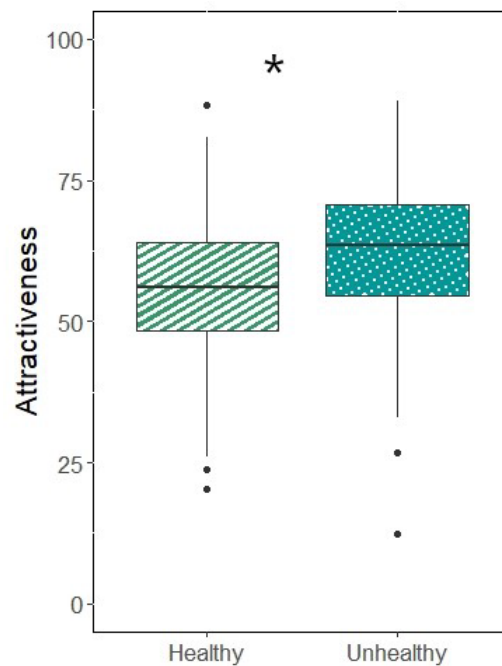

Figure 2. Mean attractiveness ratings for healthy and unhealthy food words

2.2.4. H5–7: Does perceptual strength predict attractiveness?

Simple regression models were conducted for each perceptual modality separately, with perceptual strength as a predictor and attractiveness as the dependent variable. There was no effect of auditory strength on attractiveness, but ratings of visual, $\beta = .274$, SE $= 1.21$, $t = 5.68$, $p < .001$, gustatory, $\beta = .385$, SE $= 0.89$, $t = 8.29$, $p < .001$, olfactory, $\beta = .253$, SE $= 0.83$, $t = 5.21$, $p < .001$, haptic, $\beta = .224$, SE $= 0.97$, $t = 4.58$, $p < .001$, and interoceptive, $\beta = .185$, SE $= 1.59$, $t = 3.75$, $p < .001$, strength all positively predicted attractiveness. Overall, food words were rated as more attractive the more strongly they were associated with gustation, vision, olfaction, haptics, and interoception. Similarly, food words with higher Minkowski3 values were rated as more attractive, $\beta = .419$, SE $= 0.84$, $t = 9.20$, $p < .001$. There was no effect of modality exclusivity on attractiveness, $\beta = -.025$, SE $= 14.73$, $p = .62$.

2.2.5. H8: Is the relationship between healthiness and attractiveness mediated by perceptual strength?

As pre-registered, we conducted mediation analyses to test whether the relationship between healthiness and attractiveness is mediated by perceptual strength. Mediation models were constructed based on significant relationships observed in the analyses above. The indirect relationships between healthiness and attractiveness (mediated by perceptual strength) were tested in R (R Core Team, 2020) using the *mediation* package (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014), based on 10,000 simulations. The negative relationship between healthiness and attractiveness was significantly mediated by ratings of gustatory, $\beta = .082$, $p = .02$ (17% mediation[5]), olfactory, $\beta = .058$, $p = .01$ (11% mediation), and interoceptive, $\beta = .050$, $p = .003$ (9% mediation) strength.

The models indicate the negative relationship between healthiness and attractiveness is partially mediated by perceptual strength. Specifically, the finding that unhealthy foods are perceived to be more attractive can at least partially be explained by the fact that they are more strongly associated with gustatory, olfactory, and interoceptive experience.

2.3. Discussion

Study 1 showed unhealthy food concepts are more strongly associated with gustatory, olfactory, and interoceptive experience than healthy food concepts, and they are also perceived as more attractive. This is in line with the "unhealthy = tasty" intuition reported in the literature (Raghunathan et al., 2006), as well as studies reporting unhealthy food is more likely to engage consumption simulations than healthy food (Keesman et al., 2016; Papies,

---

[5]Proportion mediated is calculated as the indirect effect between healthiness and attractiveness (mediated by perceptual strength), divided by the direct effect between healthiness and attractiveness.

2013). Here we extended this finding to a range of food concepts and specified which sensory modalities are involved. Crucially, we found the attractiveness of unhealthy food is explained by the sensory associations such food has with gustatory, olfactory, and interoceptive experience, as predicted by the grounded cognition theory of desire (Papies et al., 2017). This suggests language may increase desire for food via mental simulation.

Study 2 was designed to conceptually replicate this finding with a new set of participants. A second goal of Study 2 was to explore the effect of context on mental simulation for food concepts, specifically in terms of situatedness. Previous work has shown the degree of mental simulation can be affected by the context in which a word is presented (Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008; van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012; Zwaan, 2014; see also Ibanez et al., in press). For example, a concept like *hammer* is more likely to engage action simulations if the context focuses on action-related meaning (Hoenig et al., 2008). On the other hand, visual simulations are more likely to be engaged if the context focuses on vision-related meaning. In relation to food specifically, it has been suggested that consumption simulations (mental simulations of consuming food) are flexible: they can differ depending on both state and trait differences, such as hunger levels (Papies, Barsalou, et al., 2020; Papies, Pronk, Keesman, & Barsalou, 2015), suggesting they may be affected by context. This is particularly important when considering the potential use of sensory descriptions in real-world contexts such as on menus or food packaging, where individuals are making food choices.

As a first step to address the potential role of situatedness, we manipulated the instructions given to participants. We examine whether just thinking about eating food cued via verbal instruction changes the nature and strength of mental simulation. Specifically, we tested whether the context of imagining eating a food increases simulation in the sensory modalities most involved in eating compared to a neutral context, without imagining eating.

In the eating context, participants were asked to rate how much they experience foods through the six perceptual modalities *while eating*. In the neutral context there was no focus on eating: the instructions were the same but did not include the words "while eating". This simple instruction manipulation is comparable to other context manipulations in the field where salience of perceptual information is manipulated via task instructions, e.g., instructing participants to attend to visual or action attributes (Hoenig et al., 2008; van Dam et al., 2012).

3. Study 2

In Study 2 we conceptually replicated Study 1 by collecting sensory and attractiveness ratings from a new set of participants. This time participants only rated food words, whereas in the original dataset of sensory ratings from the Lancaster Sensory Norms (Lynott et al., 2020) participants rated concepts across a range of semantic domains. In addition, we tested the role of context on mental simulations for food. One group of participants was instructed to rate how much they experience food across sensory modalities when eating (eating context) and another group received the same instructions without the phrase "when eating" (neutral context). As well as replicating an effect of healthiness on perceptual strength (H1a)[6], we also predicted sensory ratings would be higher in the eating context (H1c), as implied by previous research showing increased simulation when attention is drawn to different contexts (e.g., Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008; van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012; Zwaan, 2014). In addition, we predicted a larger difference between healthy and unhealthy foods in the eating context (H1d—e) because participants would engage in a deeper level of mental simulation of eating which would potentially make rewarding features of unhealthy foods more salient (Keesman et al., 2016). As in Study 1 we

---

[6]Hypothesis numbers refer to hypotheses outlined in the pre-registration (https://osf.io/5mx38).

expected unhealthy foods to be perceived as more attractive than healthy foods (H2a), and for perceptual strength and Minkowski3 to positively predict perceived attractiveness (H3 and H4). We predicted that these relationships would be stronger in the eating context (H3b and H4b). Finally, we hypothesized the association between healthiness and attractiveness would be mediated by perceptual strength of gustation, olfaction, and interoception (H5a) and this mediation would be stronger in the eating context compared to neutral context (H5b).

3.2. Method

This study was approved by the University of York Psychology Departmental Ethics Committee.

3.2.1. Transparency and Openness

This study was preregistered with the OSF (https://osf.io/5mx38).

3.2.1.1. Data

All data are available at https://osf.io/z9eyg/.

3.2.1.2. Analytic methods

The analytic codes to produce the analyses are available as RMarkdown files at https://osf.io/z9eyg/.

3.2.2. Participants

One hundred and sixty-nine English speaking participants were recruited in the same manner as Study 1 (107 females, $M_{age} = 35.4$, range = 18 – 76). A power analysis with G*Power for a regression analysis with two predictors (healthiness, context) and a medium effect size of .25, indicated a required sample size of 65. In our pre-registration we aimed for 168 participants

for greater experimental power. Eighty-five participants were assigned to the eating context, and 84 to the neutral context. Note, in the original Lancaster Sensorimotor norms (Lynott et al., 2019) an average of 24 participants rated each word for sensory associations.

3.2.3. Material

The same words from Study 1 were used, with the 36 low familiarity words removed from the questionnaire, leaving 398 words. The list of food nouns is available (see link in Author Note). Words were again categorized as healthy or unhealthy using the ratings from Study 1. To reduce the duration of the study for participants, and thereby minimize potential fatigue effects in the task, words were divided into three lists with each participant rating words in only one list.

3.2.4. Procedure

For each food word, participants were instructed to rate how much they experience that food through the six perceptual modalities (feeling through touch, hearing, sensations inside your body, seeing, smelling, tasting) using a 0 (not experienced at all with that sense) to 5 (experienced greatly with that sense) scale, following the original procedure outlined in Lynott et al. (2020). Critically, in the eating instruction context participants were specifically asked how much they experience that food through the six perceptual modalities *while eating*. In the neutral instruction context, the wording was exactly the same but did not include the phrase "while eating". Participants were also asked to rate how familiar they are with the meaning of each word, how frequently they eat each food, and how attractive the food is to them. A 0 (very unfamiliar/never/very unattractive) to 5 (very familiar/very frequently/very attractive) scale was used.

3.3. Results

Nineteen words were removed from analysis for having a mean familiarity rating of less than 2.5 (4.8% trials). In addition, we removed individual trials for which a participant had given a familiarity rating of less than 2.5 (9.9% of the remaining trails). Due to experimenter error both *noodle* and *noodles* were included in the study. We analyzed these words as separate items.

3.3.1. Data analysis

In order to assess whether healthy and unhealthy foods were differentially associated with perceptual modalities, and whether this is influenced by context, we conducted linear mixed effects models for perceptual strength ratings in R (R Core Team, 2020) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). Perceptual modality, healthiness category, context, and their interactions were included as a fixed factors. To assess attractiveness ratings we used linear mixed effects models with healthiness, context, and their interaction as fixed factors. To assess whether perceptual strength predicts attractiveness we conducted separate linear mixed effects models for each perceptual modality with attractiveness as the dependent variable and perceptual strength, context, and their interaction as fixed effects. For all analyses participants and items were modelled as random intercepts only, since not all models with random slopes converged. To test for the main effects of the fixed factors and their interactions we compared models including each predictor to a simpler model without the predictor of interest, using likelihood ratio tests with chi-square. Finally, we conducted separate mediation models for the eating context and the neutral context to ascertain whether the relationship between healthiness and attractiveness is mediated by perceptual strength.

3.3.1. H1a–e: Are healthy and unhealthy foods differentially associated with perceptual modalities?

In the analysis of perceptual strength, there was a main effect of perceptual modality $\chi^2(5) =$ 51777, $p < .001$. Foods were most strongly associated with gustation, followed by vision, olfaction, haptics, interoception, and least strongly with audition. In contrast to Study 1, there was a main effect of healthiness $\chi^2(1) = 67.87$, p $< .001$. Unhealthy foods were given stronger sensory ratings than healthy foods (see Figure 3). Contrary to our hypothesis, there was no significant effect of context, $\chi^2(1) = 2.97$, $p = .09$, but there was a trend for words to be given higher sensory ratings in the eating than neutral instruction context.

There was an interaction between modality and healthiness $\chi^2(5) = 108.27$, $p < .001$. To follow up on this interaction, we tested for the effect of healthy category separately for each modality. Overall, there were higher ratings across all modalities for unhealthy food (see Table 1). Note this is different to what was observed in Study 1, where unhealthy words received higher ratings in gustation, olfaction, and interoception only.
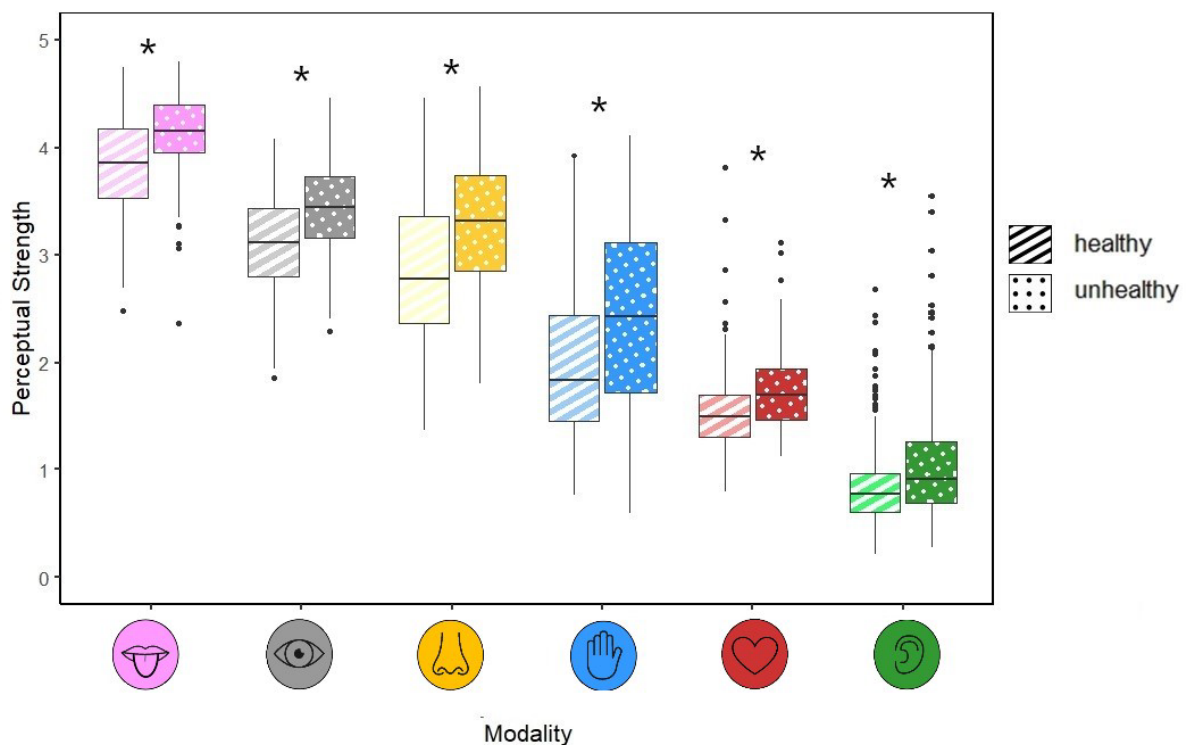
Figure 3. Mean perceptual rating across modalities (gustation, vision, olfaction, haptics, interoception, audition) for healthy and unhealthy food in Study 2. Asterisks indicate a significant different. Error bars reflect standard error.

Table 1. Effect of healthiness on perceptual ratings for each modality. Healthiness is a categorical variable with "healthy" coded as 1 and "unhealthy" as -1.

Modality	β	SE	t	p
gustation	-.22	.04	6.89	< .001
vision	-.22	.04	4.18	< .001
olfaction	-.24	.07	5.63	< .001
haptics	-.23	.08	5.34	< .001
interoception	-.13	.05	4.18	< .001
audition	-.15	.04	7.06	< .001

There was also a three-way interaction between perceptual modality, healthiness, and instruction context, $\chi^2(5) = 44.26$, $p < .001$. To follow-up, we tested the interaction between perceptual modality and healthiness for each context separately. There was a significant modality by health category interaction for the eating instruction context, $\chi^2(5) = 106.74$, p <.001, and the neutral context, $\chi^2(5) = 47.80$, p <.001. We then assessed the effect of healthy category for each modality at each level of instruction. For all conditions, unhealthy foods had higher ratings than healthy foods. Full analyses can be found in Table 2 and data is depicted in Figure 4.

Table 2. Effect of health category on perceptual ratings for each perceptual modality and within each instruction context condition.

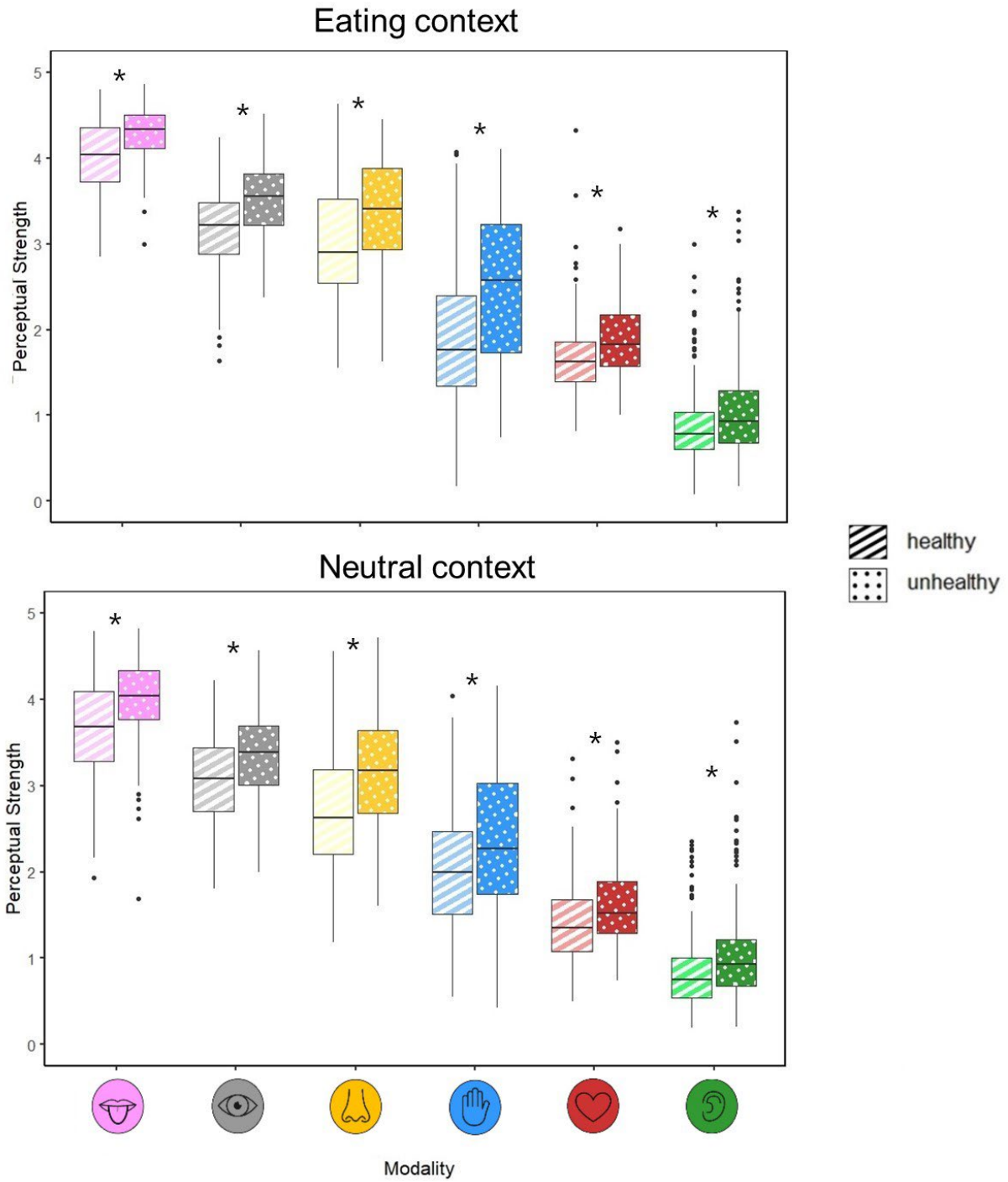| Modality	Eating context				Neutral context			
	β	SE	t	p	β	SE	t	p
taste	-.21	.04	6.81	< .001	-.23	.05	6.02	< .001
vision	-.24	.04	7.69	< .001	-19	.05	5.58	< .001
odor	-.23	.07	5.33	< .001	-.25	.07	5.47	< .001
touch	-.30	.09	6.34	< .001	-.16	.08	3.76	< .001
interoception	-.13	.04	5.24	< .001	-.13	.04	4.50	< .001
audition	-.16	.05	3.91	< .001	-.15	.05	4.04	< .001

Figure 4. Perceptual ratings by modality and instruction context for healthy and unhealthy food. Perceptual modalities depicted in the following order: gustation, vision, olfaction, haptics, interoception, audition

In contrast to Study 1, Study 2 found perceptual ratings in all modalities were higher for unhealthy compared to healthy food. Therefore, although not included in our initial hypotheses, following Study 1, we assessed whether healthiness and instruction context would predict Minkowski3 values, as this measure takes into account strength across modalities. We found a significant effect of healthiness on Minkowski3, $\chi^2 (1) = 63.13$, $\beta = -.30$, SE = .03, $t = -8.28$, $p < .001$. There was no effect of context, $\chi^2 (1) = 3.75$, $\beta = -.16$, SE = .08, $t = -1.94$, $p = .054$, and no interaction between healthiness and context on Minkowski3, $\chi^2 (1) = .01$, $p = .91$. Thus, unhealthy food is associated with more perceptual strength than healthy food, as summarized with Minkowski3 (see Figure 5).
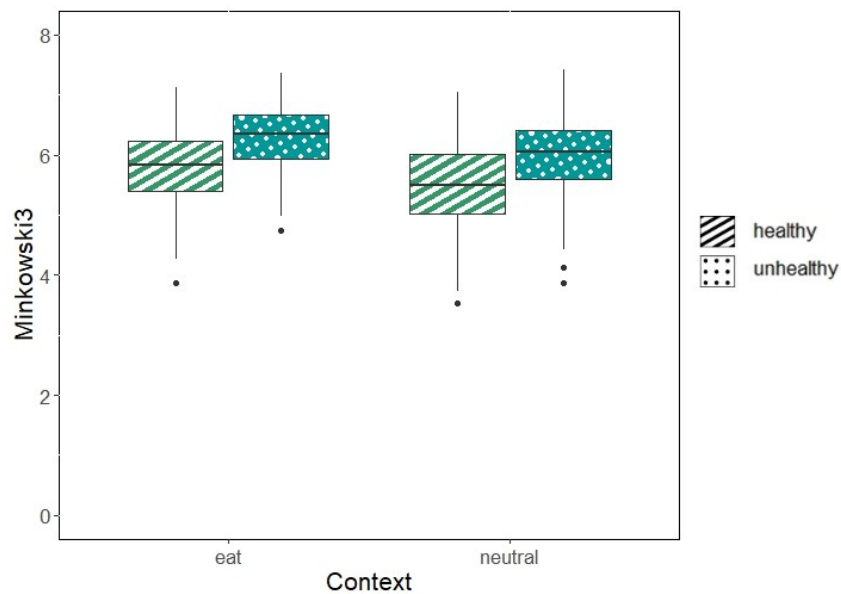

Figure 5. Mean Minkowski3 score per word by healthiness (healthy vs. unhealthy) and instruction context (eating vs. neutral)

3.3.2. H2: Are unhealthy foods more attractive than healthy foods?

As in Study 1, healthiness significantly predicted attractiveness $\chi^2 (1) = 42.58$, $\beta = -.31$, SE = .08, $t = -6.70$, $p < .001$. Unhealthy foods were rated as more attractive than healthy foods (see Figure 6).
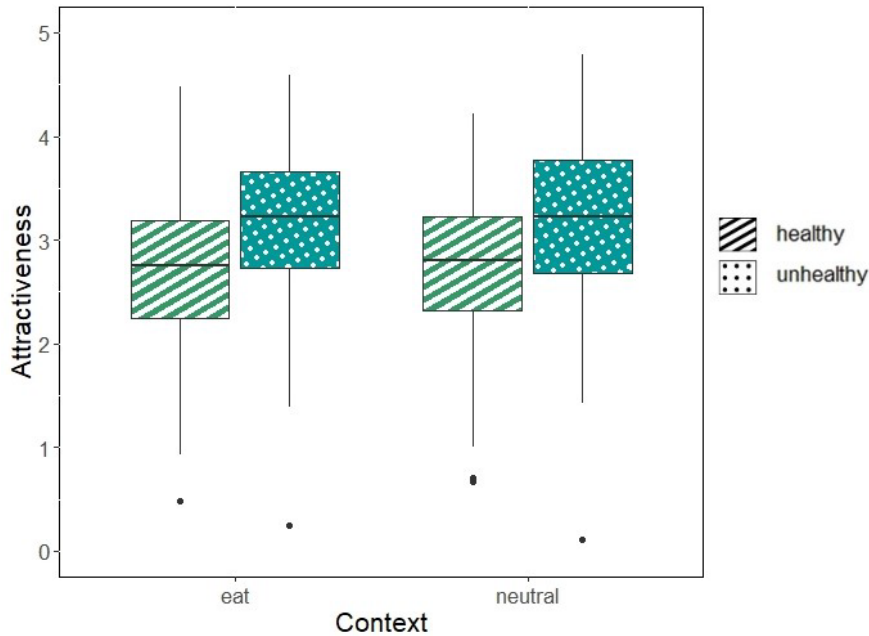

Figure 6. Mean Attractiveness per word by healthiness (healthy vs. unhealthy) and instruction context (eating vs. neutral).

3.3.3. H3–4: Does perceptual strength predict attractiveness?

Figure 7 depicts the effect of perceptual strength on attractiveness for each sensory modality. There was a significant effect of gustatory strength, $\chi^2 (1) = 3936.4$, $p < .001$, with higher gustatory ratings leading to higher ratings of attractiveness. There was also a significant effect of instruction context, $\chi^2 (1) = 5.12$, $p = .02$, with greater ratings of attractiveness in the eating context than neutral context. There was also a significant interaction between gustatory strength and context, $\chi^2 (1) = 6.09$, $p = .01$. To follow up on the interaction we looked at the effect of gustatory strength separately for each context. There was a significant effect of

gustatory strength in the eating context, $\beta = .38$, SE $= .01$, $t = 38.45$, $p < .001$, and in the neutral context, $\beta = .51$, SE $= .01$, $t = 56.26$, $p < .001$, but the effect was stronger in the neutral context.

Visual strength was a significant predictor of attractiveness, $\chi^2 (1) = 2341.7$, $p < .001$, with higher ratings of vision leading to higher ratings of attractiveness. There was no effect of instruction context, $\chi^2 (1) = 1.42$, $p = .23$, but there was a significant interaction between visual strength and context, $\chi^2 (1) = 21.09$, $p < .001$. Visual strength was a stronger predictor in the neutral context, $\beta = .42$, SE $= .01$, $t = 40.40$, $p < .001$, than eating context, $\beta = .35$, SE $= .01$, $t = 32.15$, $p < .001$.

There was significant effect of olfactory strength $\chi^2 (1) = 1727.8$, $p < .001$, with higher olfactory ratings leading to higher ratings of attractiveness. There was no effect of instruction context, $\chi^2 (1) = 2.38$, $p = .12$, but there was a significant interaction between olfactory strength and context, $\chi^2 (1) = 9.72$, $p = .002$. Following-up this interaction, we found a significant effect of olfactory strength in the eating context, $\beta = .29$, SE $= .001$, $t = 25.08$, $p < .001$, and the neutral context, $\beta = .33$, SE $= .009$, $t = 32.85$, $p < .001$, but the effect was slightly stronger in the neutral context.

There was a significant effect of haptic strength $\chi^2 (1) = 1088.7$, $p < .001$, with higher haptic ratings leading to higher ratings of attractiveness. There was no effect of instruction context, $\chi^2 (1) = 0.45$, $p = .50$, but there was a significant interaction between haptic strength and context, $\chi^2 (1) = 15.28$, $p = .002$. Again, we found a stronger effect of haptic strength in the neutral context, $\beta = .30$, SE $= .01$, $t = 25.83$, $p < .001$, than eating context, $\beta = .26$, SE $= .01$, $t = 22.75$, $p < .001$.

There was a significant effect of interoceptive strength $\chi^2 (1) = 1288.4$, $p < .001$, with higher ratings of interoception leading to higher ratings of attractiveness. There was no effect of instruction context, $\chi^2 (1) = 2.36$, $p = .12$, but there was a significant interaction $\chi^2 (1) =$

25.21, $p < .001$. The effect of interoceptive strength was stronger with the neutral context, $\beta = .36$, SE $= .01$, $t = 29.86$, $p < .001$, than eating context, $\beta = .29$, SE $= .01$, $t = 21.89$, $p < .001$.

There was a significant effect auditory strength $\chi^2 (1) = 332.04$, $p < .001$, with higher ratings of audition leading to higher ratings of attractiveness. There was no effect of instruction context, $\chi^2 (1) = 0.59$, $p = .44$, and no interaction between auditory strength and context, $\chi^2 (1) = 0.004$, $p = .95$.

Minkowski3 was also a significant predictor of attractiveness, $\beta = .48$, SE $= .001$, $\chi^2 (1) = 4231.5$, $t = 69.21$, $p < .001$. There was also a significant interaction between instruction context and Minkowski3, $\chi^2 (1) = 7.34$, $p = .007$. We therefore assessed the effect of Minkowski3 for each context. There was a significant effect of Minkowski3 in both contexts but the effect was stronger in the neutral context, $\beta = .52$, SE $= .009$, $t = 55.41$, $p < .001$, than eating context, $\beta = .44$, SE $= .01$, $t = 43.80$, $p < .001$.
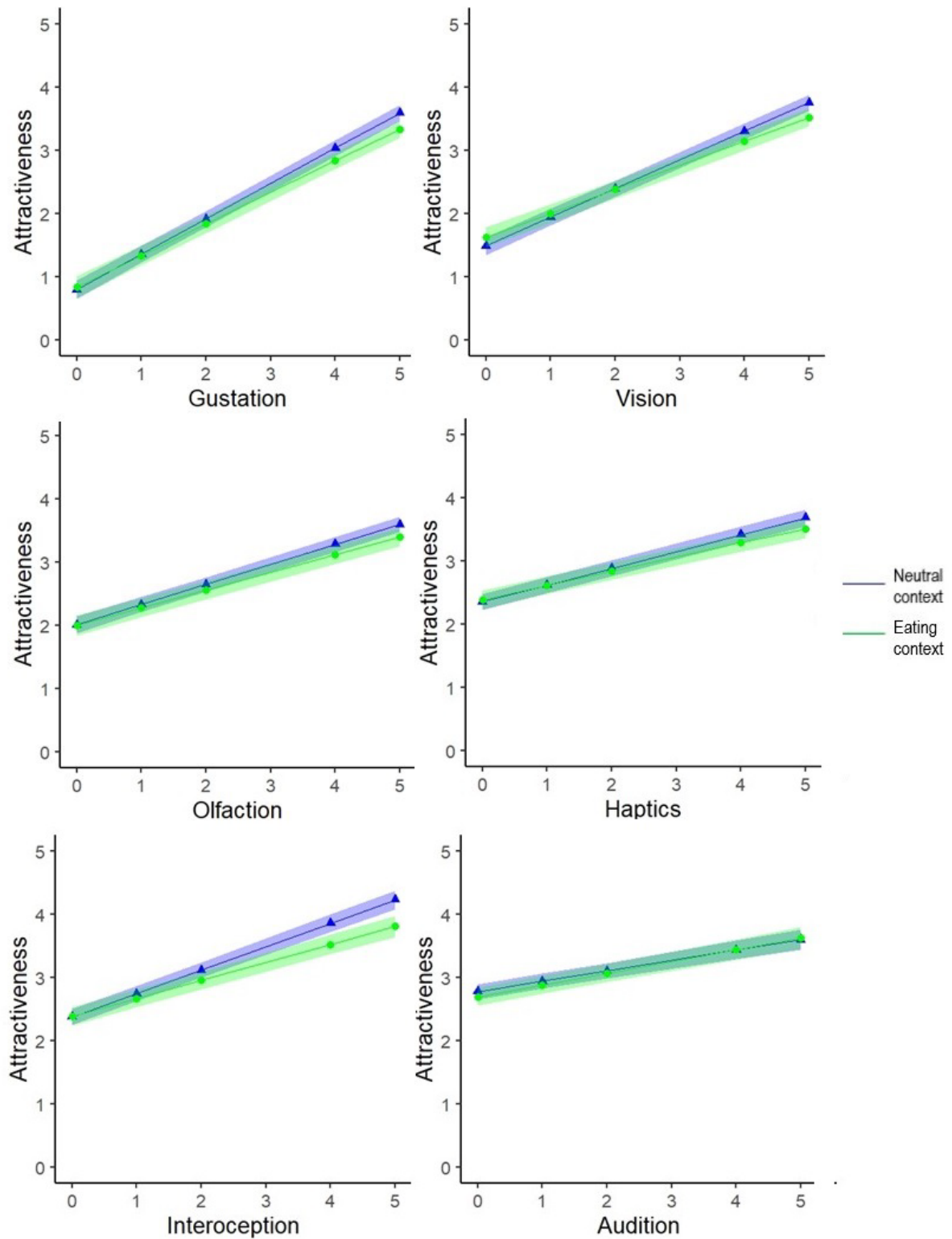
Figure 7. Unstandardized model estimates and confidence intervals for the effect of perceptual strength on attractiveness for neutral context (blue) and eating context (green).

3.3.4. H5: Is the relationship between healthiness and attractiveness mediated by perceptual strength?

To assess whether the negative relationship between healthiness and attractiveness is mediated by perceptual strength, mediation models were conducted separately for each perceptual modality and by each instruction context (see Table 3). Mediations were significant in all perceptual modalities, with the strongest mediator being gustation, followed by vision, olfaction, haptic, interoception, and audition. Mediation was stronger in the neutral context than eating context in all modalities. Thus, across modalities, the relationship between healthiness and attractiveness is explained by perceptual strength.

Table 3. Mediation models for each perceptual modality in the neutral and eating context. All mediations were significant at the $p < .001$ level. CI = confidence interval.

| | | | Neutral context | | Eating context | |
Modality	Proportion mediated	CI	Proportion mediated	CI	Proportion mediated	CI
gustation	0.36	.32, .40	0.44	.38, .50	0.30	.25, .34
vision	0.33	.30, .37	0.34	.29, .39	0.32	.28, .36
olfaction	0.24	.21, .27	0.29	.24, .34	0.20	.16, .23
haptics	0.25	.17, .22	0.20	.16, .24	0.28	.25, .33
interoception	0.16	.14, .22	0.18	.14, .22	0.14	.11, .17
audition	0.09	.08, .11	0.10	.07, .12	0.09	.07, .11
Minkowski3	0.51	.47, .56	0.54	.48, .63	0.47	.42, .53

3.4. Discussion

In this study, unhealthy food concepts were strongly associated with perceptual strength across all sensory modalities. This is in contrast to Study 1 where the effects were limited to

olfaction, gustation, and interoception. This suggests mental simulation of the senses increases when eating-related sensory information is made more salient, since Study 2 featured only food words. The context set by the instructions also played a role in mental simulation. Ratings across all modalities predicted food attractiveness, but the strength of this effect was stronger in the neutral than eating context, in all modalities except audition. One possible explanation for this is that foods are already most attractive when participants consciously imagine eating them (cf. Harvey et al., 2005), which leaves less space for spontaneous, nonconscious mental simulation to play a role. Finally, the link between healthiness and attractiveness was explained by perceptual strength in all modalities. Again, this effect was stronger in the neutral than eating context. We suggest an explanation for this in the General Discussion.

4. General discussion

In this study we examined the relationship between mental simulation and food concepts that varied in healthiness, and found unhealthy foods were more strongly associated with sensory information than healthy foods. Moreover, these differences in sensory associations predicted the attractiveness of healthy and unhealthy food. This suggests unhealthy food concepts are perceived as more attractive because they are more strongly associated with sensory experience. This provides converging psycholinguistic support for the "unhealthy = tasty" intuition (Raghunathan et al., 2006) across a large number of food concepts, but suggests this might better be characterized as "unhealthy = strongly sensory", broadening the focus from taste to the senses more generally. Overall, our evidence suggests mental simulation plays an important role in food cognition, and therefore has real-world relevance. The results imply that manipulating the affordances for mental simulation could affect how attractive food is perceived to be, for example. This could be used to increase the attractiveness of healthy food or could be used as a strategy to decrease the attractiveness of unhealthy foods.

Our findings also contribute to research highlighting the role of context in mental simulation (Hoenig et al., 2008; Ibañez et al., 2022; Lebois, Wilson-Mendenhall, & Barsalou, 2015; van Dam et al., 2012; Zwaan, 2014), and show for the first time that context can also affect sensory modality ratings, which is important to keep in mind for future research. Comparing Study 1 and Study 2, we found the relationship between healthiness and perceptual ratings differed depending on whether or not food words were presented alone and referred to as "food words" (Study 2) or were presented with words from other semantic categories (Study 1, which used the Lancaster Norms; Lynott et al., 2020). In Study 1 we found ratings of gustatory, olfactory, and interoceptive strength were higher for unhealthy foods than healthy foods, whereas in Study 2 ratings were higher for unhealthy than healthy foods across all sensory modalities. Presenting only food words may have accentuated the eating-relevant features of these concepts, which appear to differ between healthy and unhealthy foods. This suggests that word ratings, such as sensorimotor ratings, may differ depending on the composition of the word set to be rated, and more broadly, that mental simulation differs by linguistic context. While recent work has shown the presence of a congruent eating context can increase mental simulations and, assuming a positive simulated experience, affect perceived attractiveness (Papies, van Stekelenburg, Smeets, Zandstra, & Dijksterhuis, 2022), no previous work has shown such an effect of linguistic context (i.e., appearing in an all food word context vs. mixed word context). We also demonstrated a second effect via linguistic manipulation, i.e., verbal instruction. In Study 2, the mediation of perceptual strength on attractiveness tended to be stronger without the eating instruction context. This may be because sensory associations are already heightened when participants are thinking about eating so that variation in perceptual strength across words makes little difference to overall attractiveness.

Our results suggest mental simulation increases food attractiveness, but it is also possible that mental simulation is stronger *because* food is attractive. It seems plausible, at least for some sensory modalities, that attractiveness evaluations would precede mental simulation. It has been proposed for example that odor is primarily perceived in terms of valence (Khan et al., 2007; Sakamoto & Watanabe, 2016; Yeshurun & Sobel, 2010; Zarzo, 2008) and odor valence is perceived before odor quality (Majid, Burenhult, Stensmyr, de Valk, & Hansson, 2018). It has also been proposed that odor language activates emotional simulations rather than simulations of odor quality (Speed & Majid, 2018, 2020). However, our account of the present findings is in line with the grounded cognition theory of desire (Papies et al., 2017) and the elaborated intrusion theory of desire (Kavanagh et al., 2005), and previous studies that have explicitly manipulated mental simulation and found effects on desire (Harvey et al., 2005; Keesman et al., 2016; Muñoz-Vilches et al., 2019, 2020). There is also evidence that mental simulation affects emotional responses. One study found individuals with aphantasia (lack of visual mental imagery) show no physiological response to frightening stories (Wicken, Keogh, & Pearson, 2019), which suggests visual mental imagery is a necessary component to elicit an emotional reaction. In sum, our findings are consistent with theories proposing a functional role for sensory-specific mental simulations in motivation. Future studies could build on this to investigate whether perceived attractiveness may affect mental simulation: for example, mental simulation may be reduced in participants who find a food unattractive because of their dietary preferences.

There are limitations in the conclusions we can take from this study. We measured attractiveness on a rating scale, which could be susceptible to participant bias. For example, a participant may not want to admit how attractive they find a stereotypically unhealthy food. The next step in this line of research would therefore be to record more implicit measures of desire, e.g., salivation (Keesman et al., 2016) or brain activation (Pelchat, Johnson, Chan,

Valdez, & Ragland, 2004), which has not yet been applied to linguistic stimuli in this context. Another limitation of the current study is the fact we did not measure actual consumption behavior. Again, doing so could reduce the effect of participant bias, and would enable a more ecologically valid test of our hypothesis. Finally, future research could attempt a causal test of the role of sensorimotor simulations in appetitive motivation.

Nonetheless, our results have a number of new and important implications for understanding and changing eating behavior. The fact that we found effects for food words without images suggests the way we spontaneously think about food is important for the decisions we go on to make about consumption. Critically, our findings suggest that processes of mental simulation contribute to unhealthy food being considered more desirable than healthy food. This lends further support for emerging approaches that tackle unhealthy eating by encouraging different ways of thinking about healthy food. One way in which researchers have attempted to shift consumer behavior is to use taste-focused language to label healthy and sustainable food (Papies, Barsalou, et al., 2020; Turnwald et al., 2019; Turnwald, Boles, et al., 2017; Turnwald & Crum, 2019). Taste-focused language should activate simulations of eating and the associated taste experience, which should subsequently increase desire for healthy food. This has been shown to be effective in cafeteria settings when people choose food, but it is not clear whether these effects can be generalized to broader settings, for example, advertising or food packaging. Not only is it important to make healthy food more attractive in cafes and restaurants, it is also crucial to encourage healthy food choices in supermarkets and at home. This study suggests sensory modality ratings could be useful when designing such communication strategies to promote healthy food. Future work could also investigate to what extent sensory modality ratings for other word classes, such as adjectives (e.g. *Twisted* carrots and *dynamite* beets; Turnwald, Boles, et al., 2017), also predict desire for food.

To conclude, our results suggest unhealthy food concepts are more strongly associated with mental simulation across all sensory modalities than healthy food concepts. Critically, mental simulation across the senses appears to explain why unhealthy food concepts are perceived as more attractive than healthy food concepts. We show this for the first time across a range of food concepts. Beyond merely a process of language comprehension, mental simulation likely plays an important role in everyday, goal-directed behavior.

5. References

Andrade, J., May, J., Deeprose, C., Baugh, S.-J., & Ganis, G. (2014). Assessing vividness of mental imagery: The Plymouth Sensory Imagery Questionnaire. *British Journal of Psychology*, *105*(4), 547–563.

Auvray, M., & Spence, C. (2008). The multisensory perception of flavor. *Consciousness and Cognition*, *17*(3), 1016–1031. https://doi.org/10.1016/j.concog.2007.06.005

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*(04), 577–660.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Briers, B., Huh, Y. E., Chan, E., & Mukhopadhyay, A. (2020). The unhealthy = tasty belief is associated with BMI through reduced consumption of vegetables: A cross-national and mediational analysis. *Appetite*, *150*, 104639. https://doi.org/10.1016/j.appet.2020.104639

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods*, *46*(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5

Chen, J., Papies, E. K., & Barsalou, L. W. (2016). A core eating network and its modulations underlie diverse eating phenomena. *Brain and Cognition*, *110*, 20–42. https://doi.org/10.1016/j.bandc.2016.04.004

Connell, L., & Lynott, D. (2014). I see/hear what you mean: Semantic activation in visual word recognition depends on perceptual attention. *Journal of Experimental Psychology: General*, *143*(2), 527–533. https://doi.org/10.1037/a0034626

Croijmans, I. M., Speed, L. J., Arshamian, A., & Majid, A. (2019). Measuring the multisensory imagery of wine: The Vividness of Wine Imagery Questionnaire (VWIQ). *Multisensory Research*, *32*(3), 179–195.

Croijmans, I., Speed, L. J., Arshamian, A., & Majid, A. (2020). Expertise shapes multimodal imagery for wine. *Cognitive Science*, *44*(5), e12842. https://doi.org/10.1111/cogs.12842

Elder, R. S., & Krishna, A. (2010). The effects of advertising copy on sensory thoughts and perceived taste. *Journal of Consumer Research*, *36*(5), 748–756. https://doi.org/10.1086/605327

Haasova, S., & Florack, A. (2019). Practicing the (un)healthy = tasty intuition: Toward an ecological view of the relationship between health and taste in consumer judgments. *Food Quality and Preference*, *75*, 39–53. https://doi.org/10.1016/j.foodqual.2019.01.024

Harvey, K., Kemps, E., & Tiggemann, M. (2005). The nature of imagery processes underlying food cravings. *British Journal of Health Psychology*, *10*(1), 49–56. https://doi.org/10.1348/135910704X14249

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, *41*(2), 301–307.

Hoenig, K., Sim, E.-J., Bochev, V., Herrnberger, B., & Kiefer, M. (2008). Conceptual

 flexibility in the human brain: Dynamic recruitment of semantic maps from visual,

 motor, and motion-related areas. *Journal of Cognitive Neuroscience*, *20*(10), 1799–

 1814. https://doi.org/10.1162/jocn.2008.20123

Ibañez, A., Kühne, K., Miklashevsky, A., Monaco, E., Muraki, E., Ranzini, M., … Tuena, C.

 (2022). Ecological meanings: A consensus paper on individual differences and

 contextual influences in embodied language. *Journal of Cognition*.

Kaschak, M. P., Zwaan, R. A., Aveyard, M., & Yaxley, R. H. (2006). Perception of auditory

 motion affects language processing. *Cognitive Science*, *30*(4), 733–744.

Kavanagh, D. J., Andrade, J., & May, J. (2005). Imaginary relish and exquisite torture: The

 elaborated intrusion theory of desire. *Psychological Review*, *112*(2), 446–467.

 https://doi.org/10.1037/0033-295X.112.2.446

Keesman, M., Aarts, H., Ostafin, B. D., Verwei, S., Häfner, M., & Papies, E. K. (2018).

 Alcohol representations are socially situated: An investigation of beverage

 representations by using a property generation task. *Appetite*, *120*, 654–665.

 https://doi.org/10.1016/j.appet.2017.10.019

Keesman, M., Aarts, H., Vermeent, S., Häfner, M., & Papies, E. K. (2016). Consumption

 Simulations Induce Salivation to Food Cues. *PLOS ONE*, *11*(11), e0165449.

 https://doi.org/10.1371/journal.pone.0165449

Kemps, E., & Tiggemann, M. (2007). Modality-specific imagery reduces cravings for food:

 An application of the elaborated intrusion theory of desire to food craving. *Journal of*

 Experimental Psychology: Applied, *13*(2), 95–104. https://doi.org/10.1037/1076-

 898X.13.2.95

Khan, R. M., Luk, C.-H., Flinker, A., Aggarwal, A., Lapid, H., Haddad, R., & Sobel, N.

 (2007). Predicting odor pleasantness from odorant structure: Pleasantness as a

reflection of the physical world. *Journal of Neuroscience*, *27*(37), 10015–10023. https://doi.org/10.1523/JNEUROSCI.1158-07.2007

Kiefer, M., Sim, E.-J., Herrnberger, B., Grothe, J., & Hoenig, K. (2008). The sound of concepts: Four markers for a link between auditory and conceptual brain systems. *Journal of Neuroscience*, *28*(47), 12224–12230. https://doi.org/10.1523/JNEUROSCI.3579-08.2008

Lebois, L. A. M., Wilson-Mendenhall, C. D., & Barsalou, L. W. (2015). Are automatic conceptual cores the gold standard of semantic processing? The context-dependence of spatial meaning in grounded congruency effects. *Cognitive Science*, *39*(8), 1764–1801. https://doi.org/10.1111/cogs.12174

Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behavior Research Methods*, *41*(2), 558–564. https://doi.org/10.3758/BRM.41.2.558

Lynott, D., Connell, L., Brysbaert, M., Brand, J., & Carney, J. (2020). The Lancaster sensorimotor norms: Multidimensional measures of perceptual and action strength for 40, 000 English words. *Behavior Research Methods*, *52*, 1271–1291.

Majid, A., Burenhult, N., Stensmyr, M. C., de Valk, J. M., & Hansson, B. S. (2018). Olfactory language and abstraction across cultures. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, *373*(1752), 20170139.

Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, *270*(5233), 102.

Meteyard, L., Bahrami, B., & Vigliocco, G. (2007). Motion detection and motion verbs: Language affects low-level visual perception. *Psychological Science*, *18*(11), 1007–1013. https://doi.org/10.1111/j.1467-9280.2007.02016.x

Meteyard, Lotte, Cuadrado, S. R., Bahrami, B., & Vigliocco, G. (2012). Coming of age: A

    review of embodiment and the neuroscience of semantics. *Cortex*, *48*(7), 788–804.

    https://doi.org/10.1016/j.cortex.2010.11.002

Muñoz-Vilches, N. C., van Trijp, H. C. M., & Piqueras-Fiszman, B. (2019). The impact of

    instructed mental simulation on wanting and choice between vice and virtue food

    products. *Food Quality and Preference*, *73*, 182–191.

    https://doi.org/10.1016/j.foodqual.2018.11.010

Muñoz-Vilches, N. C., van Trijp, H. C. M., & Piqueras-Fiszman, B. (2020). Tell me what you

    imagine and I will tell you what you want: The effects of mental simulation on desire

    and food choice. *Food Quality and Preference*, *83*, 103892.

    https://doi.org/10.1016/j.foodqual.2020.103892

Papies, E. K. (2013). Tempting food words activate eating simulations. *Frontiers in*

    Psychology, *4*. https://doi.org/10.3389/fpsyg.2013.00838

Papies, E. K., Barsalou, L. W., & Rusz, D. (2020). Understanding desire for food and drink: A

    grounded-cognition approach. *Current Directions in Psychological Science*, *29*(2),

    193–198.

Papies, E. K., Best, M., Gelibter, E., & Barsalou, L. W. (2017). The role of simulations in

    consumer experiences and behavior: Insights from the grounded cognition theory of

    desire. *Journal of the Association for Consumer Research*, *2*(4), 402–418.

    https://doi.org/10.1086/693110

Papies, E. K., Johannes, N., Daneva, T., Semyte, G., & Kauhanen, L.-L. (2020). Using

    consumption and reward simulations to increase the appeal of plant-based foods.

    Appetite, *155*, 104812. https://doi.org/10.1016/j.appet.2020.104812

Papies, E. K., Pronk, T. M., Keesman, M., & Barsalou, L. W. (2015). The benefits of simply

    observing: Mindful attention modulates the link between motivation and behavior.

Journal of Personality and Social Psychology, *108*(1), 148–170.

https://doi.org/10.1037/a0038032

Pearson, J., Naselaris, T., Holmes, E. A., & Kosslyn, S. M. (2015). Mental imagery:

Functional mechanisms and clinical applications. *Trends in Cognitive Sciences*,

19(10), 590–602. https://doi.org/10.1016/j.tics.2015.08.003

Pelchat, M. L., Johnson, A., Chan, R., Valdez, J., & Ragland, J. D. (2004). Images of desire:

Food-craving activation during fMRI. *NeuroImage*, *23*(4), 1486–1493.

https://doi.org/10.1016/j.neuroimage.2004.08.023

R Core Team. (2020). *R: A language and environment for statistical computing*. Vienna,

Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-

project.org

Raghunathan, R., Naylor, R. W., & Hoyer, W. D. (2006). The unhealthy = tasty intuition and

its effects on taste inferences, enjoyment, and choice of food products. *Journal of

Marketing*, *70*(4), 170–184. https://doi.org/10.1509/jmkg.70.4.170

Sakamoto, M., & Watanabe, J. (2016). Cross-modal associations between sounds and drink

tastes/textures: A study with spontaneous production of sound-symbolic words.

Chemical Senses, *41*(3), 197–203. https://doi.org/10.1093/chemse/bjv078

Shepherd, G. M. (2006). Smell images and the flavour system in the human brain. *Nature*,

444(7117), 316–321. https://doi.org/10.1038/nature05405

Simmons, W. K., Martin, A., & Barsalou, L. W. (2005). Pictures of appetizing foods activate

gustatory cortices for taste and reward. *Cerebral Cortex*, *15*(10), 1602–1608.

https://doi.org/10.1093/cercor/bhi038

Speed, L. J., & Brysbaert, M. (2020). *Dutch sensory modality norms*. Retrieved from

https://doi.org/10.31234/osf.io/zv6pn

Speed, L. J., & Majid, A. (2017). Dutch modality exclusivity norms: Simulating perceptual

    modality in space. *Behavior Research Methods*, *49*(6), 2201–2218.

    https://doi.org/10.3758/s13428-017-0852-3

Speed, L. J., & Majid, A. (2018). An exception to mental simulation: No evidence for

    embodied odor language. *Cognitive Science*, *42*(4), 1146–1178.

Speed, L. J., & Majid, A. (2020). Grounding language in the neglected senses of touch, taste,

    and smell. *Cognitive Neuropsychology*, *37*(5–6), 363–392.

    https://doi.org/10.1080/02643294.2019.1623188

Speed, L. J., Papies, E. K., & Majid, A. (2022, June 6). Sensory simulation predicts

    attractiveness of food concepts. Retrieved from osf.io/z9eyg

Spence, C. (2015). Multisensory flavor perception. *Cell*, *161*(1), 24–35.

    https://doi.org/10.1016/j.cell.2015.03.007

Spence, C., Okajima, K., Cheok, A. D., Petit, O., & Michel, C. (2016). Eating with our eyes:

    From visual hunger to digital satiation. *Brain and Cognition*, *110*, 53–63.

    https://doi.org/10.1016/j.bandc.2015.08.006

Strik Lievers, F., & Winter, B. (2018). Sensory language across lexical categories. *Lingua*,

    204, 45–61. https://doi.org/10.1016/j.lingua.2017.11.002

Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). Mediation: R package

    for causal mediation analysis. *Journal of Statistical Software*, *59*(5).

    https://doi.org/10.18637/jss.v059.i05

Turnwald, B. P., Bertoldo, J. D., Perry, M. A., Policastro, P., Timmons, M., Bosso, C., …

    Crum, A. J. (2019). Increasing vegetable intake by emphasizing tasty and enjoyable

    attributes: A randomized controlled multisite intervention for taste-focused labeling.

    Psychological Science, *30*(11), 1603–1615.

    https://doi.org/10.1177/0956797619872191

Turnwald, B. P., Boles, D. Z., & Crum, A. J. (2017). Association between indulgent descriptions and vegetable consumption: Twisted carrots and dynamite beets. *JAMA Internal Medicine*, *177*(8), 1216. https://doi.org/10.1001/jamainternmed.2017.1637

Turnwald, B. P., & Crum, A. J. (2019). Smart food policy for healthy food labeling: Leading with taste, not healthiness, to shift consumption and enjoyment of healthy foods. *Preventive Medicine*, *119*, 7–13. https://doi.org/10.1016/j.ypmed.2018.11.021

Turnwald, B. P., Jurafsky, D., Conner, A., & Crum, A. J. (2017). Reading between the menu lines: Are restaurants' descriptions of "healthy" foods unappealing? *Health Psychology*, *36*(11), 1034–1037. https://doi.org/10.1037/hea0000501

van Dam, W. O., van Dijk, M., Bekkering, H., & Rueschemeyer, S.-A. (2012). Flexibility in embodied lexical-semantic representations. *Human Brain Mapping*, *33*(10), 2322–2333. https://doi.org/10.1002/hbm.21365

van der Laan, L. N., de Ridder, D. T. D., Viergever, M. A., & Smeets, P. A. M. (2011). The first taste is always with the eyes: A meta-analysis on the neural correlates of processing visual food cues. *NeuroImage*, *55*(1), 296–303. https://doi.org/10.1016/j.neuroimage.2010.11.055

Vergallito, A., Petilli, M. A., & Marelli, M. (2020). Perceptual modality norms for 1,121 Italian words: A comparison with concreteness and imageability scores and an analysis of their impact in word processing tasks. *Behavior Research Methods*. https://doi.org/10.3758/s13428-019-01337-8

Wicken, M., Keogh, R., & Pearson, J. (2019). *The critical role of mental imagery in human emotion: Insights from Aphantasia* [Preprint]. Neuroscience. https://doi.org/10.1101/726844

Winter, B. (2016). Taste and smell words form an affectively loaded and emotionally flexible

    part of the English lexicon. *Language, Cognition and Neuroscience*, *31*(8), 975–988.

    https://doi.org/10.1080/23273798.2016.1193619

Winter, B. (2019). *Sensory Linguistics. Language, perception and metaphor*.

    Amsterdam/Philadelphia: John Benjamins Publishing Company.

Winter, B., Perlman, M., & Majid, A. (2018). Vision dominates in perceptual language:

    English sensory vocabulary is optimized for usage. *Cognition*, *179*, 213–220.

    https://doi.org/10.1016/j.cognition.2018.05.008

Yeshurun, Y., & Sobel, N. (2010). An odor is not worth a thousand words: From

    multidimensional odors to unidimensional odor objects. *Annual Review of Psychology*,

    61, 219–241. https://doi.org/10.1146/annurev.psych.60.110707.163639

Zarzo, M. (2008). Relevant psychological dimensions in the perceptual space of perfumery

    odors. *Food Quality and Preference*, *19*(3), 315–322.

    https://doi.org/10.1016/j.foodqual.2007.10.007

Zwaan, R. A. (2014). Embodiment and language comprehension: Reframing the discussion.

    Trends in Cognitive Sciences, *18*(5), 229–234.

    https://doi.org/10.1016/j.tics.2014.02.008

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in

    language comprehension. *Journal of Experimental Psychology: General*, *135*(1), 1–

    11. https://doi.org/10.1037/0096-3445.135.1.1